TPS7H3XX4-SP Single-Event Effects (SEE)

The purpose of this study is to characterize the Single-Event Effects (SEE) performance due to heavy-ion irradiation of the TPS7H3XX4-SP. Heavy-ions with LET_{EFF} of 75MeV×cm^2/mg were used to irradiate twelve production devices. Flux of ≈ 6 × 10^4 to 1× 10^5 ions/cm^2×s and fluence of ≈ 10^7 ions/cm^2 per run were used for the characterization. The results demonstrate the TPS7H3XX4-SP is SEL-free and SEB/SEGR-free at T = 125°C and T = 25°C, respectively. The TPS7H3XX4-SP was also tested for SET at T = 25°C, results demonstrate the device is SET and SEFI-free.

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Trademarks

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1 Introduction

The TPS7H3xx4-SP is an integrated, 3V to 14V, four-channel radiation-hardened power-supply supervisor with watchdog. An accurate 599.7mV ± 1% threshold voltage and a 24µA ± 3% hysteresis current provide programmable monitoring voltages. A global programmable delay timer is programmed via a single resistor. Additionally, a PWRGD output is provided to monitor the global power tree status. The device also incorporates a positive edge detection watchdog timer to monitor an external processor for coherent execution. Faults can be detected and mitigated by the external controller, using the SR_UVLO input. This part is offered with push-pull and open-drain output types as well as different monitor configurations as shown in Table 1-1.

Table 1-1. TPS7H3XX4 Variant Summary

Device	Output Type	Monitor Configuration
TPS7H3024	Push-pull	2 OV + 2 UV or 2 window with push-pull RESETx
TPS7H3124	Open-Drain	
TPS7H3034	Push-pull	4 UV or 4 OV with push-pull RESETx
TPS7H3134	Open-drain	

The device is offered in a 22-pin ceramic package. General device information and test conditions are listed in Table 1-2. For more detailed technical specifications, user-guides, and application notes please go to TPS7H3XX4-SP product page.

Table 1-2. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H3XX4-SP
Orderable Number	• 5962R2420601VXC (TPS7H3024-SP) • 5962R2420602VXC (TPS7H3124-SP) • 5962R2420603VXC (TPS7H3034-SP) • 5962R2420604VXC (TPS7H3134-SP)
Device Function	4-channel supervisor with watchdog
Technology	LBC7 (Linear BiCMOS 7)
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15MeV/nucleon) and Facility for Rare Isotope Beams, K500 Cyclotron (KSEE), Michigan State University (19.5MeV/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 TPS7H3XX4-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 TPS7H3XX4-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. During the testing of the TPS7H3XX4-SP a total of twelve units were exposed under worst-case bias conditions for SEL. The TPS7H3XX4-SP did not exhibit any SEL with heavy-ions with LET_{EFF} = 75 MeV×cm^2/mg at flux of ≈1 × 10^5 ions/cm^2 ×s, fluence of ≈10^7 ions/cm^2, and a die temperature of 125°C.

The TPS7H3XX4-SP was evaluated for SEB/SEGR at a maximum voltage of 14V (V_{IN}) in the enabled and disabled states, with a total of twelve units being tested. Because it has been shown that the MOSFET susceptibility to burnout decreases with temperature [5], the device was evaluated while operating under room temperatures. The device was tested with no external thermal control device. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H3XX4-SP is SEB/SEGR-free up to LET_{EFF} = 75 MeV×cm^2/mg at a flux of ≈1 × 10^5 ions/cm^2×s, fluence of ≈10^7 ions/cm^2, and a die temperature of ≈25°C.

The TPS7H3XX4-SP was tested under nominal input conditions for SET. During the testing of twelve devices, not a single transient was recorded, showing that the TPS7H3XX4-SP is both transient free and SEFI free. To see more details please refer to Section 8.

The forcing conditions for the different DSEE and SET testing are shown in Table 2-1.

With SR_$\overline{\text{UVLO}}$ forced to 1V the device was in the enabled state with all $\overline{\text{RESETS}}$ high and in the disabled state with all $\overline{\text{RESETS}}$ low when forced to 0V.

Table 2-1. SEE Biasing Conditions

DSEE TYPE	V_{IN} (V)	V_{PULL_UPx} (V)	SR_$\overline{\text{UVLO}}$ (V)	MODE	$Watchdog_{IN}$	T_J (°C)	FLUX (ions/cm^2·s)	FLUENCE (ions/cm^2)
SEL	14	7	1	[0,1]	[Off, SW]	125	6 × 10^4/run	10^7/run
SEB/SEGR	14	7	[0,1]	[0,1]	[Off, SW]	25		
SET	3.3	1.8	[0,1]	[0,1]	[Off, SW]	25		

3 Device and Test Board Information

The TPS7H3XX4-SP is packaged in a 22-pin CFP-HFT ceramic package. Figure 3-1 shows a delidded unit. The TPS7H3024EVM-CVAL and TPS7H3124EVM-CVAL were used to evaluate the performance and characteristics of the TPS7H3XX4-SP under heavy ion radiation and can be seen in Figure 3-2 and Figure 3-3. The configuration used during the heavy-ions test campaign is provided in Figure 3-4 and Figure 3-5 for TPS7H30X4-SP and TPS7H31X4-SP, respectively.

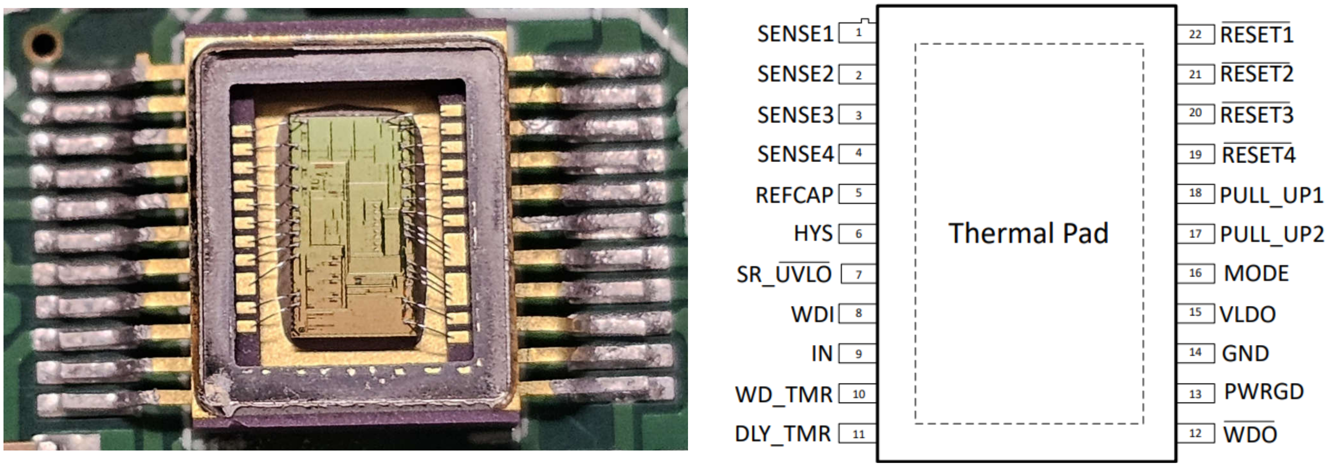

Figure 3-1. Photograph of Delidded TPS7H30X4-SP [Left] and Pinout Diagram [Right]

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

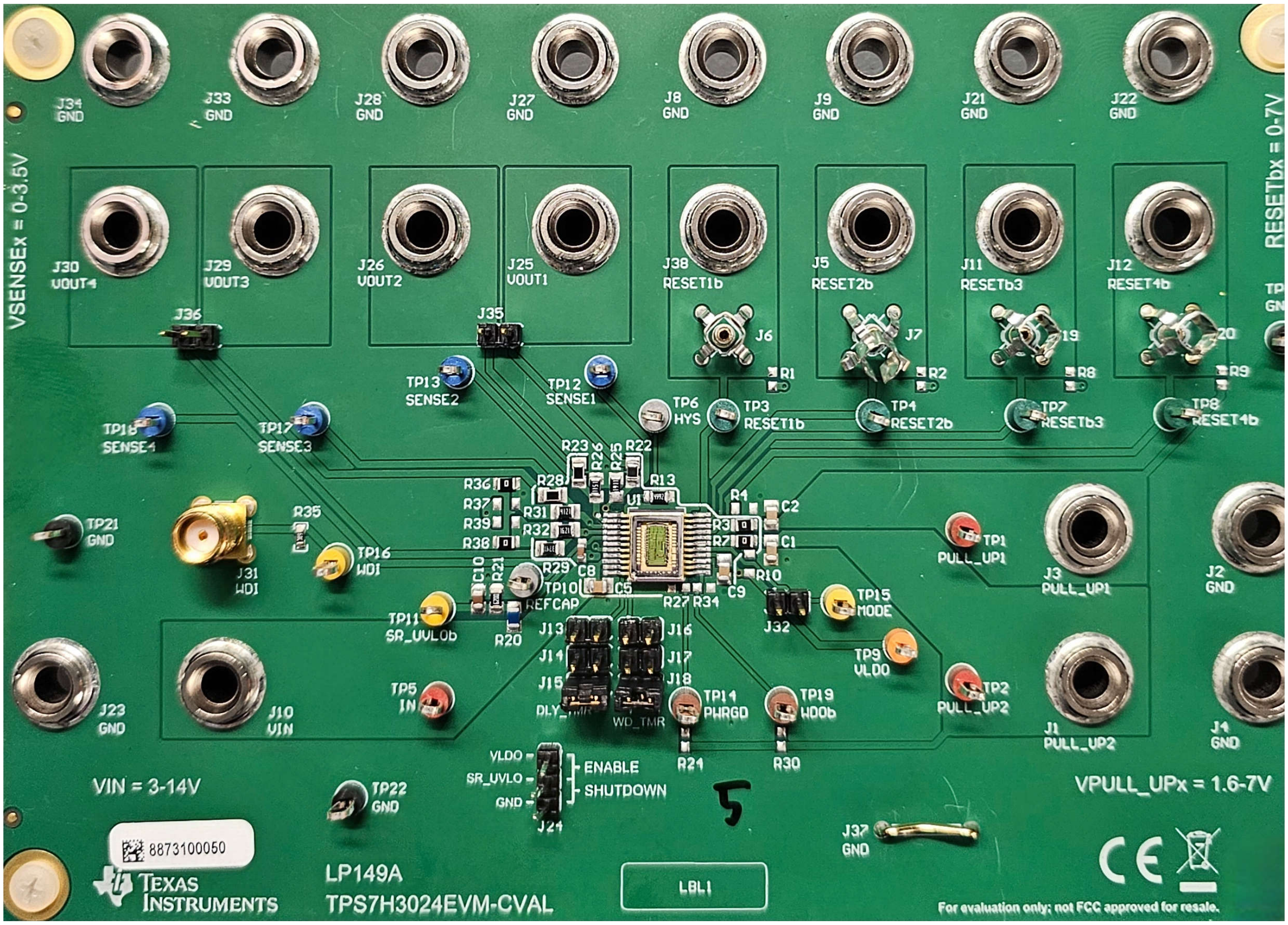

Figure 3-2. TPS7H3024EVM-CVAL Top View

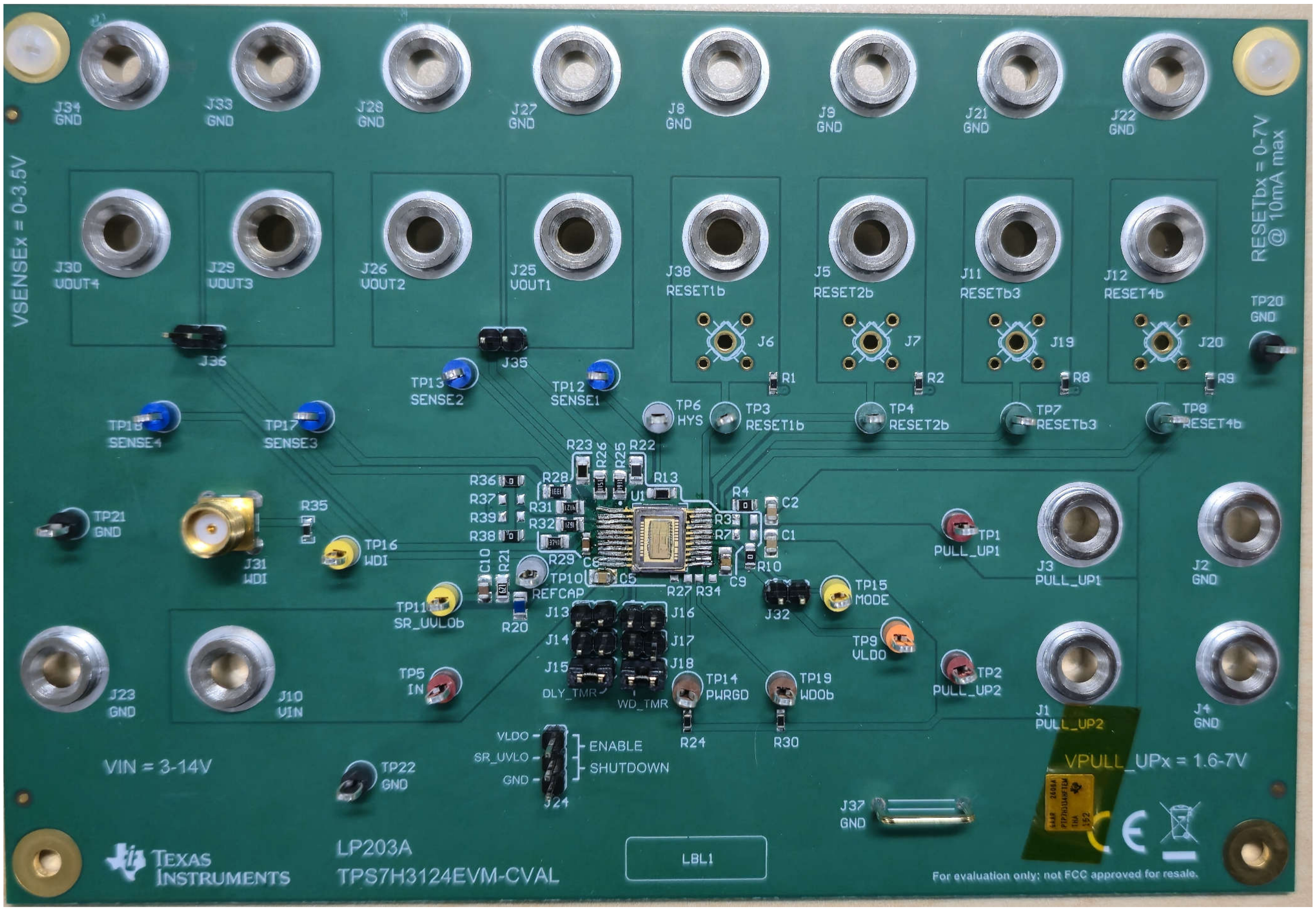

Figure 3-3. TPS7H3124EVM-CVAL Top View

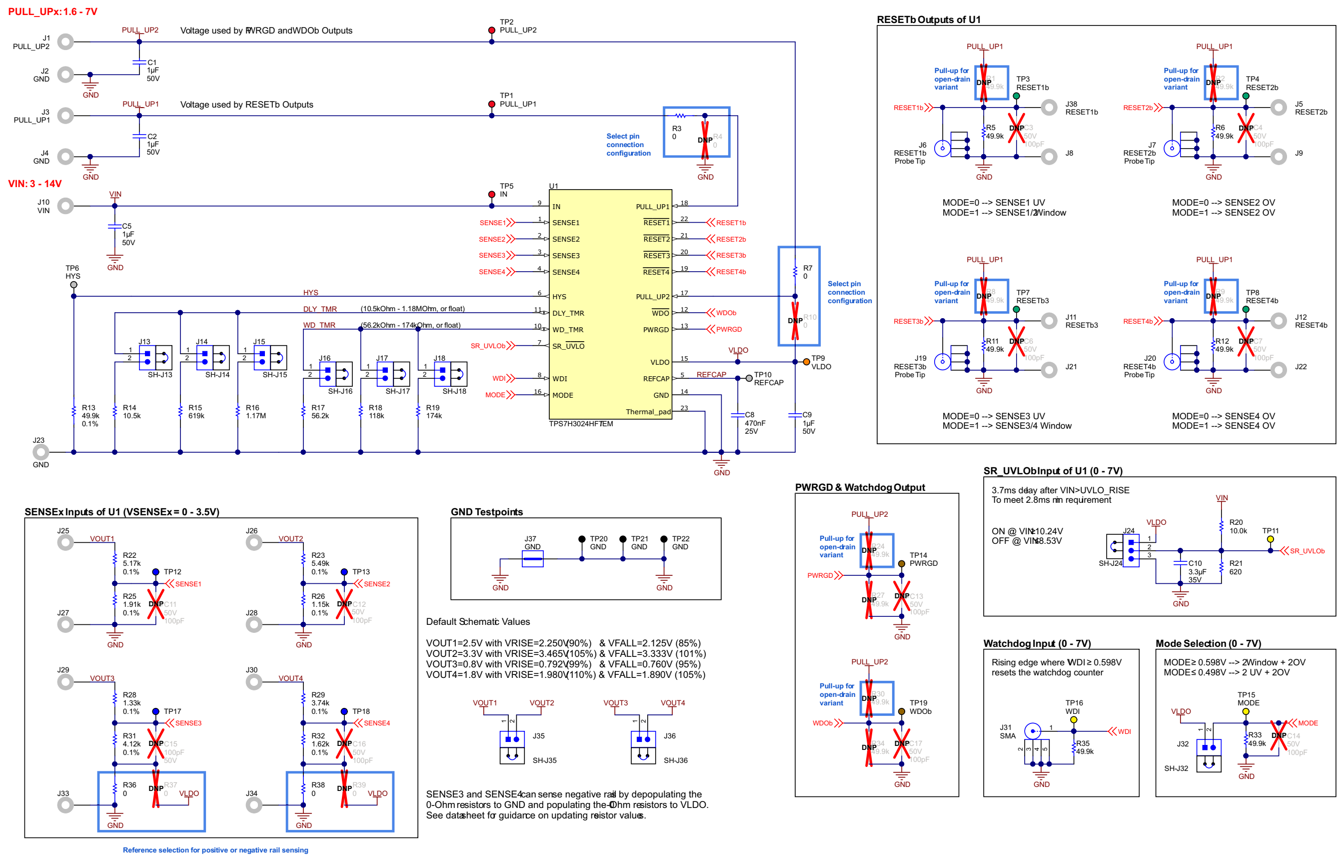

Figure 3-4. TPS7H30x4EVM-CVAL Schematic for SEE Testing

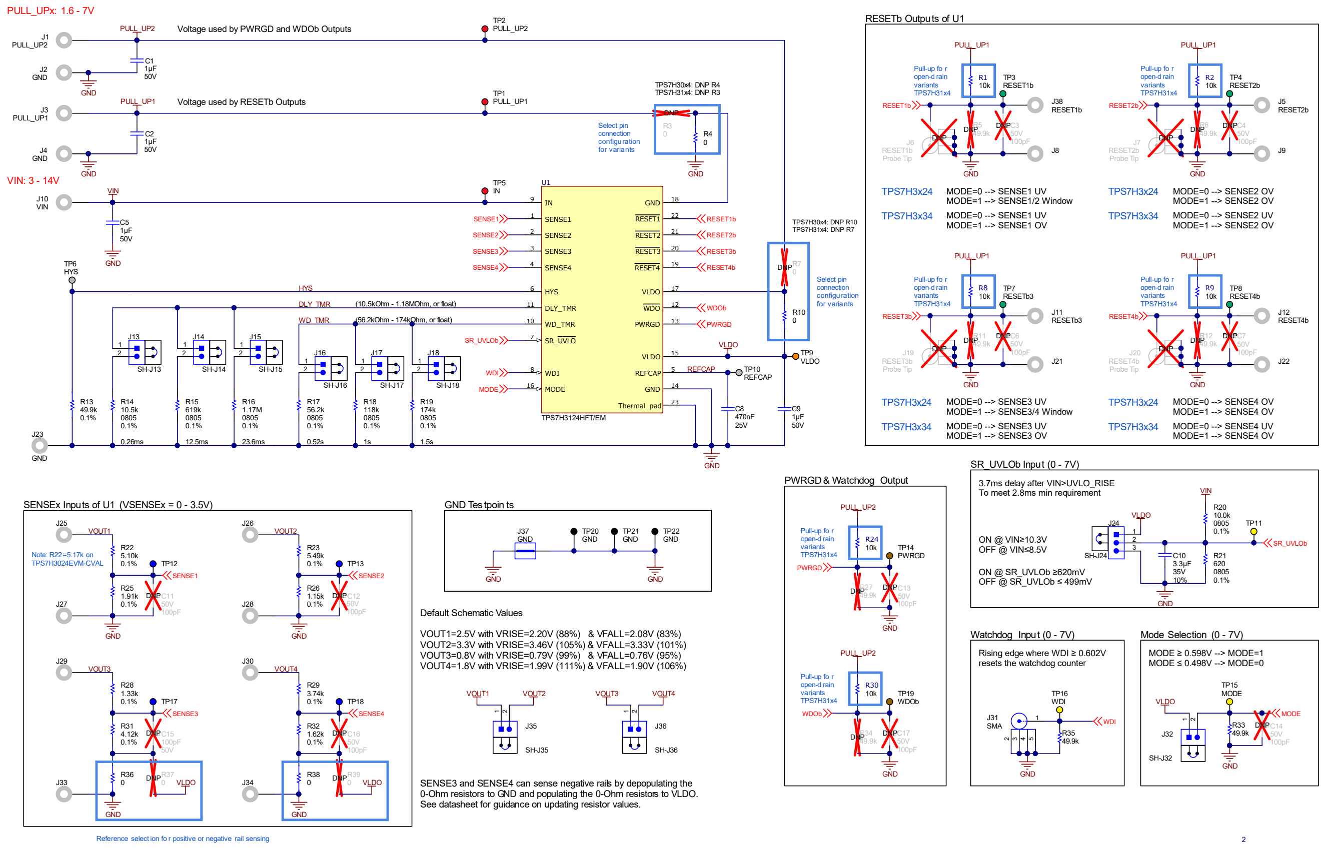

Figure 3-5. TPS7H31x4EVM-CVAL Schematic for SEE Testing

4 Irradiation Facility and Setup

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

- 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 1in 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 5.21×10^4 to 6.23×10^4 ions/cm^2·s was used to provide heavy-ion fluences of 1.00×10^7. 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.
- 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 7.74×10^4 to 1.05×10^5 was used to provide heavy-ion fluences of 1.00×10^7. 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.

For the experiments conducted for this report, two ions were used, ^{165}Ho and ^{169}Tm. Both were used to obtain LET$_{EFF}$ of 75MeV×cm^2/mg. The total kinetic energies for the ions were:

- ^{165}Ho = 2.474GeV (15 MeV/nucleon)
  - Ion uniformity for these experiments was between 92% and 94%
- ^{169}Tm = 3.295GeV (19.5 MeV/nucleon)
  - Ion uniformity for these experiments were between 79% and 91%

Figure 4-1 shows the TPS7H3024EVM-CVAL in front of the beam line at the TAMU facility.

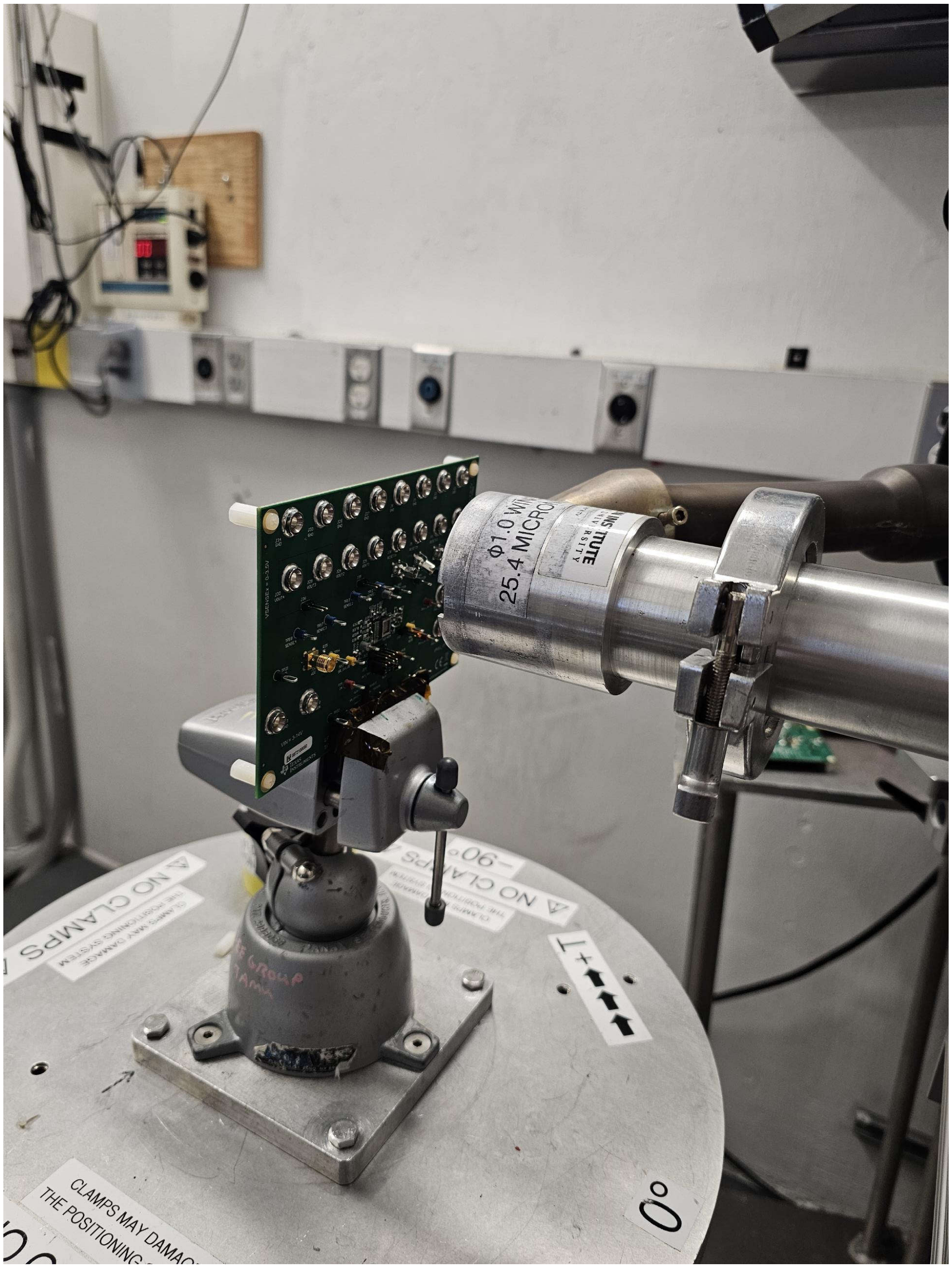

Figure 4-1. TPS7H3024EVM-CVAL in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 LET$_{EFF}$ and Range Calculation

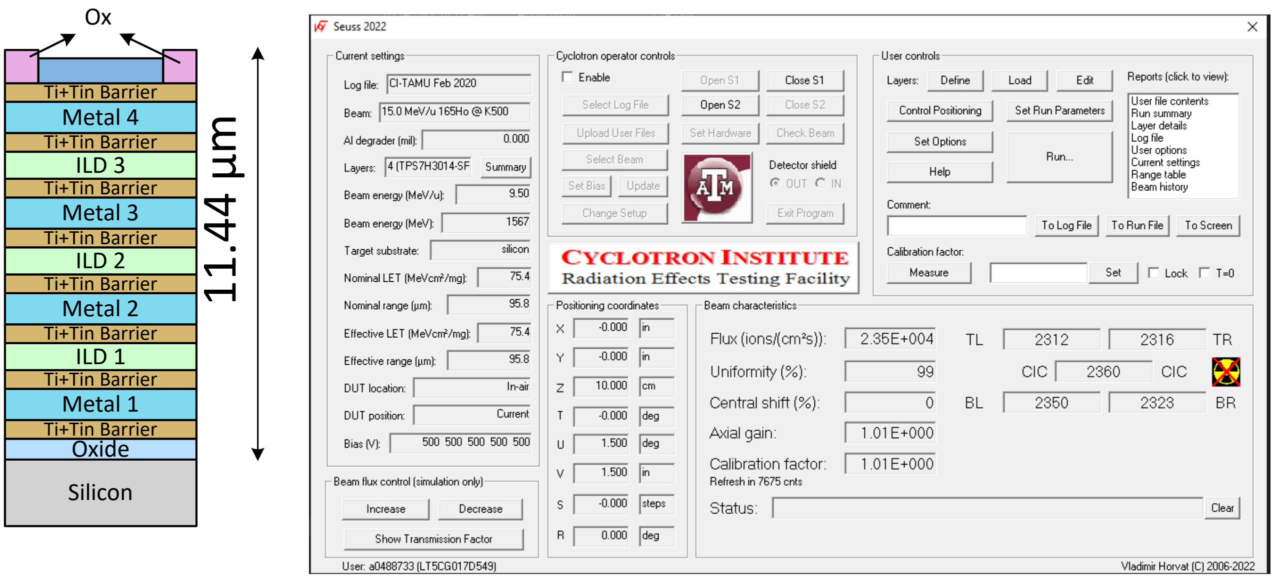

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H3XX4-SP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right]

The TPS7H3XX4-SP is fabricated in the TI Linear BiCMOS 250nm process with a back-end-of-line (BEOL) stack consisting of four levels of standard thickness aluminum. The total stack height from the surface of the passivation to the silicon surface is 11.44µm based on nominal layer thickness as shown in Figure 5-1.

Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the TPS7H3XX4-SP, the effective LET (LET$_{EFF}$) at the surface of the silicon substrate and the range was determined with:

- SEUSS 2022 software (provided by TAMU and based on the latest SRIM-2013 [7] models)
- MSU Stack-Up Calculator (provided by MSU FRIB 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)
TAMU	15	^{165}Ho	0	0	-	1-mil Aramica	40	0	75	95.7
KSEE	19.5	^{169}Tm	-	-	5	3-mil PEN	60	0	75.1	89.8

6 Test Setup and Procedures

There were five input supplies used to provide power to the TPS7H3XX4-SP. The voltage values and the model of the used equipment per the SEE test type is presented in Table 6-1.

With SR_$\overline{\text{UVLO}}$ forced to 1V the device was in the enabled state with all $\overline{\text{RESETS}}$ high and in the disabled state with all $\overline{\text{RESETS}}$ low when forced to 0V.

Table 6-1. Details of Power Supplies Used for the Heavy-Ion Test Campaign of the TPS7H3XX4-SP

VOLTAGE NAME	VOLTAGE (V)	SEE TEST TYPE	POWER SUPPLY MODEL
VIN	14	SEL, SEB/SEGR	N6766A
VPULL_UP1	7		PXIe-4139
VPULL_UP2	7		
SR_$\overline{\text{UVLO}}$	0, 1		
MODE	0, 1		
WDOG_{IN}	5 $V_{\text{Pk-Pk}}$, f_{SW}=500kHz		PXIe-5433
VIN	3.3	SET	N6766A
VPULL_UP1	1.8		PXIe-4139
VPULL_UP2	1.8		
SR_$\overline{\text{UVLO}}$	0, 1		
MODE	0, 1		
WDOG_{IN}	5 & f_{SW}=100kHz		PXIe-5433

As discussed in Section 3, the TPS7H3XX4-SP was tested (or evaluated) under heavy-ions using two unique configurations.

1. During the DSEE testing four power supplies were used to drive the external resistive divider connected to the VOUTx inputs. This voltage was forced so that the SENSEx inputs were ± 400mV of the nominal threshold voltage of 599mV
2. During the SET testing four power supplies were used to drive the external resistive divider connected to the VOUTx inputs. This voltage was forced so that the SENSEx inputs were ± 20mV of the nominal threshold voltage of 599mV

Transients were monitored on $\overline{\text{RESET}}$1, $\overline{\text{RESET}}$4, $\overline{\text{WDO}}$ and PWRGD. The equipment used and the trigger details are summarized in Table 6-2. The device was tested for transients in both the on and off state.

Table 6-2. Summary of Oscilloscope and Conditions Used for the SEE Test Campaign of the TPS7H3XX4-SP

SIGNAL NAME	EQUIPMENT USED TO MONITOR SIGNAL	TRIGGER TYPE	TRIGGER VALUE WHEN SIGNAL WAS HIGH (%)	TRIGGER VALUE WHEN SIGNAL WAS LOW (V)
$\overline{\text{RESET}}$1	PXIe-5172	Falling-edge/Rising-edge	–20% (from nominal)	0.66
$\overline{\text{RESET}}$ 4	PXIe-5172	Falling-edge/Rising-edge	–20% (from nominal)	0.66
PWRGD	PXIe-5172	Falling-edge/Rising-edge	–20% (from nominal)	0.66
$\overline{\text{WDO}}$	PXIe-5172	Falling-edge/Rising-edge	–20% (from nominal)	0.66

Figure 6-1 shows a block diagram of the setup used for SEE testing of the TPS7H3XX4-SP.

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 TPS7H3XX4-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 20% 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. Not a single transient was captured by the oscilloscope measuring the outputs, indicating that the device is SET-free.

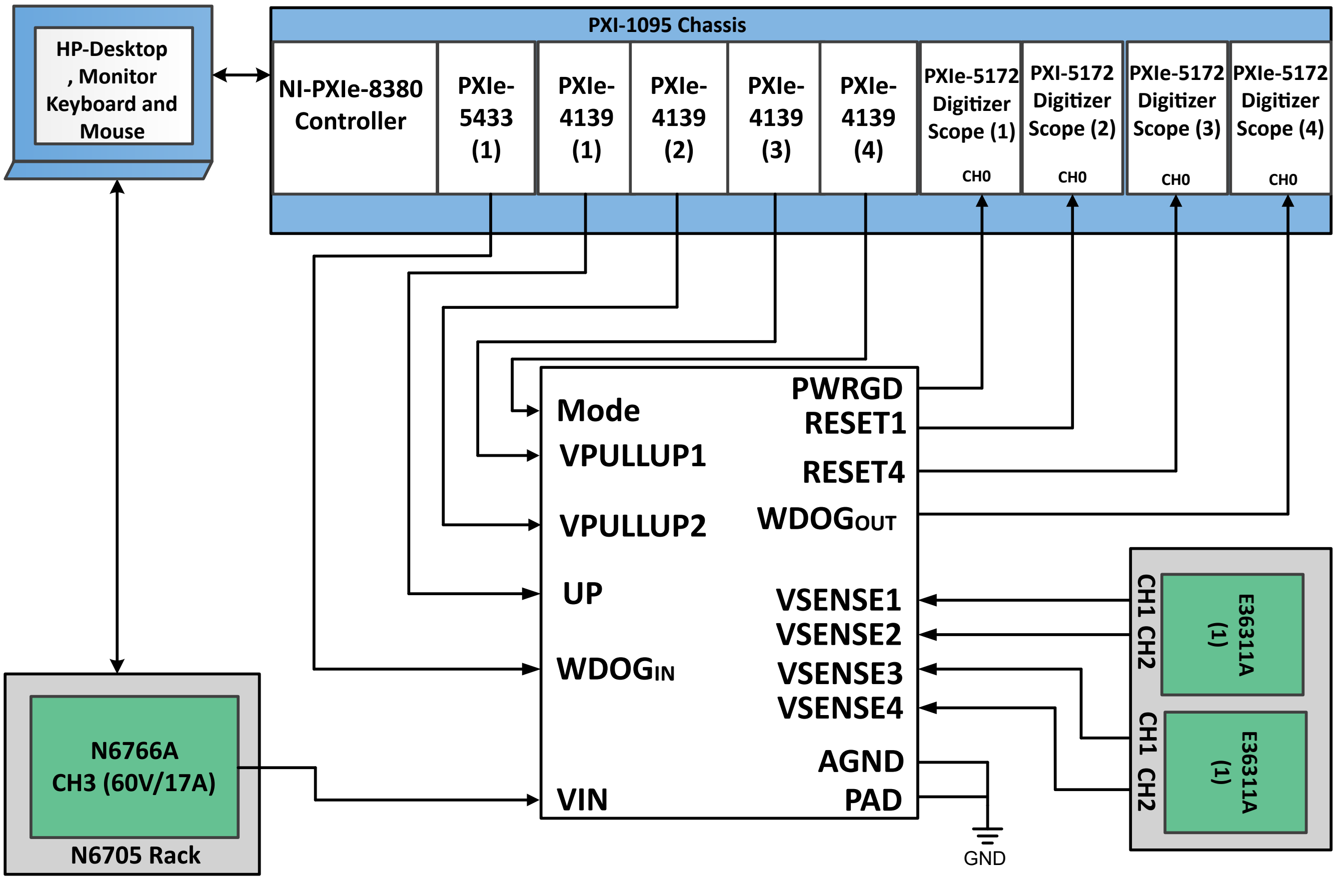

Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H3XX4-SP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-Up (SEL) Results

During SEL characterization, the device was heated using a closed-loop PID controlled heat gun [MISTRAL 6 System (120V, 2400W)] to 125°C. 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 DUT temperature was monitored prior to being irradiated with a FLIR IR-camera to ensure the junction temperature at KSEE. The species used for SEL testing was ^{165}Ho and ^{169}Tm for TAMU and KSEE, respectively. An incident angle was used which achieved an LET_{EFF} of 75MeV·cm^2/mg.

12 production units of the TPS7H3XX4-SP were tested for SEL at a flux of ≈1 × 10^5 ions/cm^2·s, a fluence of ≈ 10^7 ions/cm^2, maximum recommended V_{IN} voltage (14V), maximum recommended $V_{PULL\text{-}UPX}$ voltage (7V). For SEL testing the device was configured in the following 4 different operating modes. Table 7-1 showcases the operating modes used during testing.

1. MODE 0, WD SW
2. MODE 0, WD Off
3. MODE 1, WD SW
4. MODE 1, WD Off

Table 7-1. Operating Modes Used for SEL testing on TPS7H3XX4-SP

RUN #	UNIT #	DEVICE	MODE	WD
1	1	TPS7H3024-SP	0	SW
2	2	TPS7H3024-SP	0	OFF
3	3	TPS7H3024-SP	1	SW
4	4	TPS7H3024-SP	1	OFF
5	5	TPS7H3024-SP	0	OFF
6	6	TPS7H3024-SP	1	OFF
7	7	TPS7H3124-SP	0	OFF
8	8	TPS7H3124-SP	0	SW
9	9	TPS7H3134-SP	1	OFF
10	10	TPS7H3134-SP	1	SW
11	11	TPS7H3034-SP	0	OFF
12	12	TPS7H3034-SP	0	SW

For more configuration information please refer to Table 6-1.

Not a single functional interrupt was observed, neither a high current event on any of the power supplies of the TPS7H3XX4-SP. This indicates the TPS7H3XX4-SP is SEL-free. The results for twelve runs across all devices are shown in Table 7-2. A typical V_{IN} current versus time plot during a SEL run is shown in Figure 7-1 and Figure 7-2.

Table 7-2. Summary of TPS7H3XX4-SP SEL Test Condition and Results

RUN #	UNIT #	FACILITY	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/cm^2/s)	FLUENCE (ions/cm^2)	SEL (NUMBER OF EVENTS)
1	1	TAMU	^{165}Ho	75	5.48 × 10^4	1.00 × 10^7	0
2	2	TAMU	^{165}Ho	75	5.31 × 10^4	1.00 × 10^7	0
3	3	TAMU	^{165}Ho	75	5.85 × 10^4	1.00 × 10^7	0
4	4	TAMU	^{165}Ho	75	5.83 × 10^4	1.00 × 10^7	0
5	5	KSEE	^{169}Tm	75.1	7.72 × 10^4	1.00 × 10^7	0
6	6	KSEE	^{169}Tm	75.1	1.02 × 10^5	1.00 × 10^7	0
7	7	KSEE	^{169}Tm	75.1	1.16 × 10^5	1.00 × 10^7	0

Table 7-2. Summary of TPS7H3XX4-SP SEL Test Condition and Results (continued)

RUN #	UNIT #	FACILITY	ION	LET_{EFF} (MeV·cm²/mg)	FLUX (ions/cm²/s)	FLUENCE (ions/cm²)	SEL (NUMBER OF EVENTS)
8	8	KSEE	^{169}Tm	75.1	1.20×10^5	1.00×10^7	0
9	9	KSEE	^{169}Tm	75.1	1.23×10^5	1.00×10^7	0
10	10	KSEE	^{169}Tm	75.1	1.12×10^5	1.00×10^7	0
11	11	KSEE	^{169}Tm	75.1	1.07×10^5	1.00×10^7	0
12	12	KSEE	^{169}Tm	75.1	1.09×10^5	1.00×10^7	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluence of the twelve runs at 125°C (12×10^7) ions/cm², the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 3.07 \times 10^{-8}$ cm²/device for LET_{EFF} = 75MeV·cm²/mg and T = 125°C.

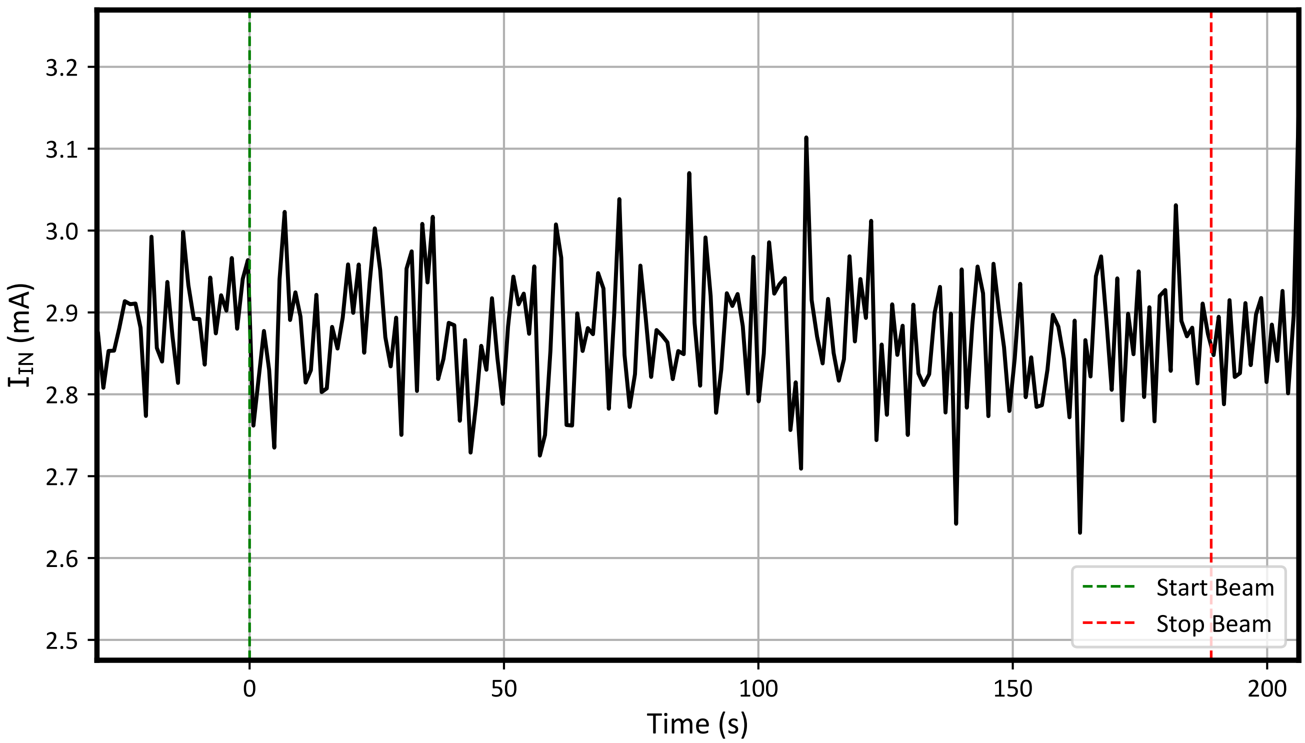

Figure 7-1. Current versus Time for I_{IN}: Run #2 (Mode 0, WD Off) of the TPS7H3XX4-SP at T = 125°C

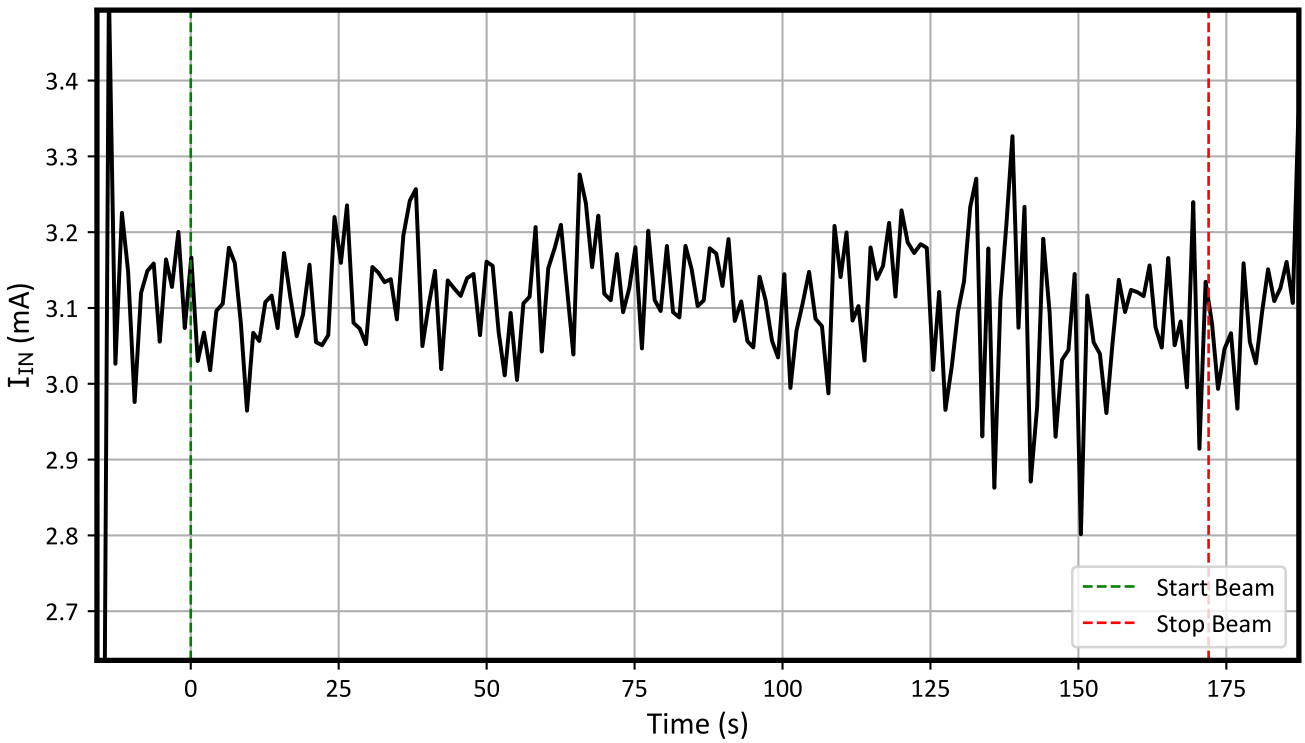

Figure 7-2. Current versus Time for I_{In}: Run #3 (Mode 1, WD SW) of the TPS7H3XX4-SP at T = 125°C

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

During SEB/SEGR testing, the device was tested at room temperature. The same test conditions, in terms of biasing and voltage levels, apply for SEB/SEGR as was used during the SEL testing. In the case of the SEB/SEGR the device was tested in the following state machine states:

- Disabled (SR_$\overline{\text{UVLO}}$ = 0V)
  - All outputs are low ($\overline{\text{RESET}}$x = Low and PWRGD = Low)
- Enabled (SR_$\overline{\text{UVLO}}$ = 1V)
  - All outputs are high ($\overline{\text{RESET}}$x = High and PWRGD = High)

For more configuration information, please refer to Table 6-1.

The device was also configured in the following 4 different operating modes. Table 7-2 showcases the operating modes used on the units during testing.

1. MODE 0, WD SW
2. MODE 0, WD Off
3. MODE 1, WD SW
4. MODE 1, WD Off

Table 7-3. Operating Modes Used for SEB/SEGR Testing on TPS7H3XX4-SP

RUN #	UNIT #	DEVICE	MODE	WD
13	1	TPS7H3024-SP	0	SW
14				
15	2	TPS7H3024-SP	0	OFF
16				
17	3	TPS7H3024-SP	1	SW
18				
19	4	TPS7H3024-SP	1	OFF
20				
21	5	TPS7H3024-SP	0	OFF
22				
23	6	TPS7H3024-SP	1	OFF
24				
25	7	TPS7H3124-SP	0	OFF
26				
27	8	TPS7H3124-SP	0	SW
28				
29	9	TPS7H3134-SP	1	OFF
30				
31	10	TPS7H3134-SP	1	SW
32				
33	11	TPS7H3034-SP	0	OFF
34				
35	12	TPS7H3034-SP	0	SW
36				

The results for 24 runs across 12 devices for SEB/SEGR are shown in Table 7-3. Over all 24 runs, none of the 12 units exhibited any SEB/SEGR failures, indicating the TPS7H3XX4-SP is SEB/SEGR free at 75 MeV·cm^2/mg. Typical V_{IN} current vs time plots for SEB/SEGR on and off runs are shown in Figure 7-5 and Figure 7-6. Typical V_{PULL_UPx} current vs time plots for SEB/SEGR on and off runs are shown in Figure 7-3 through Figure 7-6.

Table 7-4. Summary of TPS7H3XX4-SP SEB/SEGR Test Condition and Results

RUN #	UNIT #	FACILITY	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/(cm^2·s))	FLUENCE (ions/cm^2)	ON/OFF STATUS	SEB EVENT?
13	1	TAMU	^{165}Ho	75	5.70×10^4	1.00×10^7	On	No
14					5.21×10^4		Off	
15	2	TAMU	^{165}Ho	75	5.55×10^4	1.00×10^7	On	No
16					5.26×10^4		Off	
17	3	TAMU	^{165}Ho	75	5.76×10^4	1.00×10^7	On	No
18					5.86×10^4		Off	
19	4	TAMU	^{165}Ho	75	5.95×10^4	1.00×10^7	On	No
20					5.63×10^4		Off	
21	5	KSEE	^{169}Tm	75.1	1.05×10^5	1.00×10^7	On	No
22					1.04×10^5		Off	
23	6	KSEE	^{169}Tm	75.1	9.98×10^4	1.00×10^7	On	No
24					9.44×10^4		Off	
25	7	KSEE	^{169}Tm	75.1	1.16×10^5	1.00×10^7	On	No
26					1.15×10^5		Off	
27	8	KSEE	^{169}Tm	75.1	1.13×10^5	1.00×10^7	On	No
28					1.17×10^5		Off	
29	9	KSEE	^{169}Tm	75.1	1.19×10^5	1.00×10^7	On	No
30					1.15×10^5		Off	
31	10	KSEE	^{169}Tm	75.1	1.14×10^5	1.00×10^7	On	No
32					1.08×10^5		Off	
33	11	KSEE	^{169}Tm	75.1	1.01×10^5	1.00×10^7	On	No
34					1.02×10^5		Off	
35	12	KSEE	^{169}Tm	75.1	1.11×10^5	1.00×10^7	On	No
36					1.08×10^5		Off	

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:

$\sigma_{SEB} \leq 1.54 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75 MeV·cm^2/mg and T = 25°C.

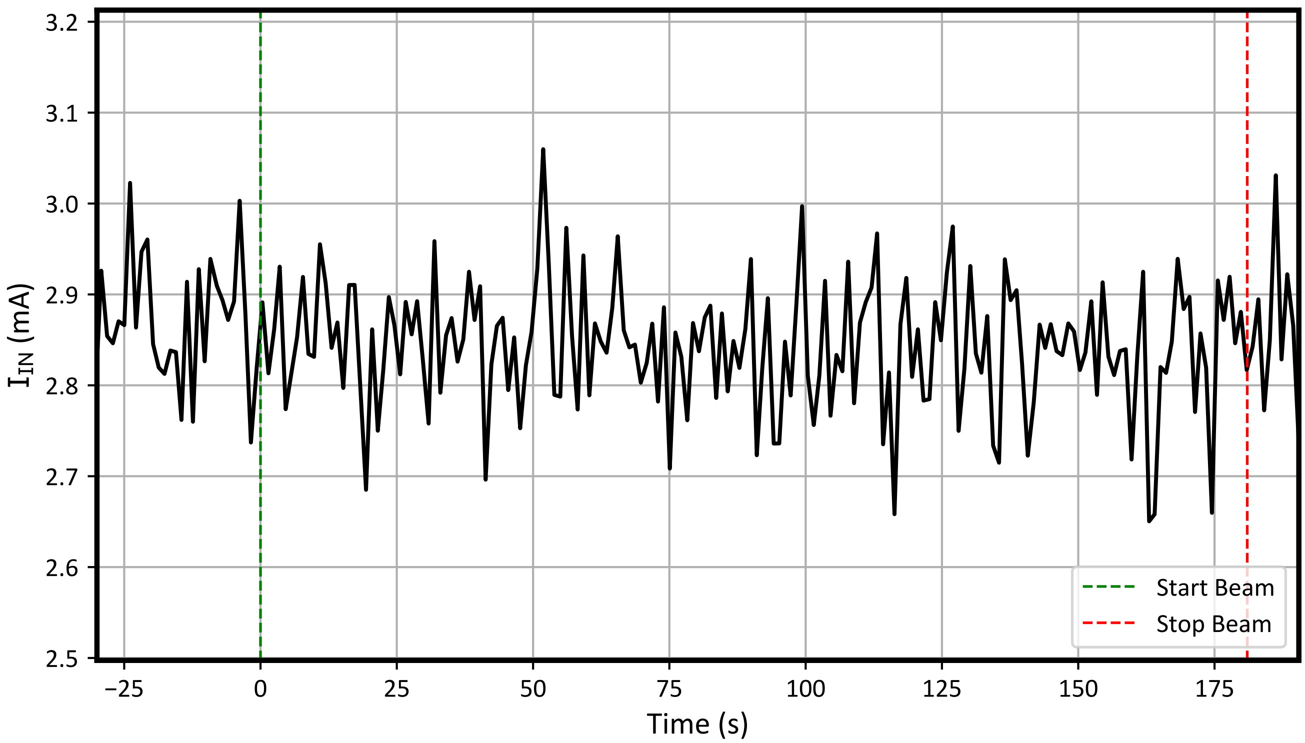

Figure 7-3. Current versus Time for I_{IN}: SEB On (Mode 0, WD Off) Run #7

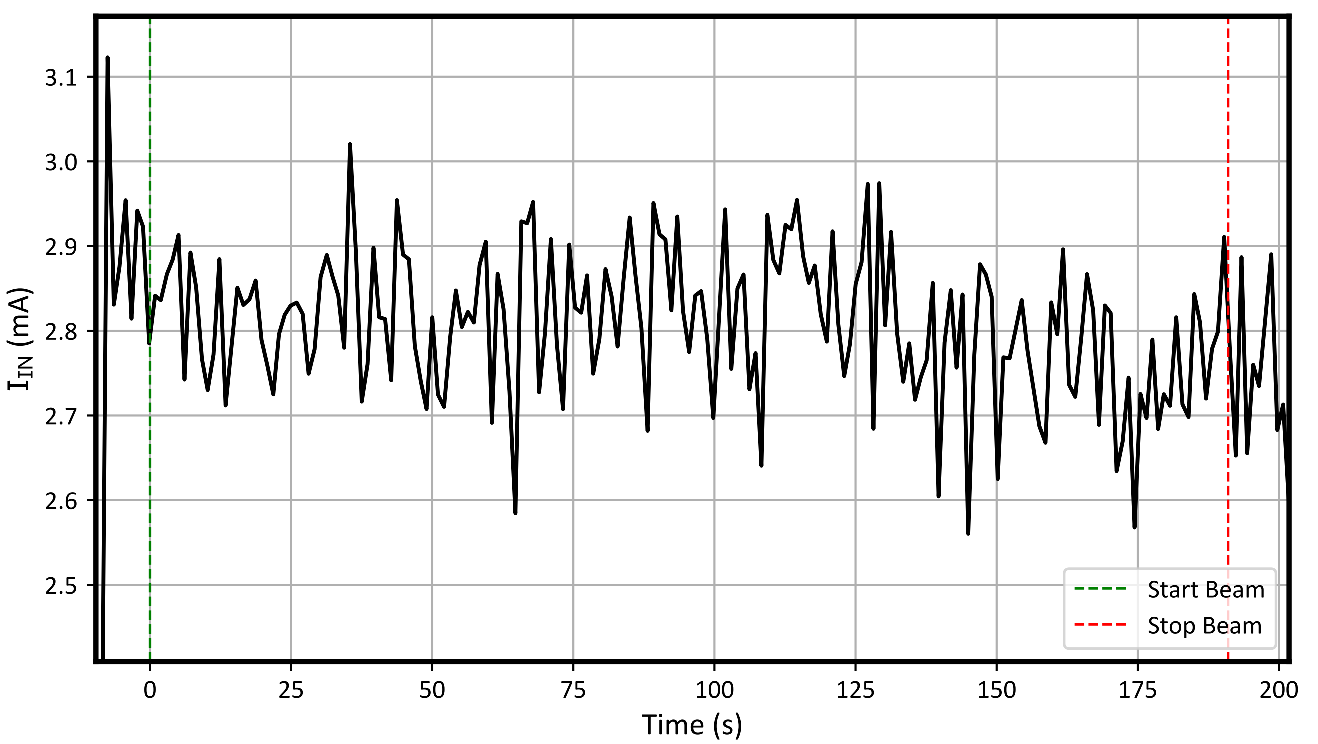

Figure 7-4. Current versus Time for I_{IN}: SEB Off (Mode 0, WD Off) Run #8

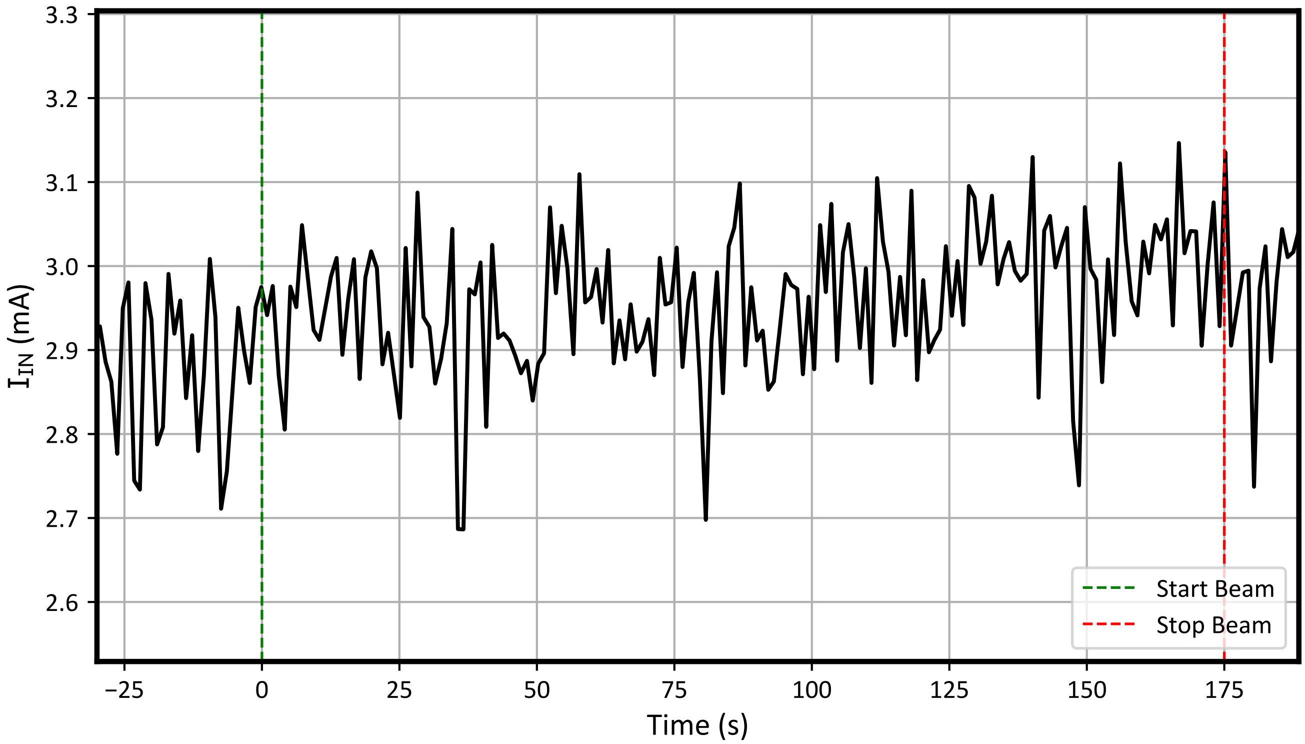

Figure 7-5. Current versus Time for I_{IN}: SEB On (Mode 1, WD SW) Run #9

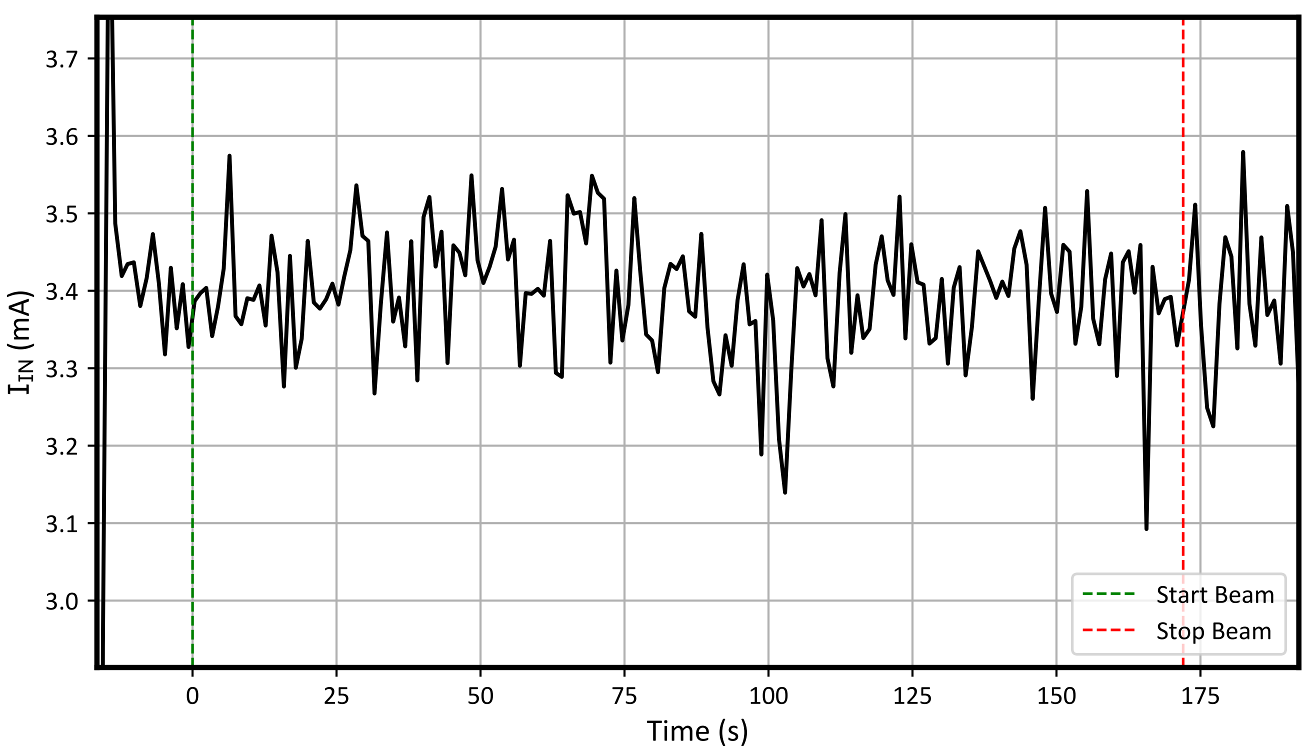

Figure 7-6. Current versus Time for I_{IN}: SEB Off (Mode 1, WD SW) Run #10

8 Single-Event Transients (SET)

The primary focus of SETs were heavy-ion-induced transient upsets on $\overline{\text{RESET}}$1, PWRGD, or $\overline{\text{WDO}}$. SET testing was done at room temperature using ^{165}Ho which produced a LET_{EFF} of 75MeV·cm^2/mg. The output signals were monitored by four NI PXIe-5172. The PXIe-5172 was triggered with an edge-negative at –20% below the high voltage when in the on state **.** During the testing when the device was in the off state, the trigger was set to 0.66V with an edge-positive trigger.

The PXIe-5172 sample rate was set to 100MS/s with a record length of 100k points (or samples). The device was configured with an external voltage that was set to provide an overdrive voltage of ±20mV (typically). The device was tested under the following conditions.

1. Disabled (SR_$\overline{\text{UVLO}}$ = 0V) with –20mV.
2. Enabled (SR_$\overline{\text{UVLO}}$ = 1V) with +20mV.

The device was tested under a typical voltage for IN (3.3V) and PULL_UPx (1.8V). Under these configurations not a single transient was recorded on all signals. This demonstrates the TPS7H3XX4-SP is SET and SEFI-free. The SET test conditions and results for eight units are shown in Table 8-1.

Table 8-1. Summary of TPS7H3XX4-SP SET Test Condition and Results

RUN #	UNIT #	FACILITY	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/(cm^2·s))	FLUENCE (ions/cm^2)	WD_IN (Hz)	On/Off	PXIe-5172 $\overline{\text{RESET}}$1(# OF TRANSIENTS)	PXIe-5172 $\overline{\text{RESET}}$4(# OF TRANSIENTS)	PXIe-5172 $\overline{\text{WDO}}$ (# OF TRANSIENTS)	PXIe-5172 PWRGD (# OF TRANSIENTS)
37	5	TAMU	^{165}Ho	75	9.53×10^4	1.00×10^7	100k	On	0	0	0	0
38	5	TAMU	^{165}Ho	75	9.25×10^4	1.00×10^7	0	On	0	0	0	0
39	5	TAMU	^{165}Ho	75	8.96×10^4	1.00×10^7	100k	Off	0	0	0	0
40	6	TAMU	^{165}Ho	75	8.00×10^4	1.00×10^7	100k	On	0	0	0	0
41	6	TAMU	^{165}Ho	75	8.00×10^4	1.00×10^7	0	On	0	0	0	0
42	6	TAMU	^{165}Ho	75	8.50×10^4	1.00×10^7	100k	Off	0	0	0	0
43	7	KSEE	^{169}Tm	75.1	1.12×10^5	1.00×10^7	0	On	0	-	0	0
44	8	KSEE	^{169}Tm	75.1	1.10×10^5	1.00×10^7	100k	On	0	-	0	0
45	9	KSEE	^{169}Tm	75.1	1.21×10^5	1.00×10^7	0	On	0	-	0	0
46	10	KSEE	^{169}Tm	75.1	1.10×10^5	1.00×10^7	100k	On	0	-	0	0
47	11	KSEE	^{169}Tm	75.1	1.08×10^5	1.00×10^7	0	On	0	-	0	0
48	12	KSEE	^{169}Tm	75.1	1.17×10^5	1.00×10^7	100k	On	0	-	0	0

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 (2.54mm) 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, SEB/SEGR, and SET, the event rate calculation for the SEL, SEB/SEGR, and SET are shown in Table 9-1, Table 9-2, and Table 9-3 and Table 9-4, respectively. **It is important to note that this number is for reference since no SEL, SEB/SEGR, or SET 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}	3.07×10^{-8}	1.92×10^{-12}	8.02×10^{-5}	1.42×10^{9}
GEO		1.77×10^{-4}		5.43×10^{-12}	2.26×10^{-4}	5.04×10^{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}	1.54×10^{-8}	9.62×10^{-13}	4.01×10^{-5}	2.85×10^{9}
GEO		1.77×10^{-4}		2.72×10^{-12}	1.13×10^{-4}	1.01×10^{9}

Table 9-3. SET (Enabled) 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}	3.69×10^{-8}	2.31×10^{-12}	9.62×10^{-5}	1.19×10^{9}
GEO		1.77×10^{-4}		6.52×10^{-12}	2.72×10^{-4}	4.20×10^{8}

Table 9-4. SET (Disabled) 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}	1.84×10^{-7}	1.15×10^{-11}	4.81×10^{-4}	2.37×10^{8}
GEO		1.77×10^{-4}		3.26×10^{-11}	1.36×10^{-3}	8.40×10^{7}

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 TPS7H3XX4-SP. Heavy-ions with LET_{EFF} = 75MeV·cm^2/mg were used for the SEE characterization campaign. Flux of ≈6 × 10^4 to ≈1× 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 TPS7H3XX4-SP is free of destructive SEL and SEB/SEGR. The device also proved to be SET and SEFI-free at LET_{EFF} = 75MeV·cm^2/mg across the full electrical specifications. CREME96-based worst-week event-rate calculations for LEO (ISS) and GEO orbits for the DSEE and SET are presented for reference.

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12 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (August 2025) to Revision A (August 2026)	Page
• Expanded the report scope to include three additional device variants and incorporate newly collected heavy-ion irradiation data. The document now covers the TPS7H3124-SP, TPS7H3034-SP, and TPS7H3134-SP to provide a more comprehensive SEE characterization	0

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