Radiation Report

TPS7H3024-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 TPS7H3024-SP. Heavy-ions with LET_{EFF} of 75MeV·cm^2/mg were used to irradiate eight production devices. Flux of ≈ 6 × 10^4 ions/cm^2·s and fluence of ≈ 10^7 ions/cm^2 per run were used for the characterization. The results demonstrate the TPS7H3024-SP is SEL-free and SEB/SEGR-free at T = 125°C and T = 25°C, respectively. The TPS7H3024-SP was also tested for SET at T = 25°C, results demonstrate the device is SET and SEFI-free.

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1 Introduction

The TPS7H3024-SP is an integrated 3V to 14V, four channel radiation-hardness assured power-supply supervisor with watchdog. Features for the device include:

- A 599.7mV ± 1% threshold voltage
- 24μA ± 3% hysteresis current
- Global programmable timer through a single resistor
- Positive edge detection watchdog timer to monitor an external processor
- Faults mitigated and controlled by SR_$\overline{\text{UVLO}}$

The device is offered in a 22-pin ceramic 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 TPS7H3024-SP product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H3024-SP
Orderable Number	5962R2420601VXC
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 Istotope 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 TPS7H3024-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 TPS7H3024-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 TPS7H3024-SP a total of six units were exposed under worst-case bias conditions for SEL. The TPS7H3024-SP did not exhibit any SEL with heavy-ions with LET_{EFF} = 75 MeV·cm^2/mg at flux of ≈6 × 10^4 to 1 × 10^5 ions/cm^2 ·s, fluence of ≈10^7 ions/cm^2, and a die temperature of 125°C.

The TPS7H3024-SP was evaluated for SEB/SEGR at a maximum voltage of 14V (V_{IN}) in the on and off states. 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. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H3024-SP is SEB/SEGR-free up to LET_{EFF} = 75 MeV·cm^2/mg at a flux of ≈6 × 10^4 to 1 × 10^5 ions/cm^2·s, fluence of ≈10^7 ions/cm^2, and a die temperature of ≈25°C.

The TPS7H3024-SP was tested under nominal input conditions for SET. During the testing of two devices, not a single transient was recorded, showing that the TPS7H3024-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 TPS7H3024-SP is packaged in a 22-pin CFP-HFT ceramic package as shown in Figure 3-1. The TPS7H3024EVM-CVAL was used to evaluate the performance and characteristics of the TPS7H3024-SP under heavy ion radiation. The TPS7H3024EVM-CVAL is shown in Figure 3-2. The configuration used during the heavy-ions test campaign in provided in Figure 3-3.

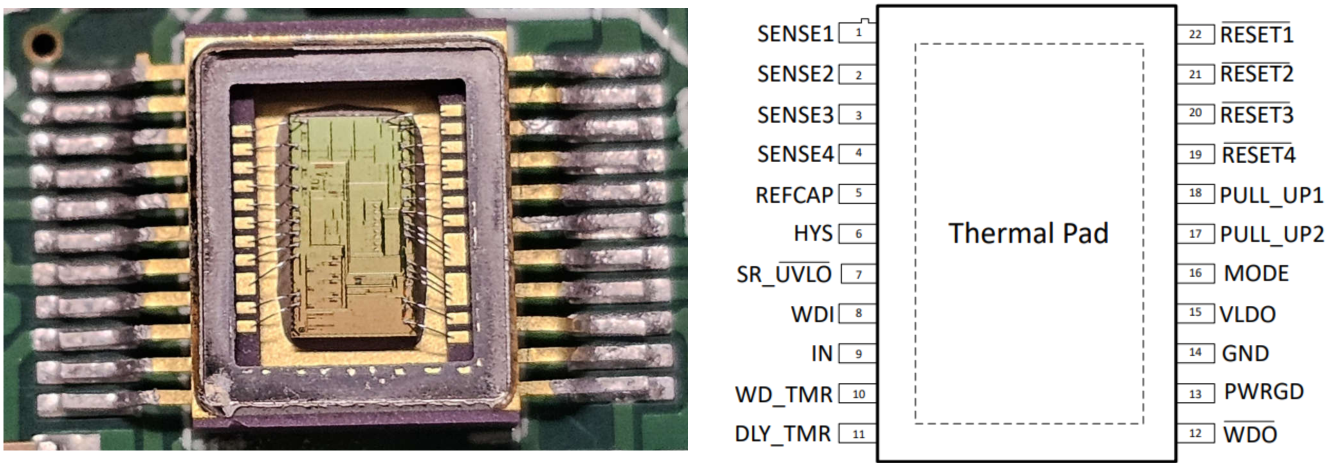

Figure 3-1. Photograph of Delidded TPS7H3024-SP [Left] and Pinout Diagram [Right]

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

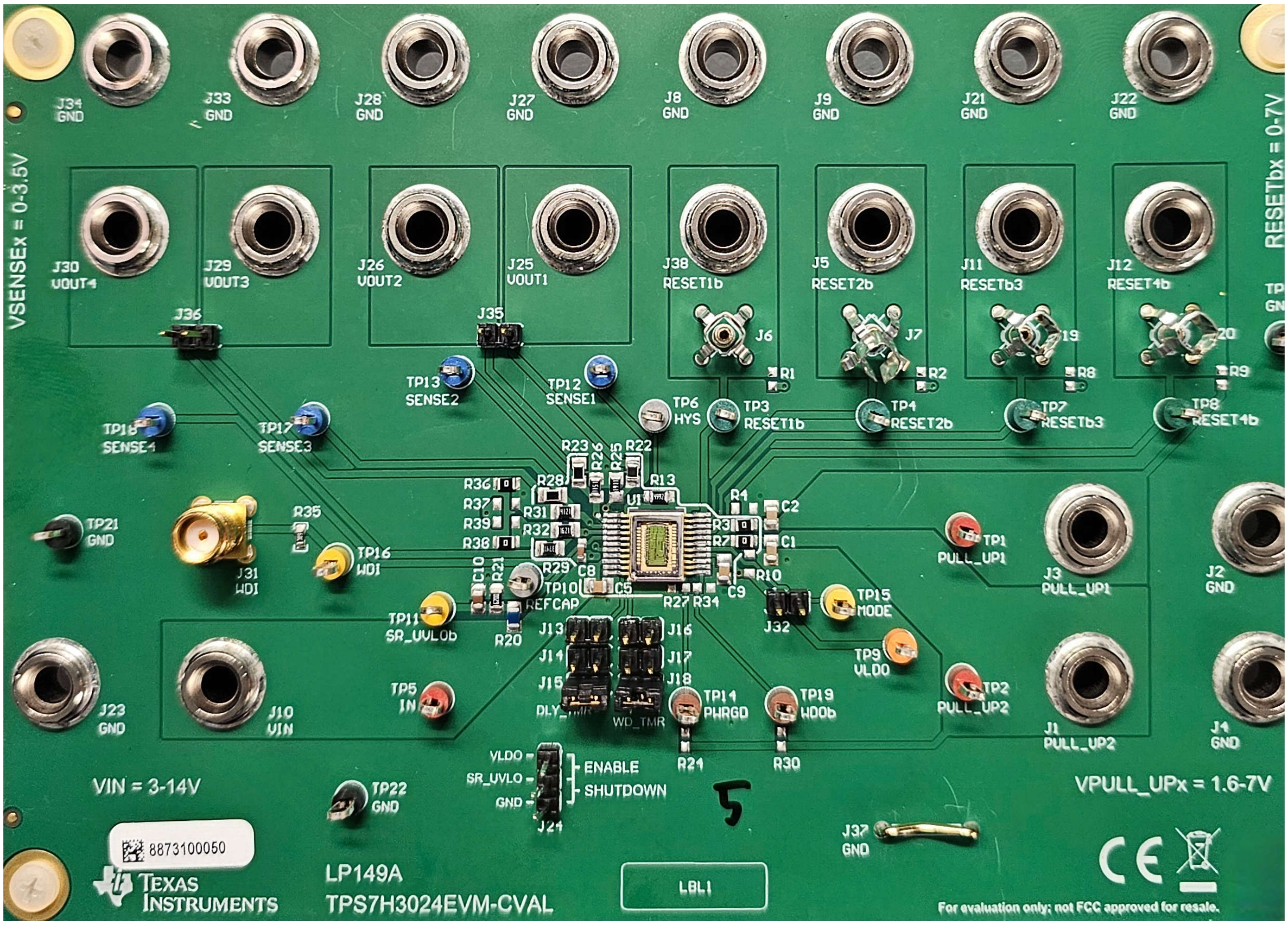

Figure 3-2. TPS7H3024EVM-CVAL Top View

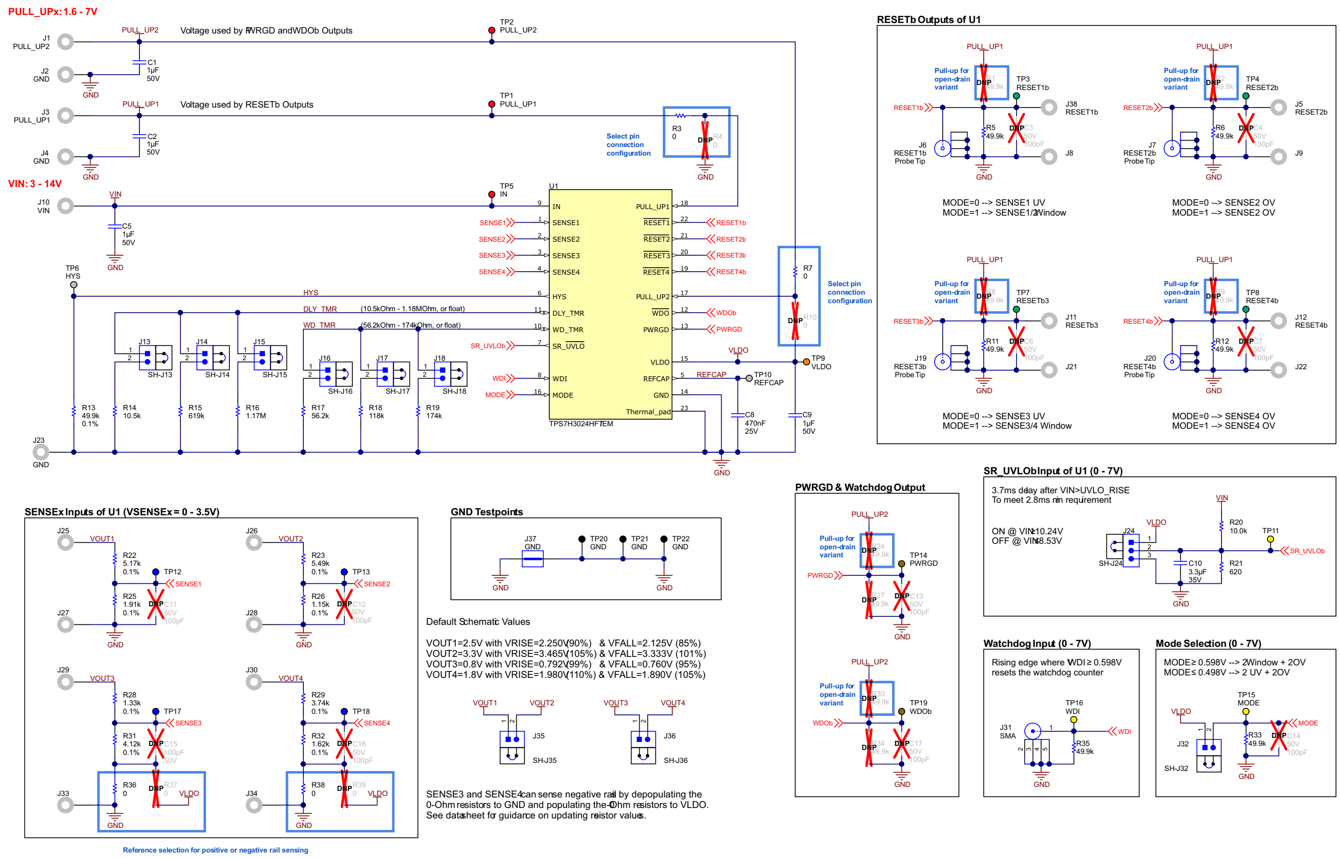

Figure 3-3. TPS7H3024EVM-CVAL Schematic for SEE Testing

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/$cm^2 \cdot s$ 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 between 60mm for all runs.

For the experiments conducted on this report, there was 2 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 = 3.295 GeV (19.5 MeV/nucleon)
  - Ion uniformity for these experiments were between 79% and 80%

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

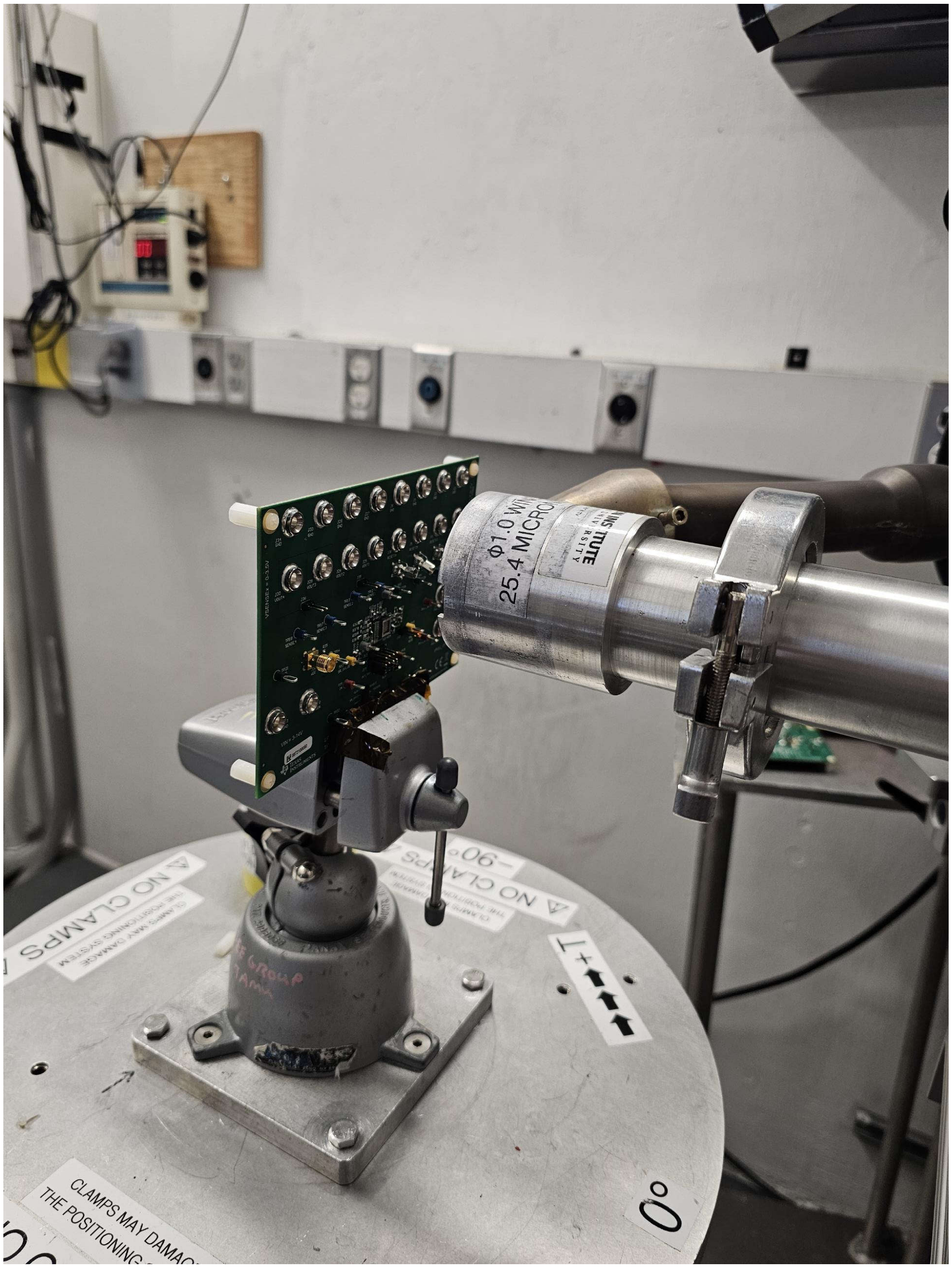

Figure 4-1. TPS7H3024EVM-CVAL in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 LET_{EFF} and Range Calculation

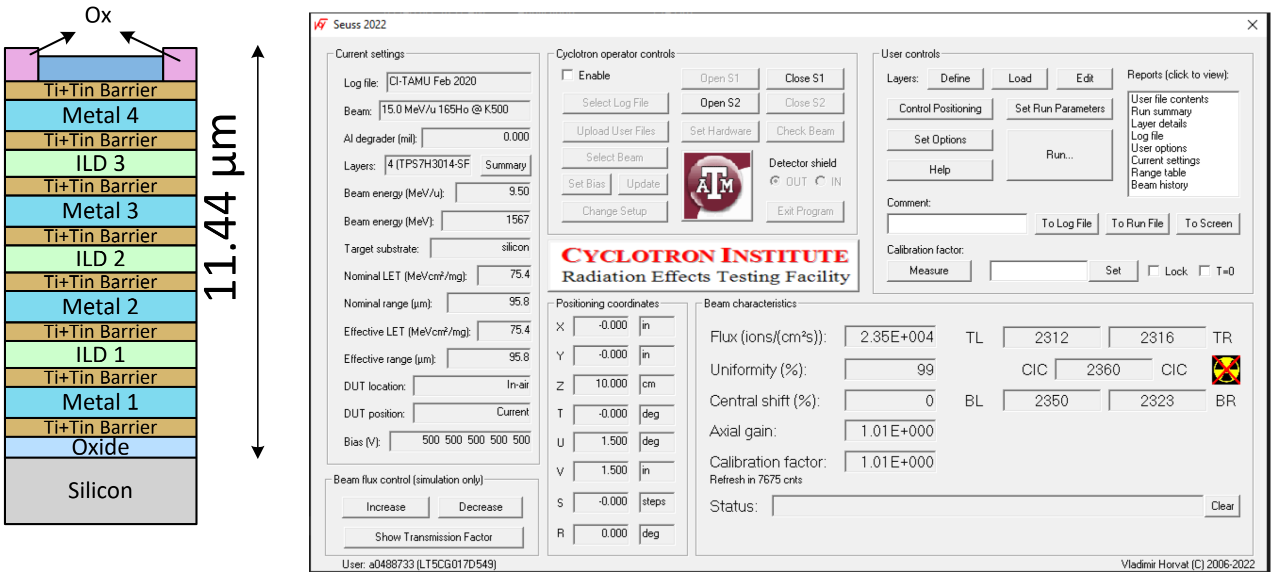

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H3024-SP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right]

The TPS7H3024-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 TPS7H3024-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 TPS7H3024-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 TPS7H3024-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 & 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}=500kHz		PXIe-5433

As discussed in Section 3 the TPS7H3024-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 TPS7H3014-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 TPS7H3024-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 TPS7H3024-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. Neither, a single transient was capture by the oscilloscope measuring the outputs indicting the device is SET-free.

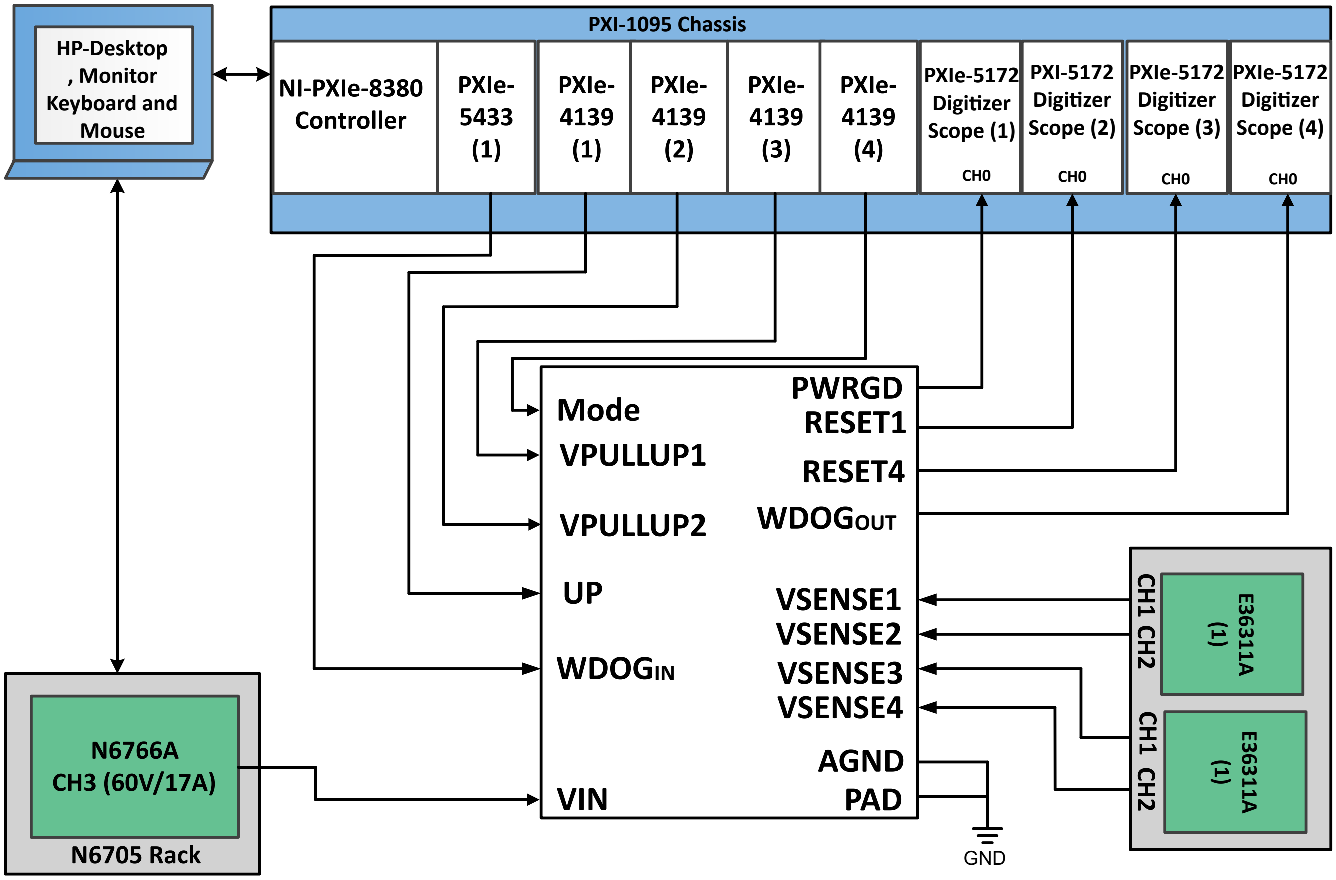

Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H3024-SP

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. Incident angle was used which achieved an LET_{EFF} of 75MeV·cm^2/mg.

6 production units of the TPS7H3024-SP were tested for SEL at a flux of ≈6 × 10^4 ions/cm^2·s, a fluence of ≈ 10^7 ions/cm^2, maximum recommended V_{IN} voltage (14V), maximum recommended $V_{PULL-UPX}$ voltage (7V). For SEL testing the device was configured in 4 different operating modes.

1. U1 - MODE 0, WD SW
2. U2 - MODE 0, WD Off
3. U3 - MODE 1, WD SW
4. U4 - MODE 1, WD Off

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 TPS7H3024-SP. This indicates the TPS7H3024-SP is SEL-free. The results for four runs across four devices are shown in Table 7-1. A typical V_{IN} current versus time plot during a SEL run is shown in Figure 7-1 and Figure 7-2.

Table 7-1. Summary of TPS7H3024-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
19	7	KSEE	^{169}Tm	75.1	7.72 × 10^4	1.00 × 10^7	0
20	8	KSEE	^{169}Tm	75.1	1.02 × 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 six runs at 125°C (6 × 10^7) ions/cm^2, the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 6.15 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75MeV·cm^2/mg and T = 125°C.

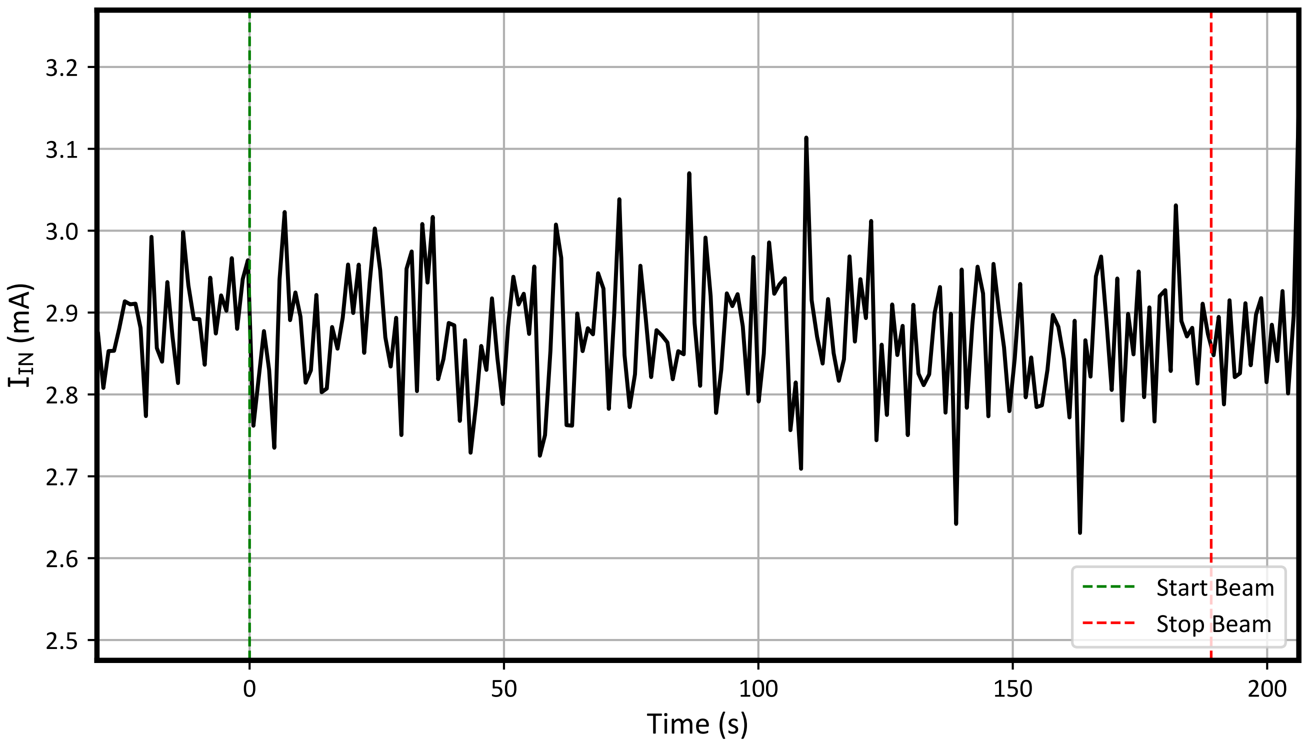

Figure 7-1. Current versus Time for I_{IN}: Run #2 (Mode 0, WD Off) of the TPS7H3024-SP at T = 125°C

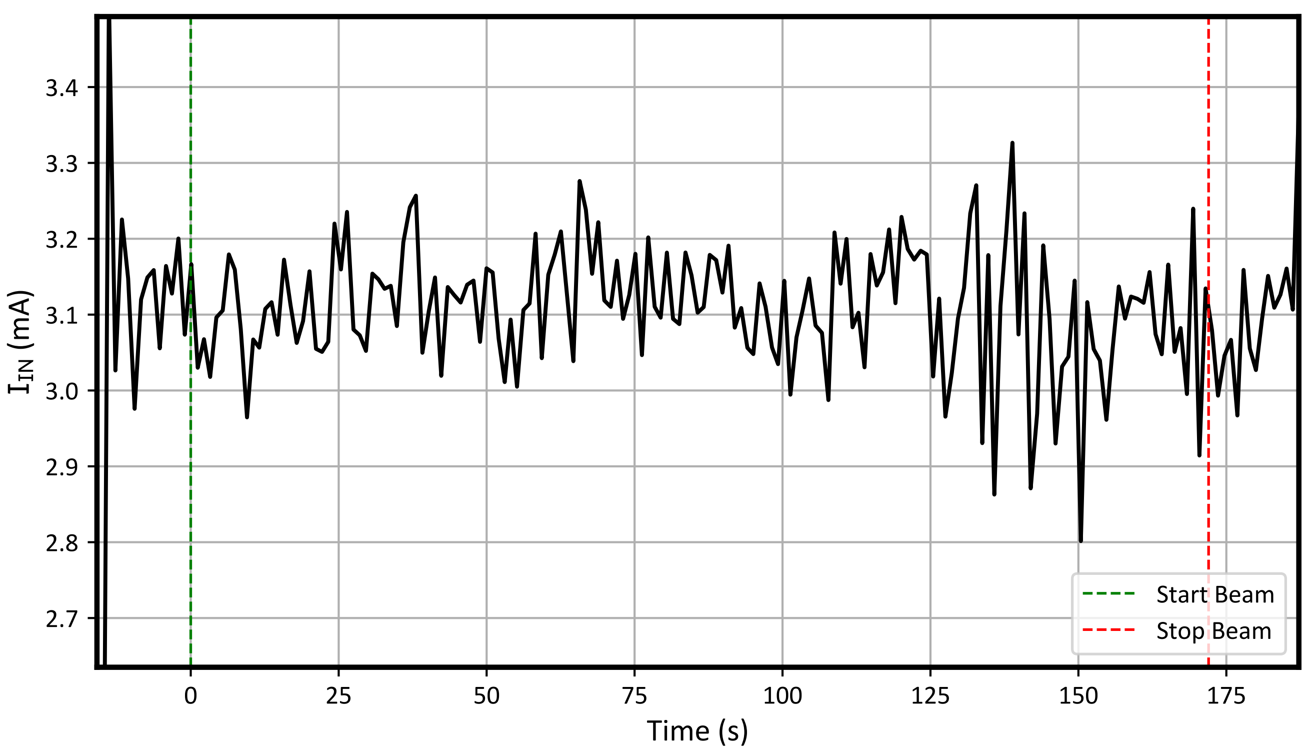

Figure 7-2. Current versus Time for I_{In}: Run #3 (Mode 1, WD SW) of the TPS7H3024-SP at T = 125°C

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 results for twelve runs across six devices for SEB_X are shown in Table 7-2. Over all eight runs (four enabled and four disabled) none of the four units exhibited any SEB/SEGR failures, indicating the TPS7H3024-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 7-2. Summary of TPS7H3024-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?
5	1	TAMU	^{165}Ho	75	5.70×10^4	1.00×10^7	On	No
6	1	TAMU	^{165}Ho	75	5.21×10^4	1.00×10^7	Off	No
7	2	TAMU	^{165}Ho	75	5.55×10^4	1.00×10^7	On	No
8	2	TAMU	^{165}Ho	75	5.26×10^4	1.00×10^7	Off	No
9	3	TAMU	^{165}Ho	75	5.76×10^4	1.00×10^7	On	No
10	3	TAMU	^{165}Ho	75	5.86×10^4	1.00×10^7	Off	No
11	4	TAMU	^{165}Ho	75	5.95×10^4	1.00×10^7	On	No
12	4	TAMU	^{165}Ho	75	5.63×10^4	1.00×10^7	Off	No
21	7	KSEE	^{169}Tm	75.1	1.05×10^5	1.00×10^7	On	No
22	7	KSEE	^{169}Tm	75.1	1.04×10^5	1.00×10^7	Off	No
23	8	KSEE	^{169}Tm	75.1	9.98×10^4	1.00×10^7	On	No
24	8	KSEE	^{169}Tm	75.1	9.44×10^4	1.00×10^7	Off	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:

$\sigma_{SEB} \le 3.07 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75 MeV·cm^2/mg and T = 25°C.

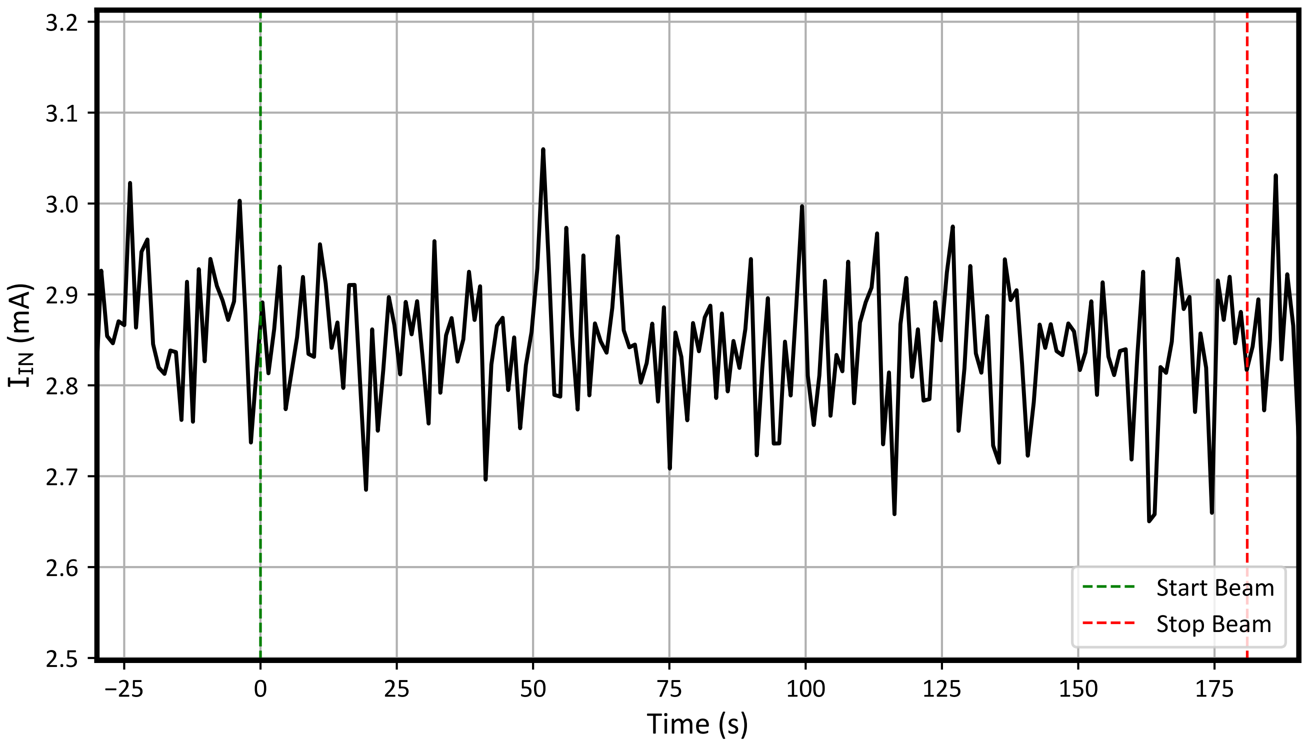

Figure 7-3. Current versus Time for I_{IN}: SEB On (Mode 0, WD Off) Run #7

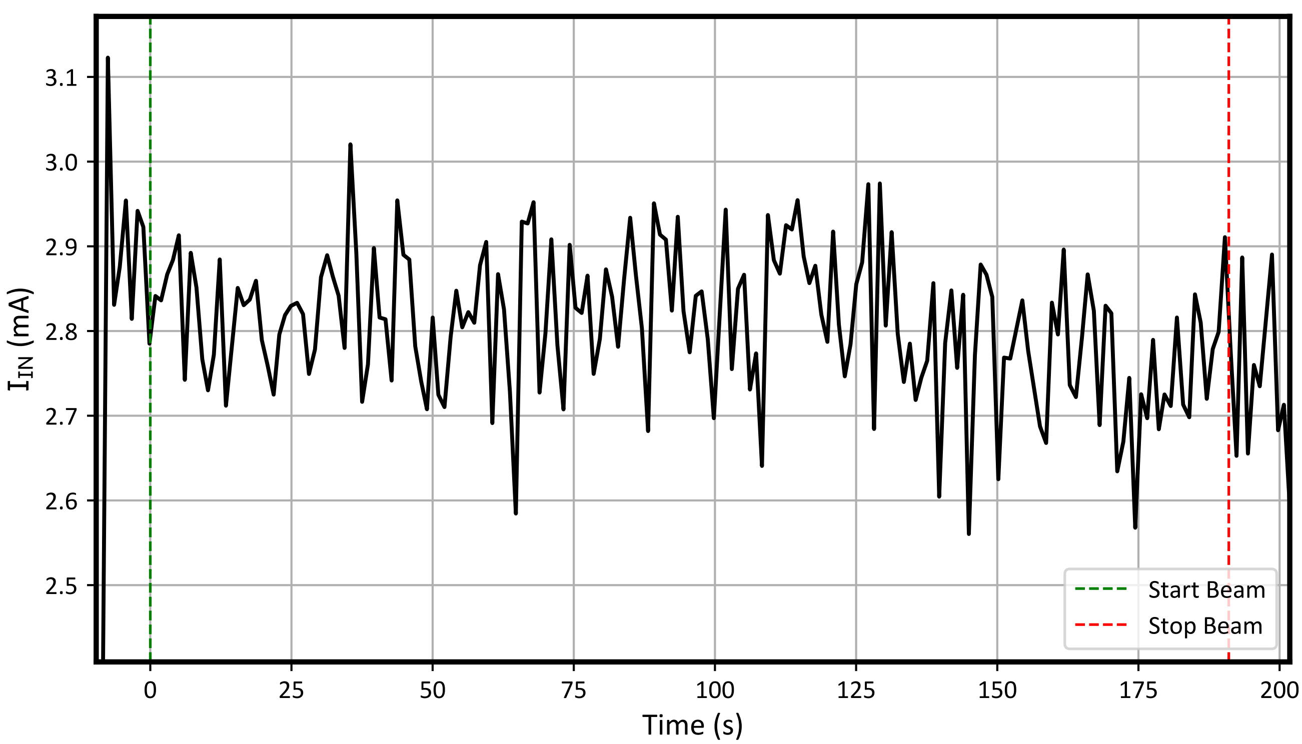

Figure 7-4. Current versus Time for I_{IN}: SEB Off (Mode 0, WD Off) Run #8

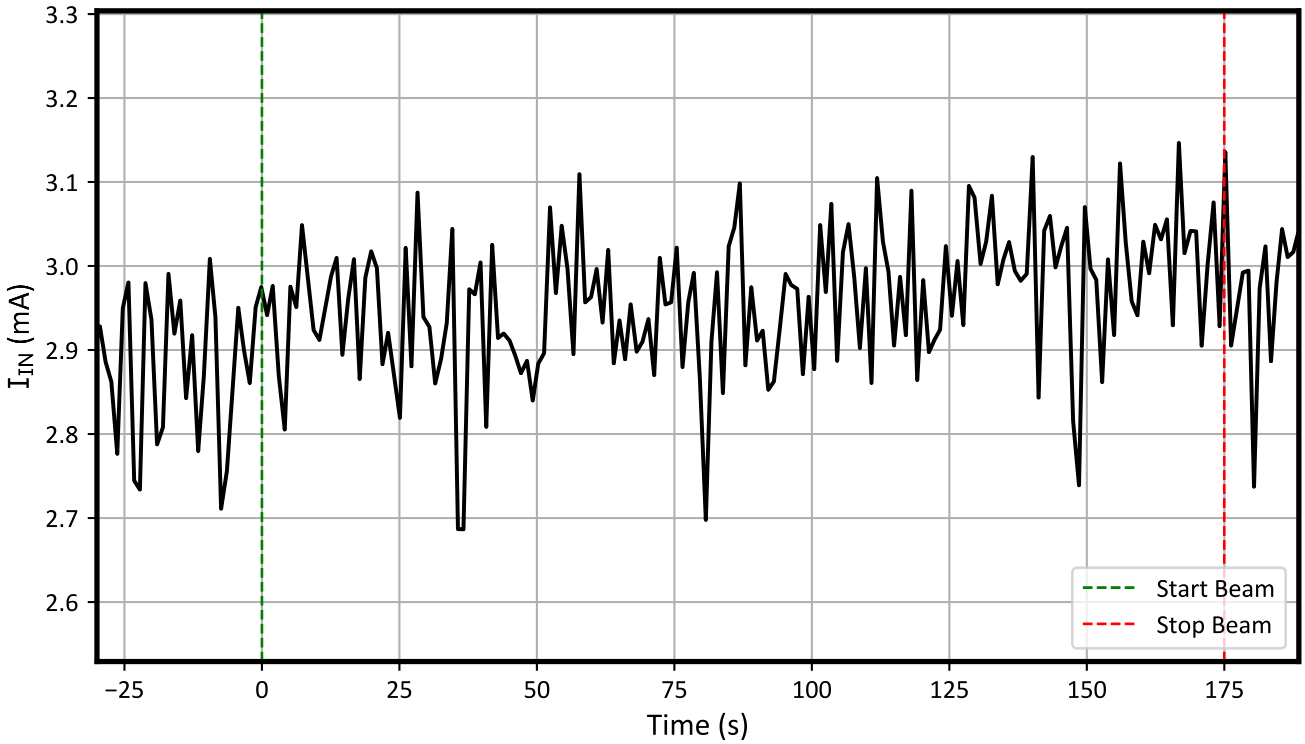

Figure 7-5. Current versus Time for I_{IN}: SEB On (Mode 1, WD SW) Run #9

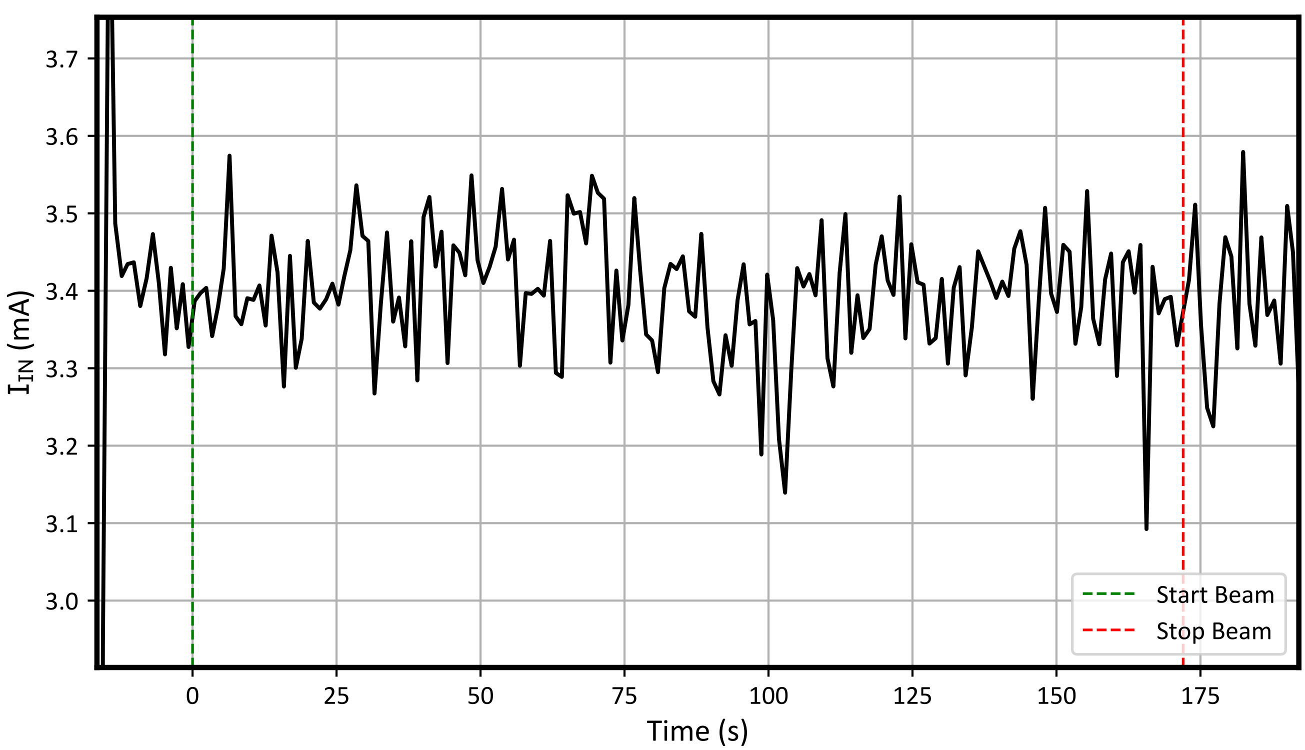

Figure 7-6. Current versus Time for I_{IN}: SEB Off (Mode 1, WD SW) Run #10

8 Single-Event Transients (SET)

The primary focus of SETs were heavy-ion-induced transient upsets on $\overline{\text{RESET}}$1, $\overline{\text{RESET}}$4, 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 was controlled 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 TPS7H3024-SP is SET and SEFI-free. The SET test conditions and results for three units are shown in Table 8-1.

Table 8-1. Summary of TPS7H3024-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)
13	5	TAMU	^{165}Ho	75	9.53×10^4	1.00×10^7	100k	On	0	0	0	0
14	5	TAMU	^{165}Ho	75	9.25×10^4	1.00×10^7	0	On	0	0	0	0
15	5	TAMU	^{165}Ho	75	8.96×10^4	1.00×10^7	100k	Off	0	0	0	0
16	6	TAMU	^{165}Ho	75	8.00×10^4	1.00×10^7	100k	On	0	0	0	0
17	6	TAMU	^{165}Ho	75	8.00×10^4	1.00×10^7	0	On	0	0	0	0
18	6	TAMU	^{165}Ho	75	8.50×10^4	1.00×10^7	100k	Off	0	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 9-2, 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}	6.15×10^{-8}	3.85×10^{-12}	1.60×10^{-4}	7.12×10^{8}
GEO		1.77×10^{-4}		1.09×10^{-11}	4.53×10^{-4}	2.52×10^{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}	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 9-3. 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}	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 9-4. 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 TPS7H3024-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 TPS7H3024-SP is free of destructive SEL and SEB/SEGR. The device also shown to be SET and SEFI-free at LET_{EFF} = 75MeV·cm^2/mg and 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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