*Radiation Report*

# *Single-Event Effects (SEE) Radiation Report of the TPS7H5030-SP and TPS7H5031-SP*

## ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TPS7H503x-SP. Heavy-ions with $LET_{EFF}$ of 75MeV×cm$^2$/mg were used to irradiate 6 devices. Flux of approximately 10$^5$ions/cm$^2$/s and fluence of approximately 10$^7$ions/cm$^2$ per run were used for the characterization. The results demonstrated that the TPS7H503x-SP is SEL-free up to 75MeV×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 output pulse-width excursions ≥ |20%| from the nominal pulse-width in an open-loop configuration are discussed.

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# 1 Introduction

The TPS7H503x-SP is a radiation-hardened, current mode, single-ended PWM controller with an integrated gate driver that can be utilized in silicon based converter designs. The TPS7H503x-SP integrates several key functions such as:

- Soft-start, enable, and adjustable slope compensation
- 0.6V ±1% voltage reference tolerance
- Internal oscillator through the RT pin or external frequency control through the SYNC pin
- Switching frequencies up to 500kHz
- Input voltage range from 8V to 14V

The TPS7H5030 has a maximum duty cycle of 100% and the TPS7H5031 has a maximum duty cycle of 50%. The controller supports numerous power converter topologies, including flyback, forward, and boost.

The device is offered in a 24-pin plastic package. Table 1-1 lists the general device information and test conditions. 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 | TPS7H503x-SP |
| Orderable Part Number | 5962R2420103PYE (TPS7H5030-SP) or 5962R420104PYE (TPS7H5031-SP) |
| Device Function | PWM Controller with Integrated Gate Driver |
| Technology | LBC7 (Linear BiCMOS 7) |
| Exposure Facility | 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 TPS7H503x-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 TPS7H503x-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 TPS7H503x-SP was tested for SEL at the maximum recommended operating conditions of VIN = PVIN = 14V and a fixed VLDO = 5V for the silicon mode. During testing of the four devices, the TPS7H503x-SP did not exhibit any SEL with heavy-ions with $LET_{EFF}$ = 75MeV×cm$^2$/mg at a flux of approximately 10$^5$ ions/cm$^2$/s, fluence of approximately 10$^7$ions/cm$^2$, and a die temperature of 125°C.

The TPS7H503x-SP was evaluated for SEB/SEGR at a maximum voltage of 14V 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. The TPS7H503x-SP was tested for SEB at the maximum recommended operating conditions of $V_{IN}$=$P_{VIN}$=14V and a fixed $V_{LDO}$ = 5V. 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 TPS7H503x-SP is SEB/SEGR-free up to $LET_{EFF}$ = 75MeV×cm$^2$/mg at a flux of approximately 10$^5$ions/cm$^2$/s, fluences of approximately 10$^7$ ions/cm$^2$, and a die temperature of approximately 25°C.

The TPS7H503x-SP was characterized for SET at flux of approximately 10$^5$ions/cm$^2$/s , fluences of approximately 10$^7$ ions/cm$^2$, and room temperature. The device was characterized at $P_{VIN}$ = $V_{IN}$ of 12V with a fixed $V_{LDO}$ = 5V. Heavy-ions with $LET_{EFF}$ of 75MeV×cm$^2$/mg were used to characterize the transient performance. To see the SET results of the TPS7H503x-SP, please refer to Single-Event Transients (SET).

# 3 Device and Test Board Information

The TPS7H503x-SP is packaged in a 24-pin HTSSOP PWP plastic package as shown in Figure 3-1. A custom TPS7H503x-SP evaluation module, designed for open-loop SEE testing, was used to evaluate the performance and characteristics of the TPS7H503x-SP under heavy ion radiation. Figure 3-2 shows the evaluation modules. Figure 3-3 shows the schematics.

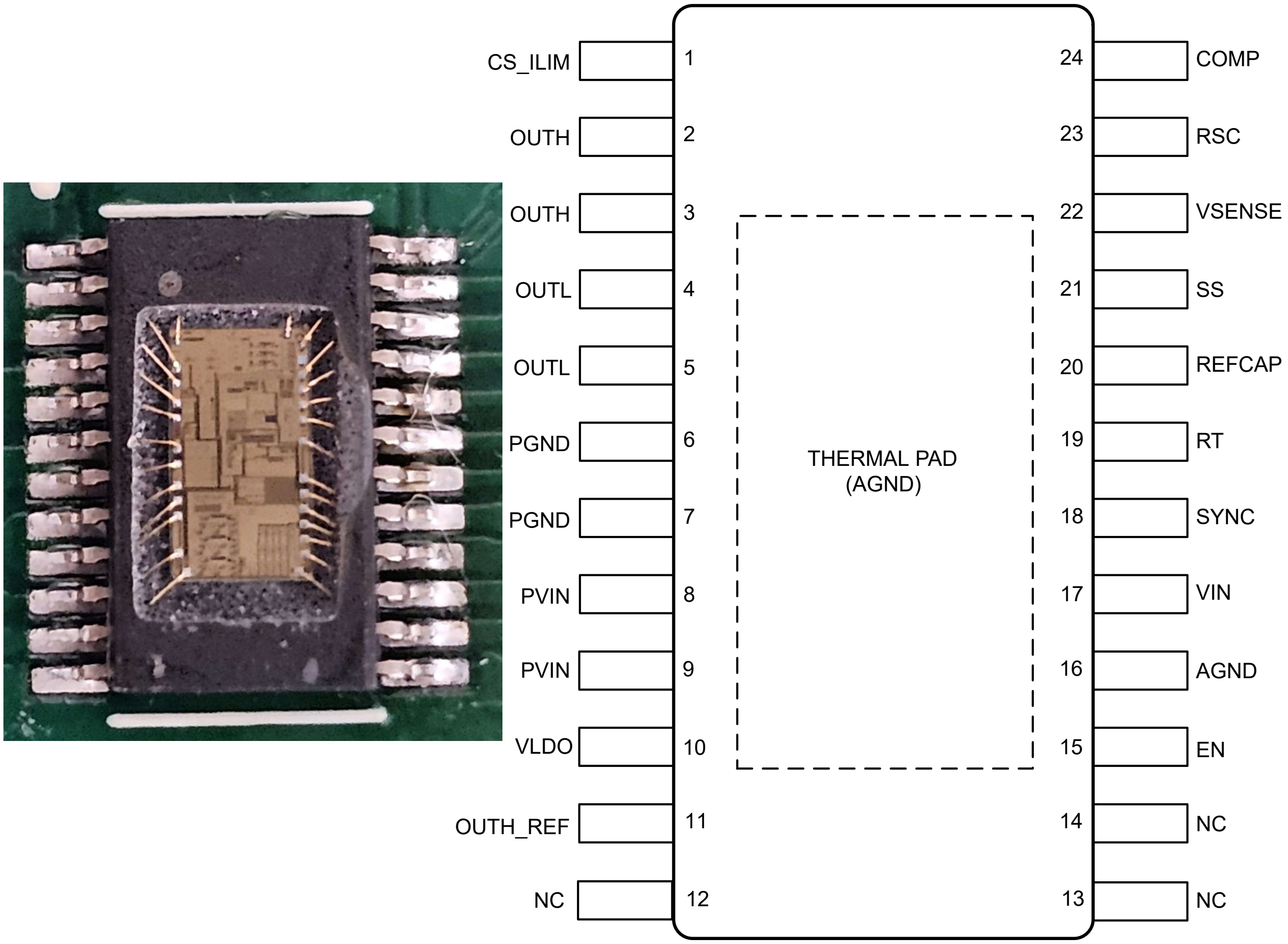

**Figure 3-1. Photograph of Delidded TPS7H503x-SP [Left] and Pinout Diagram [Right]**

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

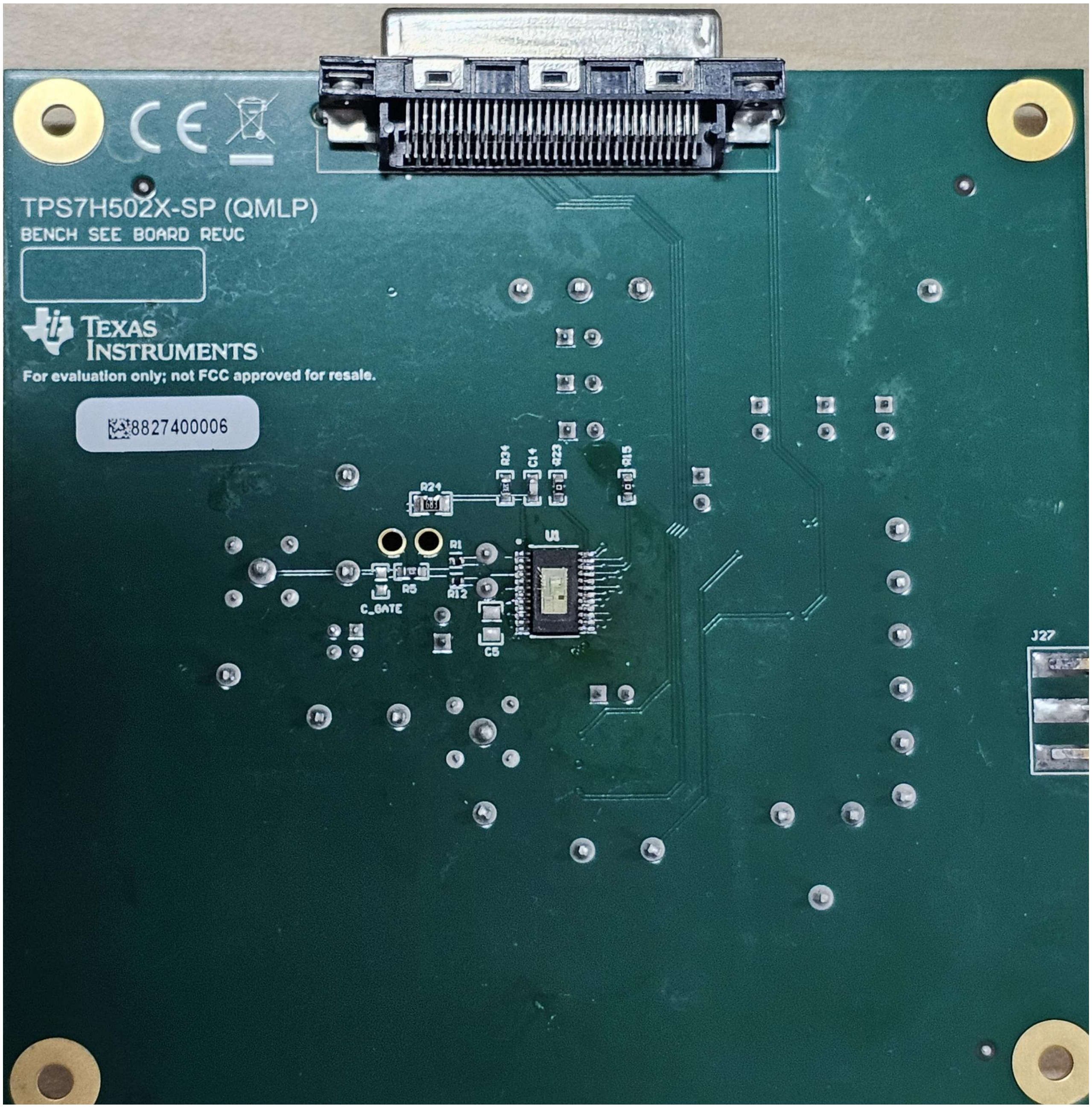

Figure 3-2. TPS7H503x-SP Custom EVM Top View

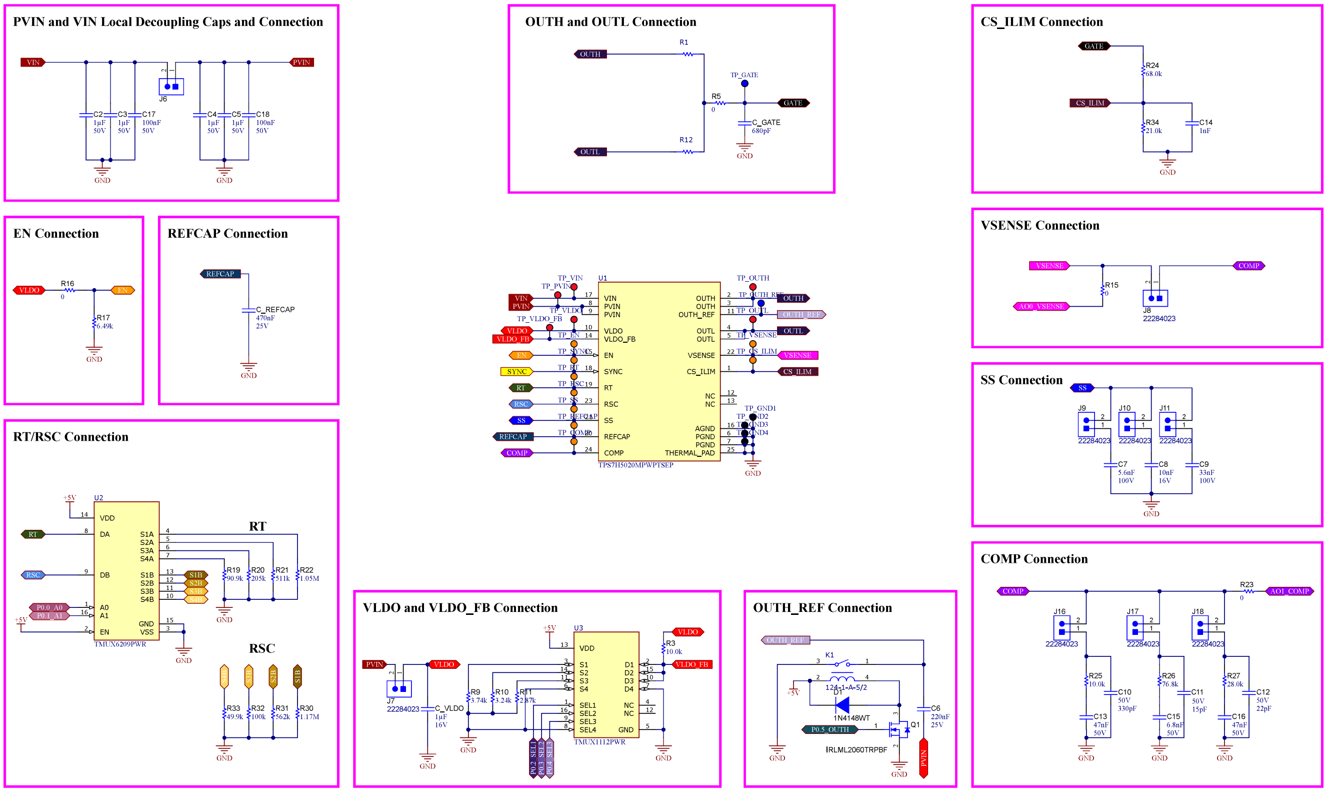

Figure 3-3. TPS7H503x-SP Custom EVM Controller Schematic

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**Note**

VLDO_FB is not applicable for TPS7H503x because the VLDO is fixed to 5V.

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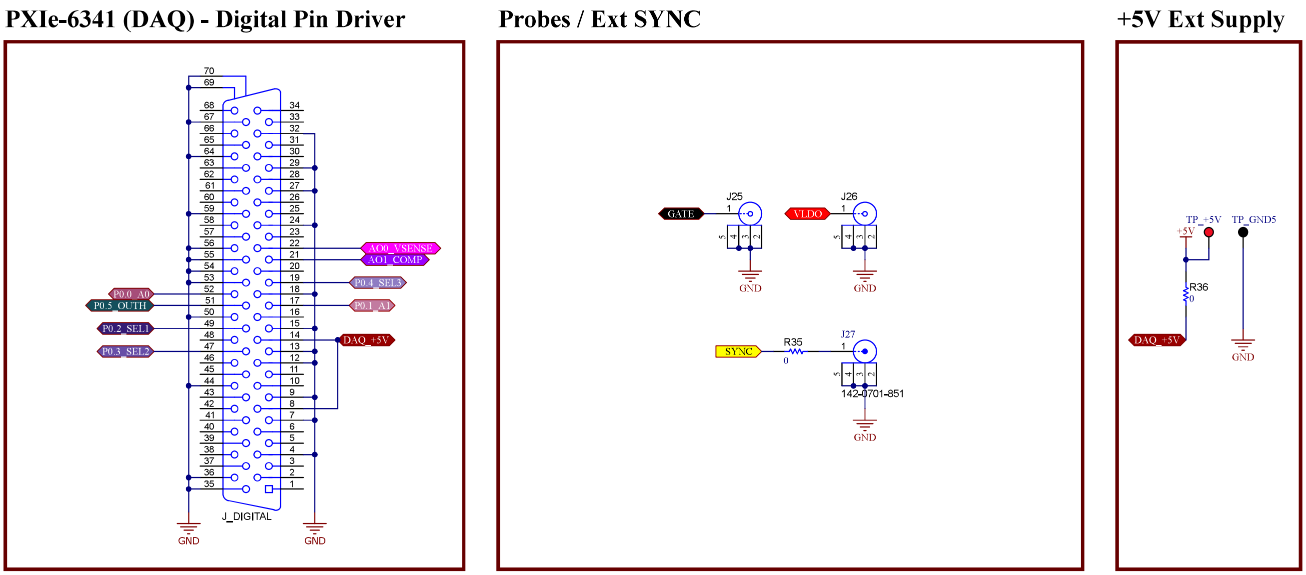


Figure 3-4. TPS7H503x-SP Custom EVM Auxiliary Schematic

# 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 approximately $10^5$ions/cm$^2$/s was used to provide heavy-ion fluences of $1.00 \times 10^7$ions/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.

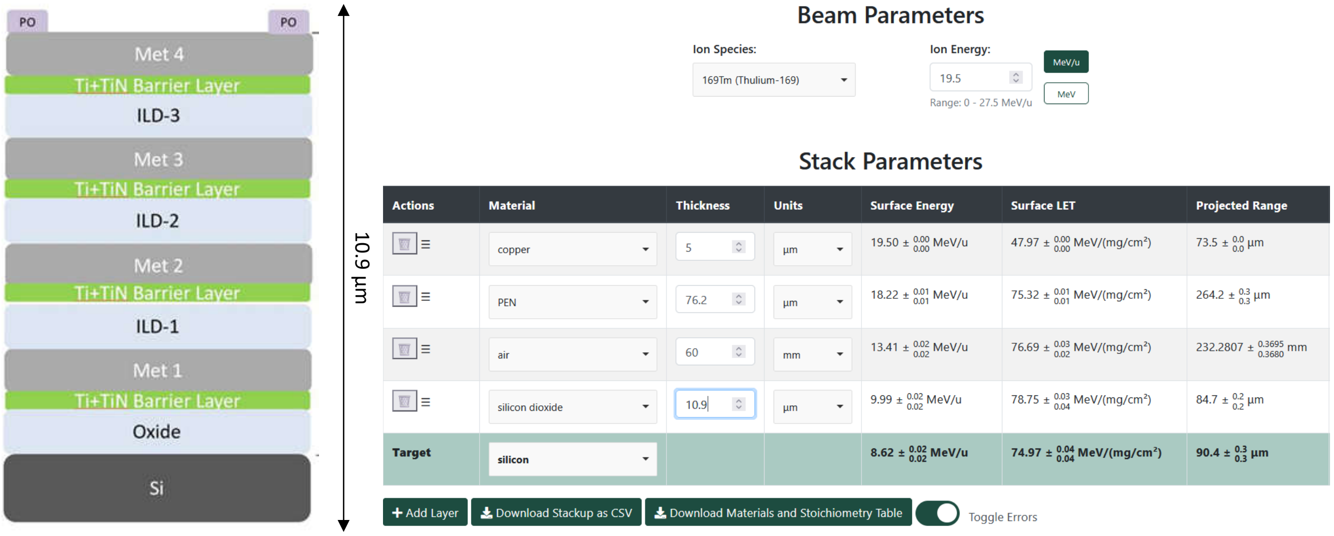
For the experiments conducted on this report, the $^{169}$Tm ion was used to obtain LET$_{EFF}$ of 75MeV×cm$^2$/mg. The total kinetic energies for the ion was:

- $^{169}$Tm = 3.295GeV (19.5MeV/nucleon)
  - Ion uniformity for these experiments was approximately 90%

Figure 4-1 shows the open-loop custom SEE evaluation module in front of the beam line at the KSEE facility.

**Figure 4-1. TPS7H503x-SP EVM in Front of the Heavy-Ion Beam Exit Port at the MSU KSEE Cyclotron**

# 5 LET$_{EFF}$ and Range Calculation



Beam Parameters

Ion Species: 169Tm (Thulium-169)

Ion Energy: 19.5

Range: 0 - 27.5 MeV/u

Stack Parameters

| Actions | Material | Thickness | Units | Surface Energy | Surface LET | Projected Range |
|---|---|---|---|---|---|---|
| ≡ | copper | 5 | µm | 19.50 $\pm^{0.00}_{0.00}$ MeV/u | 47.97 $\pm^{0.00}_{0.00}$ MeV/(mg/cm$^2$) | 73.5 $\pm^{0.0}_{0.0}$ µm |
| ≡ | PEN | 76.2 | µm | 18.22 $\pm^{0.01}_{0.01}$ MeV/u | 75.32 $\pm^{0.01}_{0.01}$ MeV/(mg/cm$^2$) | 264.2 $\pm^{0.3}_{0.3}$ µm |
| ≡ | air | 60 | mm | 13.41 $\pm^{0.02}_{0.02}$ MeV/u | 76.69 $\pm^{0.03}_{0.02}$ MeV/(mg/cm$^2$) | 232.2807 $\pm^{0.3695}_{0.3680}$ mm |
| ≡ | silicon dioxide | 10.9 | µm | 9.99 $\pm^{0.02}_{0.02}$ MeV/u | 78.75 $\pm^{0.03}_{0.04}$ MeV/(mg/cm$^2$) | 84.7 $\pm^{0.2}_{0.2}$ µm |
| **Target** | **silicon** | | | **8.62 $\pm^{0.02}_{0.02}$ MeV/u** | **74.97 $\pm^{0.04}_{0.04}$ MeV/(mg/cm$^2$)** | **90.4 $\pm^{0.3}_{0.3}$ µm** |

**Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H503x-SP [Left] and MSU Stack-Up Calculator Application Used to Determine Key Ion Parameters [Right]**

The TPS7H503x-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. Figure 5-1 shows the total stack height from the surface of the passivation to the silicon surface is 10.9µm based on nominal layer thickness.

Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the TPS7H503x-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)

The results are shown in Ion LET$_{EFF}$ and Range in Silicon.

**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 |

# 6 Test Setup and Procedures

There were two input supplies used to power the TPS7H503x-SP which provided $P_{VIN}$ = $V_{IN}$ and EN. The $P_{VIN}$ = $V_{IN}$ for the device was provided via Ch. 3 of an N6705C power module and ranged from 12V to 14V for SEL, SEB/SEGR, and SET testing. The EN of the device was driven by an E36311A power supply and was either forced to 0V or 5V to enable or disable the device. A NI PXIe-6363 DAQ was used to drive $V_{SNS}$ and $V_{COMP}$.

The primary signal monitored during testing was GATE (OUTH and OUTL tied together on the EVM) and this was done so using a PXIe-5110 triggering using a pulse-width trigger at 20%.

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 6-1 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 TPS7H503x-SP.

**Table 6-1. Equipment Settings and Parameters Used During the Open-Loop SEE Testing of the TPS7H503x-SP**

| PIN NAME | EQUIPMENT USED | CAPABILITY | COMPLIANCE | RANGE OF VALUES USED |
|---|---|---|---|---|
| $V_{IN}$ | N6705C(CH #3) | 60V, 17.4A | 5A | 12V, 14V |
| EN | E36311A (CH #1) | 6V, 5A | 0.1A | 0V, 5V |
| $V_{SNS}$ | PXIe-6363 | ±10V, ±5mA | N/A | 0.6V |
| $V_{COMP}$ | PXIe-6363 | ±10V, ±5mA | N/A | 0.8V |
| $V_{LDO}$ | PXIe-6363 | ±10V, ±5mA | N/A | 5V |
| GATE | PXIe-5110 | 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 TPS7H503x-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 pulse-width or 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.

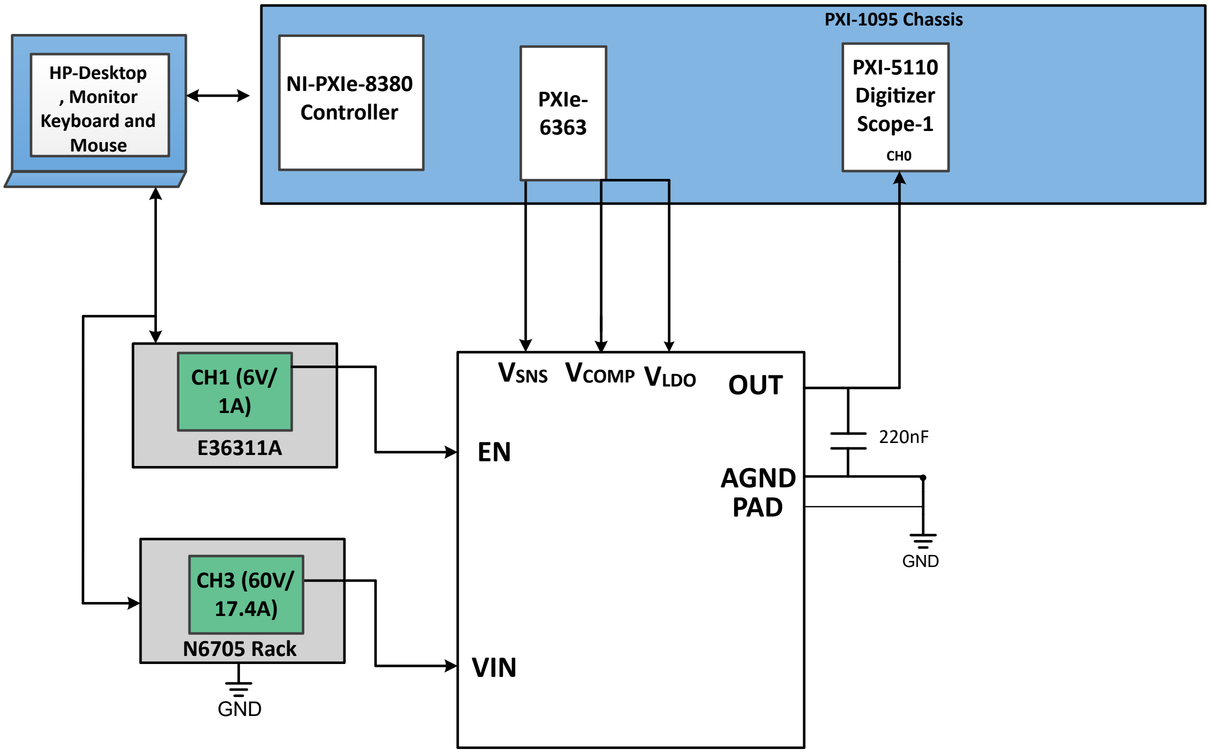


Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H503x-SP

# 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 species used for the SEB testing was $^{169}$Tm at 19.5MeV/nucleon. An angle of 0° was used to achieve a LET$_{EFF}$ of approximately 75MeV×cm$^2$/mgMeV/nucleon. The kinetic energy in the vacuum for $^{169}$Tm is 3.295GeV. Flux of approximately 10$^5$ions/cm$^2$/s and a fluence of approximately 10$^7$ions/cm$^2$ was used for the run. Run duration to achieve this fluence was approximately two minutes. Four units were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 14V and a fixed V$_{LDO}$ voltage of 5V. No SEL events were observed during all four runs, indicating that the TPS7H503x-SP is SEL-free up to 75MeV×cm$^2$/mg. Table 7-1 shows the SEL test conditions and results. Figure 7-1 shows a plot of the current versus time for run #1.

**Table 7-1. Summary of TPS7H503x-SP SEL Test Condition and Results**

| Run # | Unit # | Facility | Device Type | Ion | LET$_{EFF}$ (MeV×cm$^2$/mg) | Flux (ions/cm$^2$/s) | Fluence (ions/cm$^2$) | V$_{IN}$/P$_{VIN}$ (V) | V$_{LDO}$ (V) | SEL (# Events) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | KSEE | TPS7H5030-SP | $^{169}$Tm | 75 | $1.01 \times 10^5$ | $1.00 \times 10^7$ | 14 | 5 | 0 |
| 2 | 2 | KSEE | TPS7H5030-SP | $^{169}$Tm | 75 | $1.04 \times 10^5$ | $1.00 \times 10^7$ | 14 | 5 | 0 |
| 3 | 3 | KSEE | TPS7H5031-SP | $^{169}$Tm | 75 | $1.09 \times 10^5$ | $1.00 \times 10^7$ | 14 | 5 | 0 |
| 4 | 4 | KSEE | TPS7H5031-SP | $^{169}$Tm | 75 | $1.02 \times 10^5$ | $1.00 \times 10^7$ | 14 | 5 | 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 (8 × 10$^7$ions/cm$^2$), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 4.61 \times 10^{-8}$cm$^2$/device for LET$_{EFF}$ = 75MeV×cm$^2$/mg and T = 125°C.

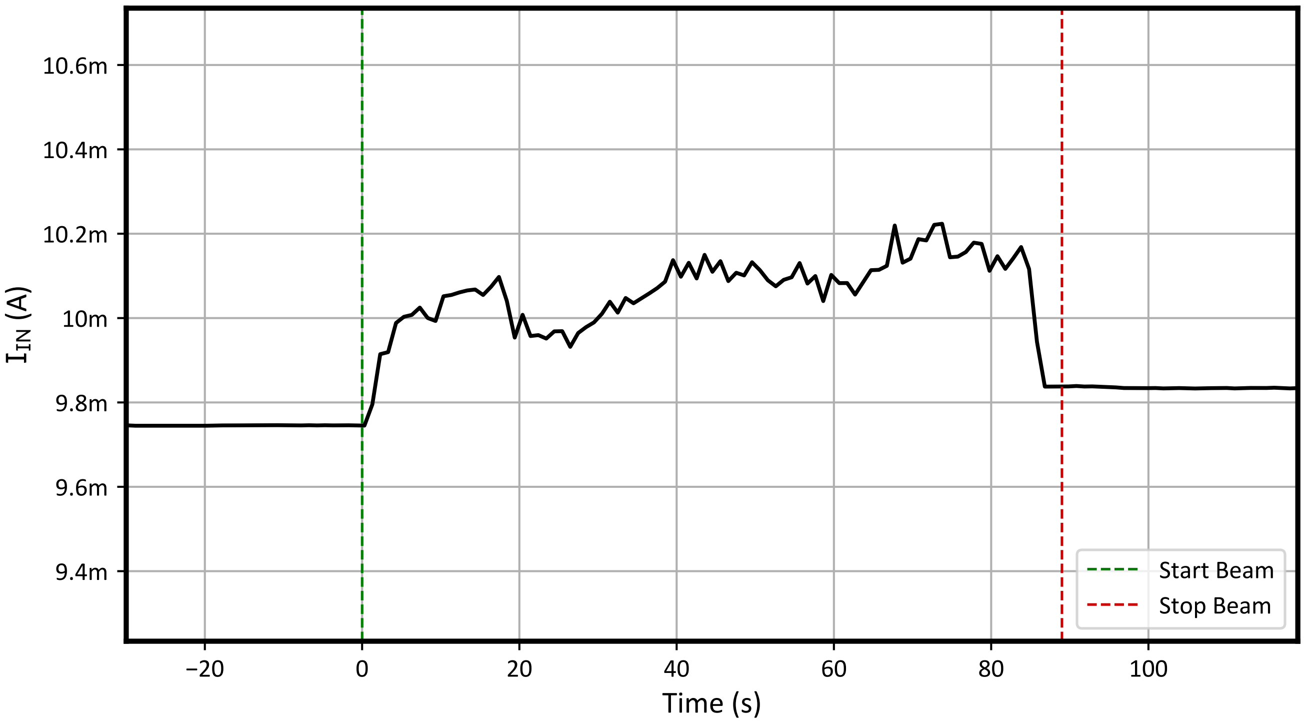


**Figure 7-1. Current versus Time for Run #1 (SEL) of the TPS7H5030-SP at T = 125°C**

## 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 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 $^{169}$Tm at 19.5MeV/nucleon. An angle of 0° was used to achieve a $\text{LET}_{\text{EFF}}$ of approximately 75MeV×cm$^2$/mg (for more details refer to Table 5-1). The kinetic energy in the vacuum for $^{169}$Tm is 3.295GeV. Flux of approximately 10$^5$ions/cm$^2$/s and a fluence of approximately 10$^7$ions/cm$^2$ was used for the run. Run duration to achieve this fluence was approximately two minutes. The four devices (same as used in SEL testing) were powered up and exposed to the heavy-ions using the maximum recommended bias conditions. No SEB/SEGR current events were observed during the eight runs, indicating that the TPS7H503x-SP is SEB/SEGR-free up to $\text{LET}_{\text{EFF}}$ = 75MeV×cm$^2$/mg and across the full electrical specifications. Table 7-2 shows the SEB/SEGR test conditions and results.

**Table 7-2. Summary of TPS7H503x-SP SEB/SEGR Test Condition and Results**

| RUN # | UNIT # | Facility | Device Type | ION | $\text{LET}_{\text{EFF}}$ (MeV×cm$^2$ /mg) | FLUX (ions/cm$^2$/s ) | FLUENCE (ions/ cm$^2$) | ENABLED STATUS | $P_{VIN}=V_{IN}$ (V) | $V_{LDO}$ (V) | SEB EVENT? |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | KSEE | TPS7H5030-SP | $^{169}$Tm | 75 | $1.19 \times 10^5$ | $1.00 \times 10^7$ | EN | 14 | 5 | No |
| 6 | 1 | KSEE | TPS7H5030-SP | $^{169}$Tm | 75 | $1.23 \times 10^5$ | $1.00 \times 10^7$ | DIS | 14 | 5 | No |
| 7 | 2 | KSEE | TPS7H5030-SP | $^{169}$Tm | 75 | $1.04 \times 10^5$ | $1.00 \times 10^7$ | EN | 14 | 5 | No |
| 8 | 2 | KSEE | TPS7H5030-SP | $^{169}$Tm | 75 | $1.05 \times 10^5$ | $1.00 \times 10^7$ | DIS | 14 | 5 | No |
| 9 | 3 | KSEE | TPS7H5031-SP | $^{169}$Tm | 75 | $1.00 \times 10^5$ | $1.00 \times 10^7$ | EN | 14 | 5 | No |
| 10 | 3 | KSEE | TPS7H5031-SP | $^{169}$Tm | 75 | $9.21 \times 10^4$ | $1.00 \times 10^7$ | DIS | 14 | 5 | No |
| 11 | 4 | KSEE | TPS7H5031-SP | $^{169}$Tm | 75 | $1.35 \times 10^5$ | $1.00 \times 10^7$ | EN | 14 | 5 | No |
| 12 | 4 | KSEE | TPS7H5031-SP | $^{169}$Tm | 75 | $1.20 \times 10^5$ | $1.00 \times 10^7$ | DIS | 14 | 5 | 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:

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

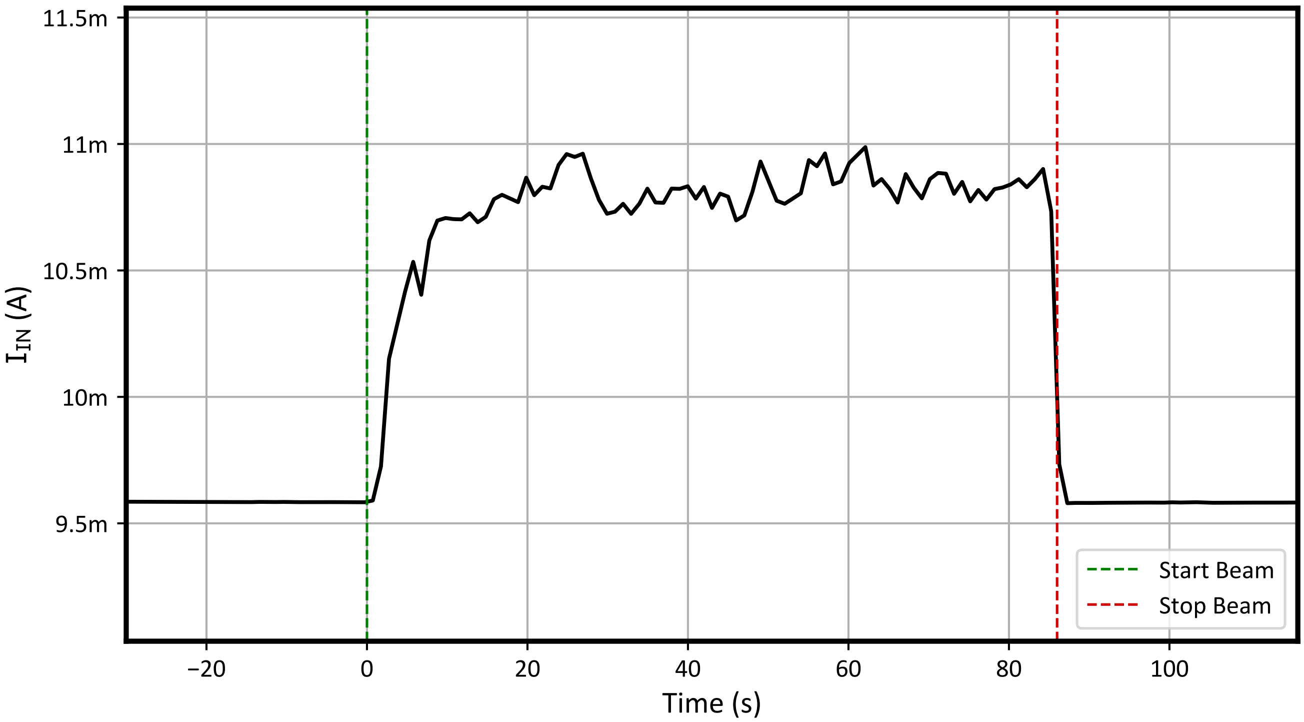


**Figure 7-2. Current versus Time for Run #5 (SEB On) of the TPS7H5030-SP at T = 25°C**

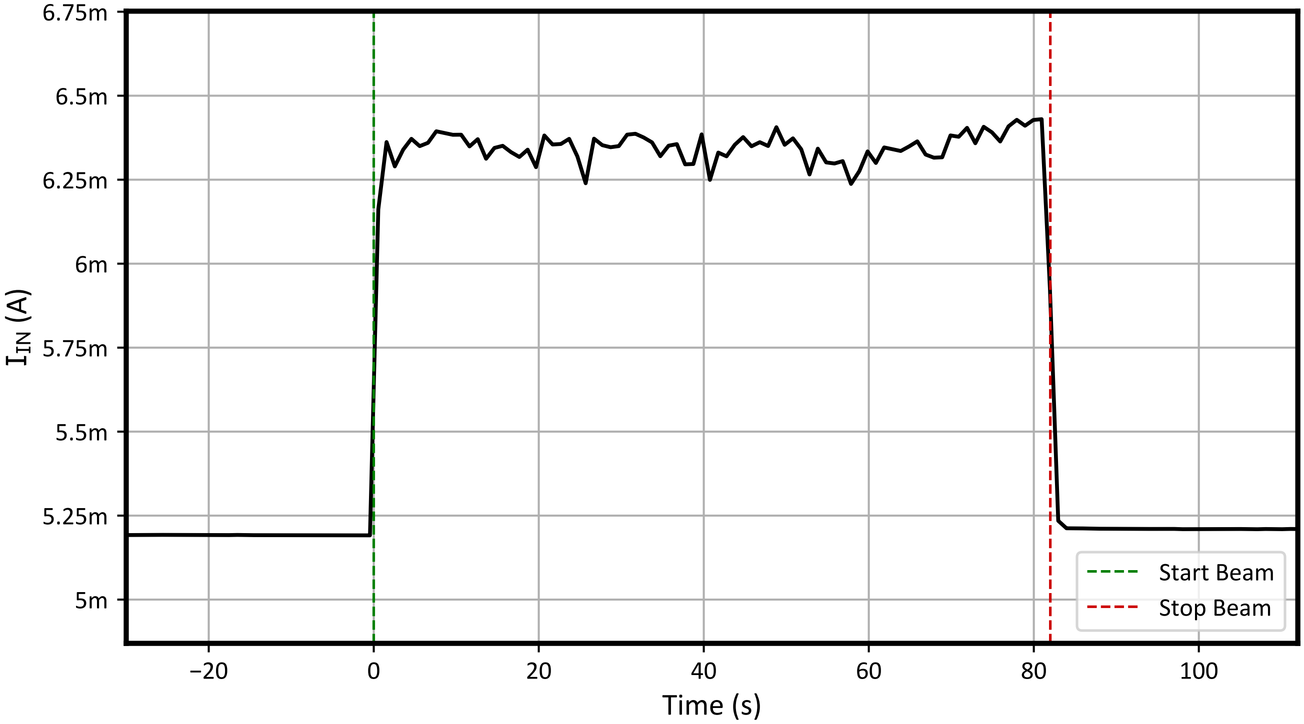


**Figure 7-3. Current versus Time for Run #6 (SEB Off) of the TPS7H5030-SP at T = 25°C**

# 8 Single-Event Transients (SET)

SET are defined as heavy-ion-induced transients upsets on the GATE (OUTH and OUTL tied together) of the TPS7H503x-SP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for the SET testing was $^{169}$Tm at 19.5MeV/nucleon (for more details refer to Table 5-1). Flux of approximately $10^5$ions/cm$^2$/s and a fluence of approximately $10^7$ions/cm$^2$, per run were used for the SET characterization discussed in this chapter.

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[1] | Trigger Type | Trigger Value | Record Length | Sample Rate |
|---|---|---|---|---|---|
| PXIe-5110 | GATE | Pulse-Width | ±20% | 50k | 100MS/s |

## Open-Loop Configuration

The primary focus of SETs were heavy-ion-induced transient upsets on output signal GATE (OUTH and OUTL tied together). SET testing was done at room temperature at $^{169}$Tm which produced a LET$_{EFF}$ of 75MeV×cm$^2$/mg. GATE was monitored using a NI PXIe-5110 and SS was monitored using a NI PXIe-5172. During testing the scope was set to trigger if the signal exceeded |20%| from nominal using a pulse width trigger. During all SET testing, TPS7H503x-SP is SEFI free and there was one type of SET recorded on GATE that was self-recoverable. SS was SET and SEFI free.

The SET results for 4 devices (the same 4 devices used for DSEE) are shown below in the following tables. The transient signature on GATE is shown and the number of transients across the runs, voltages, and frequencies is shown. Since only this transient signature occurred there is high confidence that the TPS7H503x-SP is SEFI free and the recorded transient signature does not show any overshoot.

The upper-bound cross-sections for all bias conditions are shown in Figure 8-1.

**Table 8-2. Summary of TPS7H503x-SP Open-Loop SET Test Condition and Results**

| RUN # | UNIT # | Facility | Device Type | $P_{VIN}$=$V_{IN}$ (V) | $F_{SW}$ (Hz) | ION | $LET_{EFF}$ (MeV×cm$^2$/mg) | FLUX (ions/cm$^2$/s) | FLUENCE (ions/cm$^2$) | # GATE ≥ \|20%\| |
|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 1 | KSEE | TPS7H5030-SP | 12 | 500k | $^{169}$Tm | 75 | $1.01 \times 10^5$ | $1.00 \times 10^7$ | 44 |
| 14 | 2 | KSEE | TPS7H5030-SP | 12 | 500k | $^{169}$Tm | 75 | $1.01 \times 10^5$ | $1.00 \times 10^7$ | 44 |
| 15 | 3 | KSEE | TPS7H5031-SP | 12 | 500k | $^{169}$Tm | 75 | $9.40 \times 10^4$ | $1.00 \times 10^7$ | 71 |
| 16 | 4 | KSEE | TPS7H5031-SP | 12 | 500k | $^{169}$Tm | 75 | $1.97 \times 10^5$ | $1.00 \times 10^7$ | 28 |

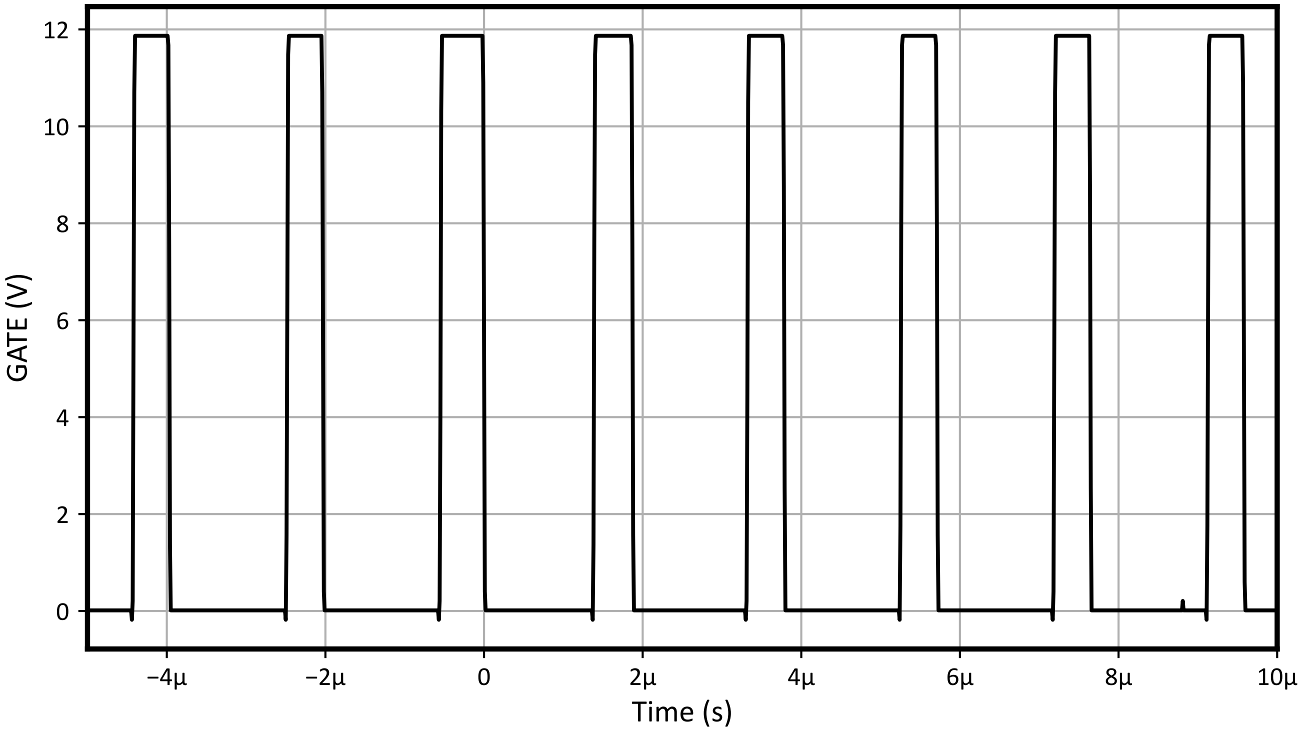


**Figure 8-1. Largest Observed GATE Positive Pulse-Width Transient**

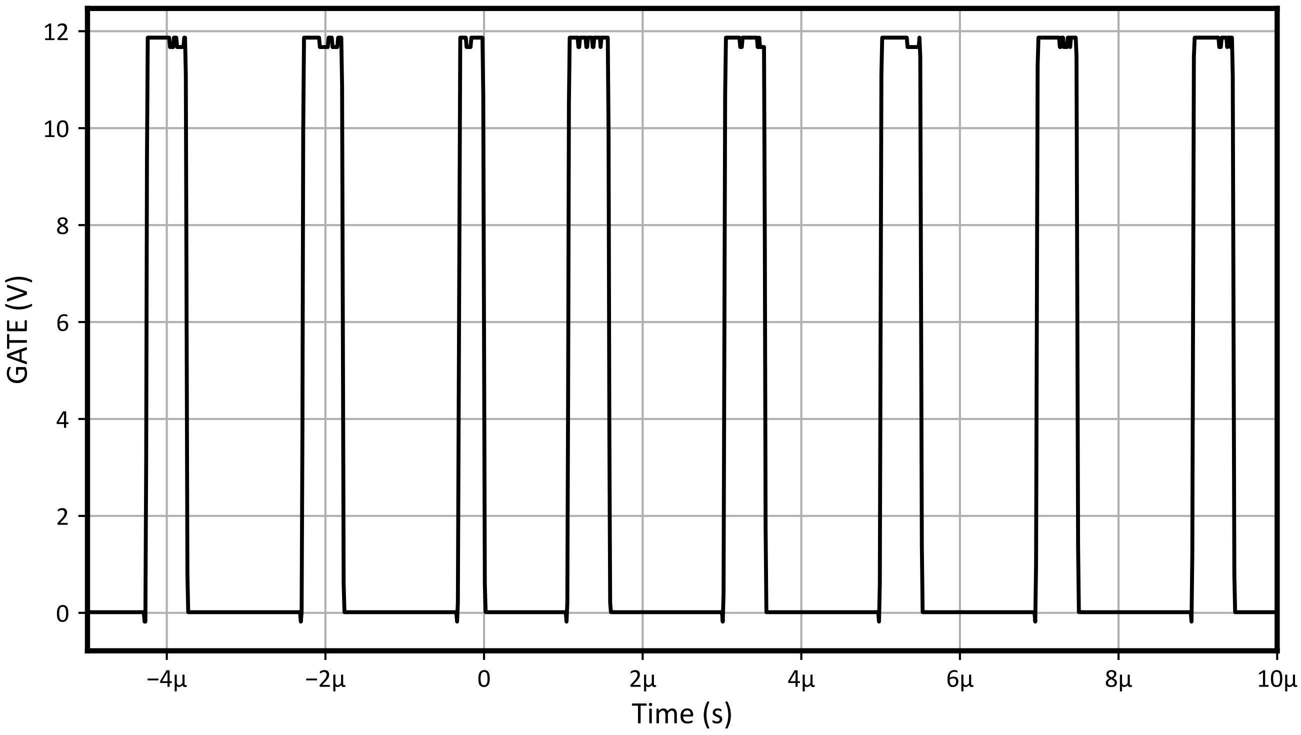


**Figure 8-2. Smallest Observed GATE Negative Pulse-Width Transient**

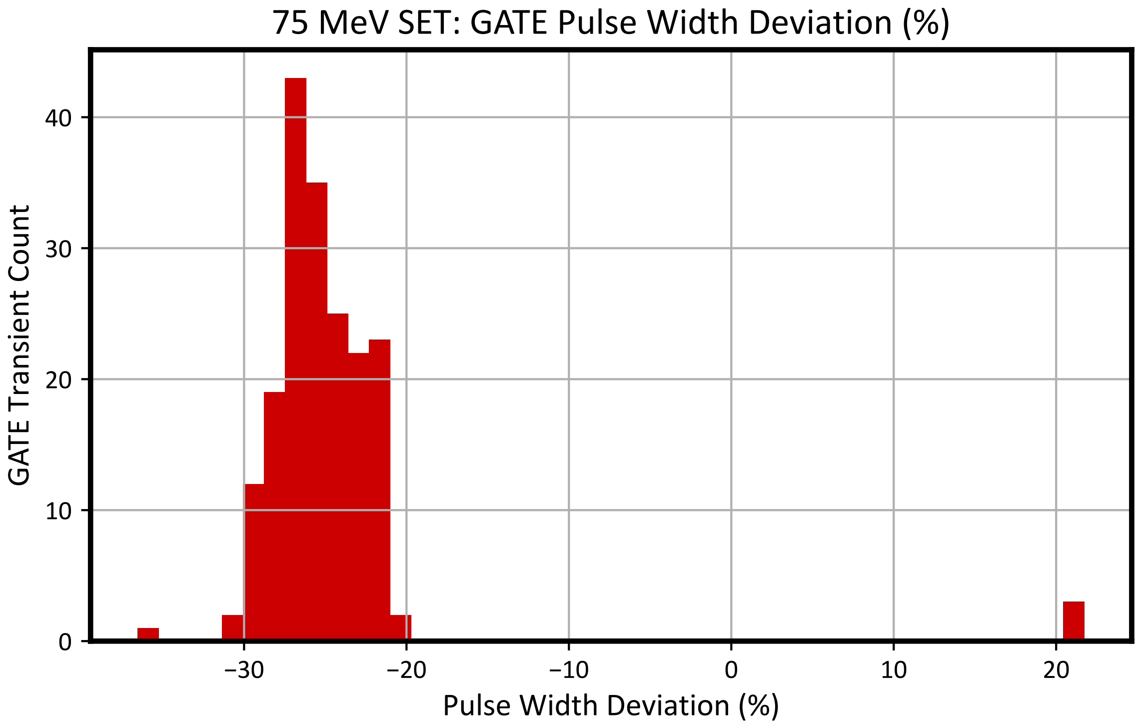


**Figure 8-3. GATE Pulse-Width Deviation Histogram (All Runs)**

### Table 8-3. TPS7H503x-SP SET Cross-Sections

| $LET_{EFF}$ (MeV×cm$^2$/mg) | Frequency (Hz) | $V_{IN}$ (V) | Fluence (ions/cm$^2$) | # Transients | Upper-Bound Cross-Section (cm$^2$) |
|---|---|---|---|---|---|
| 75 | 500k | 12 | $4 \times 10^7$ | 187 | $5.40 \times 10^{-6}$ |

# 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 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.**

**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 | $6.26 \times 10^{-5}$ | $9.22 \times 10^{-8}$ | $5.77 \times 10^{-12}$ | $2.41 \times 10^{-4}$ | $4.75 \times 10^{8}$ |
| GEO | | $1.77 \times 10^{-4}$ | | $1.63 \times 10^{-11}$ | $6.79 \times 10^{-4}$ | $1.68 \times 10^{8}$ |

**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 | $6.26 \times 10^{-5}$ | $4.61 \times 10^{-8}$ | $2.89 \times 10^{-12}$ | $1.20 \times 10^{-4}$ | $9.49 \times 10^{8}$ |
| GEO | | $1.77 \times 10^{-4}$ | | $8.15 \times 10^{-12}$ | $3.40 \times 10^{-4}$ | $3.36 \times 10^{8}$ |

## 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 TPS7H503x-SP radiation-hardened, current mode, single-ended PWM controller with an integrated gate driver. Heavy-ions with $LET_{EFF}$ = 75MeV×cm$^2$/mg were used for the SEE characterization campaign. Flux of approximately $10^5$ions/cm$^2$/s and fluences of approximately 1x10 $^7$ ions/cm$^2$ per run were used for the characterization. The SEE results demonstrated that the TPS7H503x-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 CREME96-based worst week event-rate calculations for LEO(ISS) and GEO orbits for DSEE are presented for reference.

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