Radiation Report

TPS7H4003-SEP Synchronous Step-Down Converter Single-Event Effects (SEE)

ABSTRACT

The purpose of this study is to characterize the single-event-effects (SEE) performance due to heavy-ion irradiation of the TPS7H4003-SEP. Heavy-ions with LET_{EFF} of 48.2 MeV·cm^2/mg were used to irradiate 3 production devices. Flux of ≈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 TPS7H4003-SEP is SEL and SEB/SEGR-free up to 48.2 MeV·cm^2/mg, at T = 125°C and T = 25°C, respectively, and across the full electrical specifications. SET transients performance for output voltage excursions ≥ |3%| from the nominal voltage and PGOOD ≤ V_{IN} – 0.5 V are presented and discussed.

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1 Introduction

The TPS7H4003-SEP is an space-enhanced-plastic, 3-V to 7-V input, 18-A, synchronous step-down buck point-of-load (POL) voltage converter. The device provides exceptional efficiency and output accuracy in a very small design size. Along with the small design size, the configurable switching frequency (0.1 to 1 MHz), can reduce the output filter lumped components, optimizing the power density (W/in^3). The TPS7H4003-SEP has many use cases, as well as circuit protection capabilities, enabled by the following features:

- A voltage start-up ramp controlled by the SS/TR pin for different operations.
- Power sequencing through enable and power good configurations.
- Ability to configure in primary-secondary mode depending on the SYNC2 pin.
- Cycle-by-cycle current limiting on high-side FET to protect the device in overload situations.
- Low-side-sourcing current protection to prevent current runaway.
- Low-side-sinking current protection turns off low-side MOSFET to prevent reverse current.
- Thermal shutdown disables the part when die temperature exceeds thermal limit.

The device is offered in a 44-pin plastic package. General device information and test conditions are listed in Table 1-1. For more detailed technical specifications, user guides, and application notes, see the TPS7H4003-SEP product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H4003-SEP
Orderable Number	TPS7H4003MDDWSEP
Device Function	Point-of-load (POL) switching regulator
Technology	LBC7
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/nucleon)
Heavy Ion Fluence per Run	9.95×10^6 – 1×10^7 ions/cm^2
Irradiation Temperature	25°C (for SET and SEB/SEGR testing) and 125°C (for SEL testing)

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2 Single-Event Effects (SEE)

The primary concern for the TPS7H4003-SEP 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 TPS7H4003-SEP, 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 TPS7H4003-SEP was tested for SEL at the maximum recommended voltage of 7 V, maximum load current of 18 A, and V_{OUT} of 1 V. The device exhibited no SEL when heavy-ions with LET_{EFF} = 48.2 MeV·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.

Since this device is designed to conduct large currents (up to 18 A) and withstand up to 7 V during the off-state, the power LDMOS introduces a potential susceptibility for SEB and SEGR [2]. The TPS7H4003-SEP was evaluated for SEB/SEGR at full load conditions of 18 A, and a maximum voltage of 7 V in both the enabled and disabled modes. All testing for SEB and SEGR was done at room temperature with no external heating or cooling implemented. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H4003-SEP is SEB/SEGR-free up to LET_{EFF} = 48.2 MeV·cm^2/mg at a flux of ≈10^5 ions/cm^2·s, fluence of ≈10^7 ions/cm^2.

The TPS7H4003-SEP was characterize for SET at flux of ≈10^5 ions/cm^2·s, fluence of 1 × 10^7 ions/cm^2, and room temperature. The device was characterized at P_{VIN} = 5, 6, and 6.5 V to V_{OUT} = 1 V at full load of 18-A load. Under these conditions the device showed one SET signature under heavy-ion irradiation. All observed types of SETs were self-recoverable without the need of external intervention. The SET signature occurred with test conditions of a ±3% window trigger on V_{OUT} , a negative edge trigger on SS with a trigger value of 0.6 V, and a negative edge trigger on PGOOD with a trigger value of V_{IN} – 0.5 V.

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3 Device and Test Board Information

The TPS7H4003-SEP is packaged in a 44-pin plastic package as shown in Figure 3-1. The TPS7H4003 evaluation module was used to evaluate the performance and characteristics of the TPS7H4003-SEP under heavy-ions. Figure 3-2 shows the top view of the evaluation board used for the radiation testing. Figure 3-3 shows the EVM board schematic used for the heavy-ion testing campaign.

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

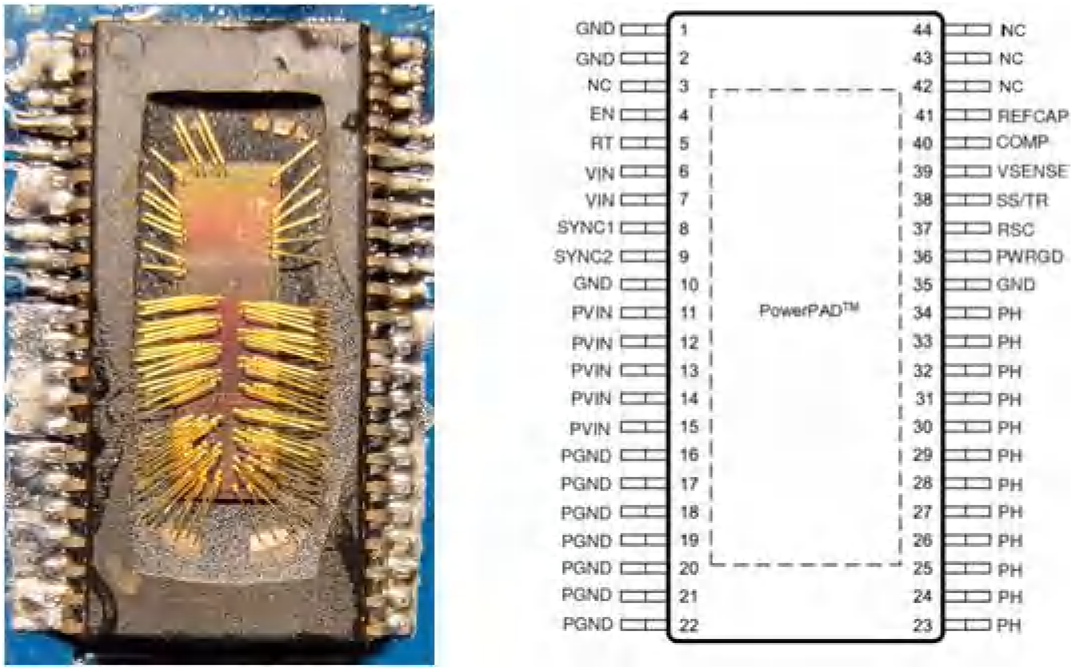

Figure 3-1. Photograph of Delidded TPS7H4003-SEP [Left] and Pinout Diagram [Right]

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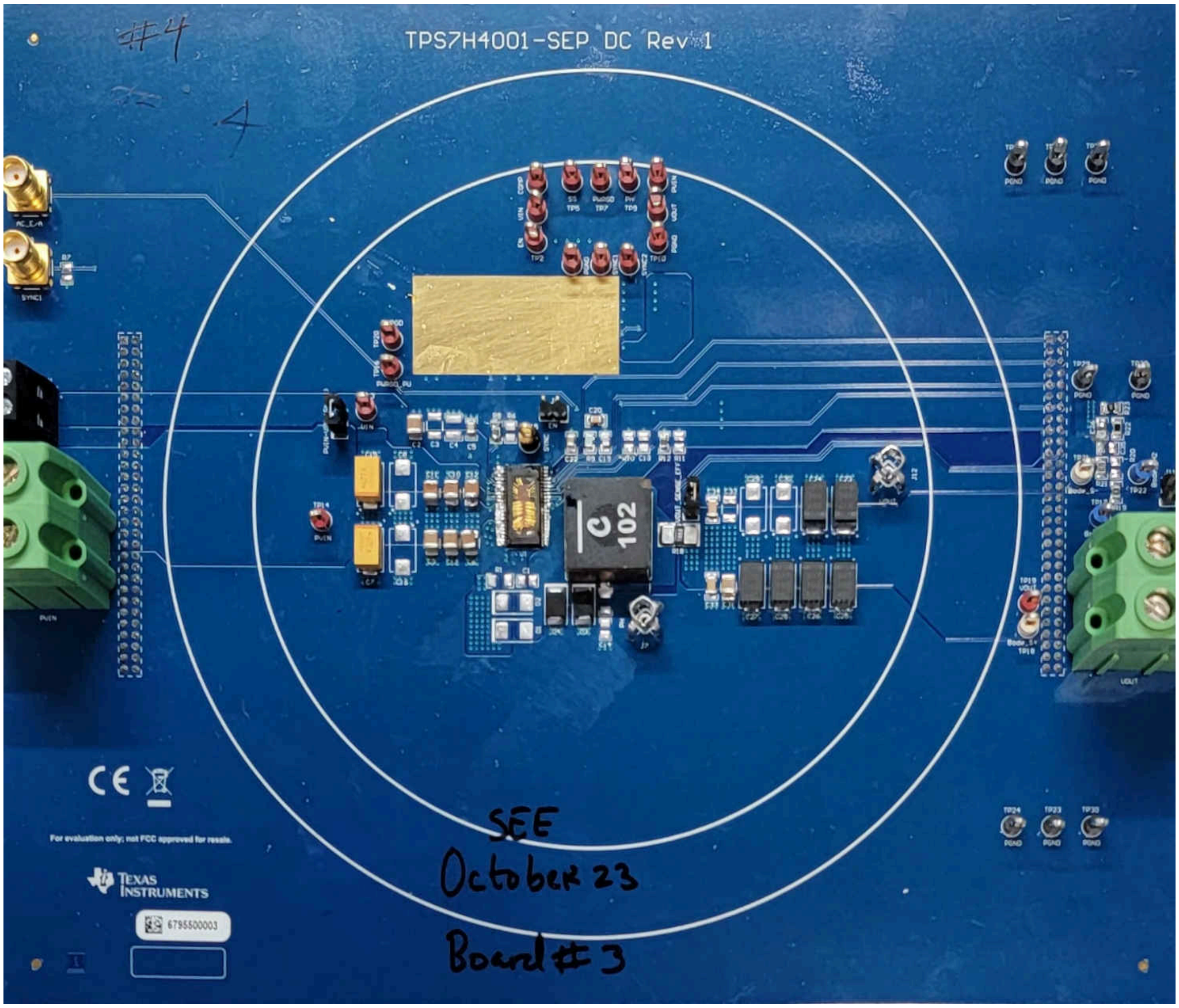

Figure 3-2. TPS7H4003-SEP Board Top View

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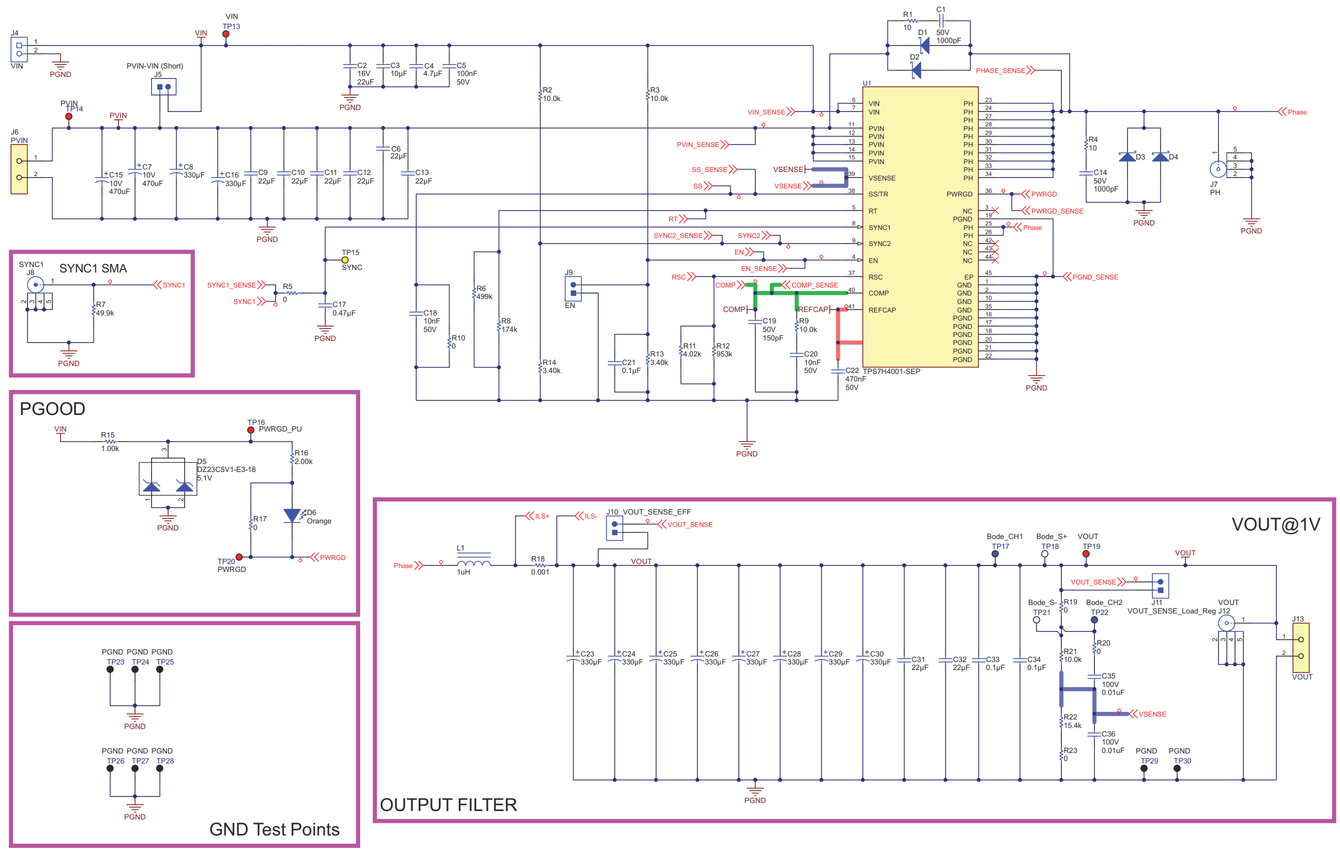

Figure 3-3. TPS7H4003 Daughter Card Schematic

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4 Irradiation Facility and Setup

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

For the experiments conducted on this report, Silver, ^{109}Ag, ions at angle of incidence of 0° for an LET_{EFF} of 48.2 MeV·cm^2/mg were used. The total kinetic energy of ^{109}Ag in the vacuum is 1.634 GeV (15 MeV/nucleon). Ion uniformity for these experiments was between 94% and 97%.

Figure 4-1 shows the TPS7H4003-SEP test board used for the experiments at the TAMU facility. Although not visible in this photo, the beam port has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the accelerator with only minor ion energy loss. All trough-hole test points were soldered backwards for easy access of the signals while having enough room to change the angle of incidence and maintaining the 40-mm distance to the die. The in-air gap between the device and the ion beam port window was maintained at 40 mm for all runs.

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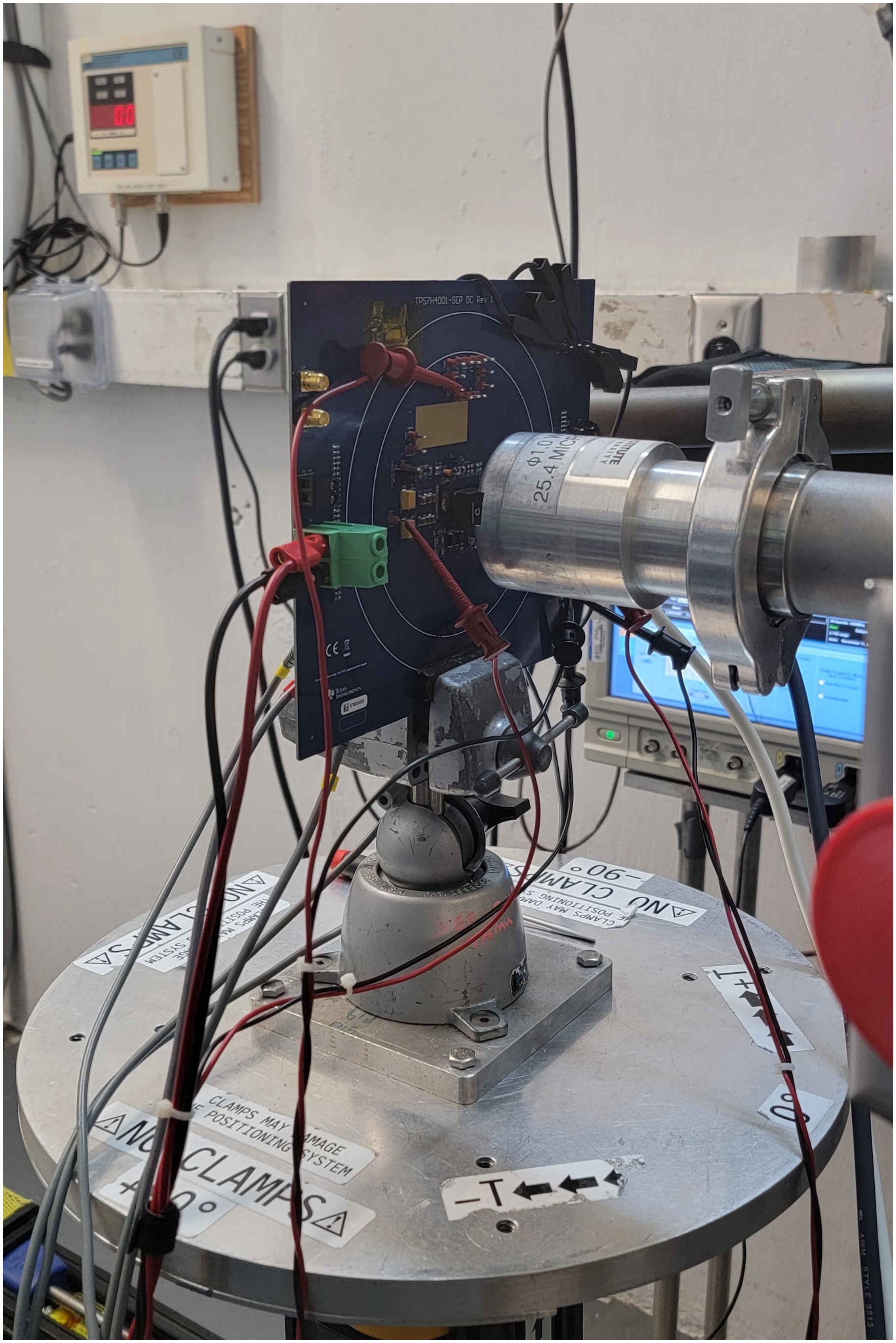

Figure 4-1. Photograph of the TPS7H4003-SEP Daughter Card Mounted in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

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5 Depth, Range, and LET_{EFF} Calculation

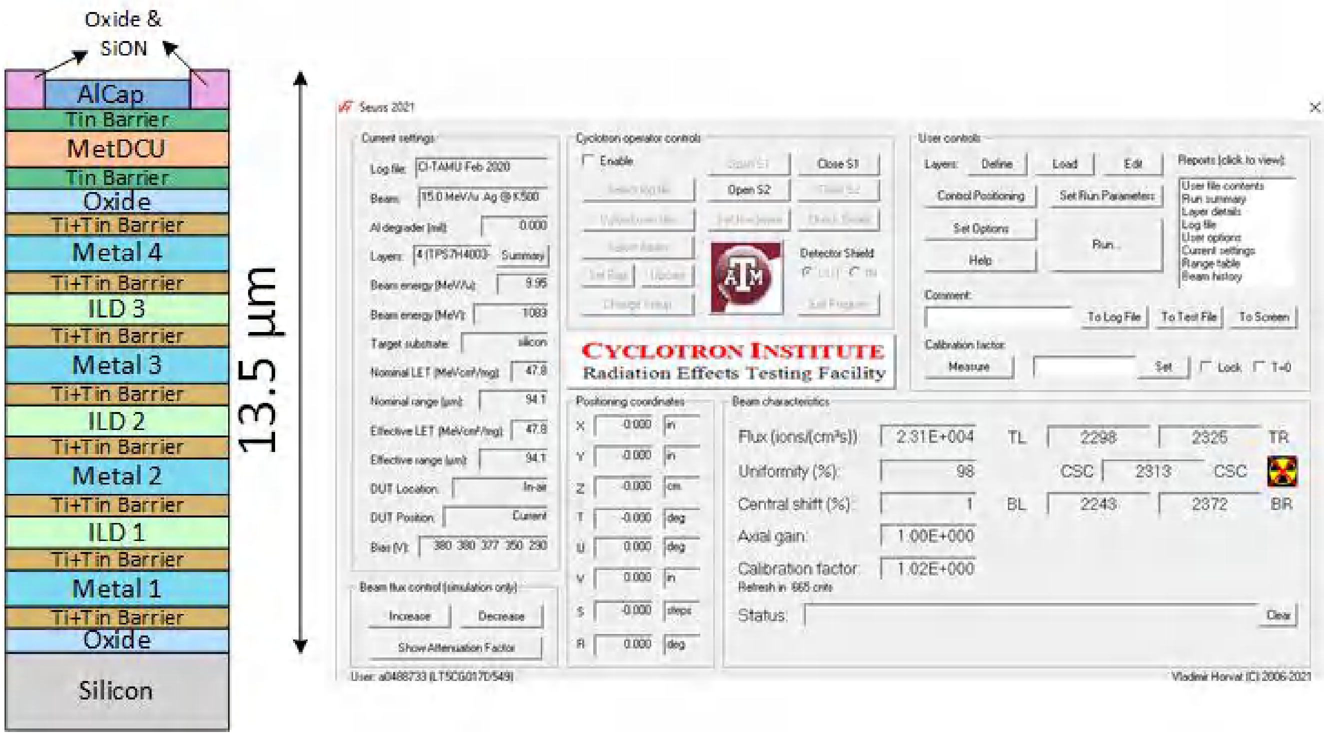

Figure 5-1. Generalized Cross-Section of the LBC8 Technology BEOL Stack on the TPS7H4003-SEP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right]

The TPS7H4003-SEP is fabricated in the TI Linear BiCMOS 250-nm process with a back-end-of-line (BEOL) stack consisting of 5 levels of standard thickness aluminum metal on a 0.6-µm pitch. The total stack height from the surface of the passivation to the silicon surface is 13.54 µm based on nominal layer thickness as shown in Figure 5-1. Accounting for energy loss through the 1-mil thick Aramica beam port window, the 40-mm air gap, and the BEOL stack over the TPS7H4003-SEP, the effective LET (LET_{EFF}) at the surface of the silicon substrate, the depth, and the ion range was determined with the SEUSS 2020 Software (provided by the Texas A&M Cyclotron Institute and based on the latest SRIM-2013 [7] models). The results are shown in Table 5-1. The LET_{EFF} vs range for the ^{109}Ag heavy-ion is shown on Figure 5-2. The stack was modeled as a homogeneous layer of silicon dioxide (valid since SiO_2 and aluminum density are similar).

Table 5-1. Silver Ion LET_{EFF}, Depth, and Range in Silicon

ION TYPE	DEGRADER ANGLE	RANGE IN SILICON	LET_{EFF} (MeV·cm^2/mg)
^{109}Ag	0	91.6	48.2

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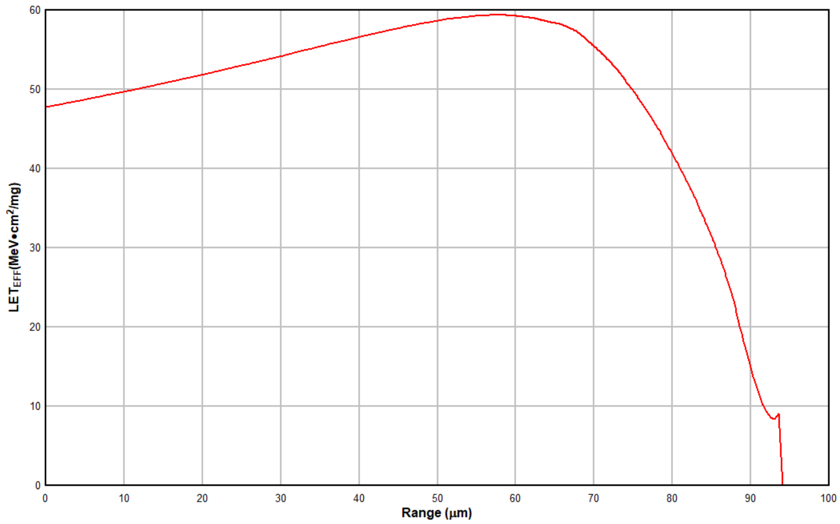

Figure 5-2. LET_{EFF} vs Range for ^{109}Ag at the Conditions Used for the SEE Test Campaign

6 Test Setup and Procedures

SEE testing was performed on a TPS7H4003-SEP device mounted on a TPS7H4003 evaluation module. The device power was provided using the J19 (PVIN) and (GND) inputs with the N6766A PS Module mounted on a N6705 precision power supply in a 4-wire configuration. The Constant Current mode on a E3600 Chroma Load was used to load the device to 18 A for the SEE testing campaign.

For SEL, SEB, and SEGR testing, the device was powered up to the maximum recommended operating voltage of 7 V and loaded with the maximum load of 18 A. 1 V was used at the output voltage for the SEE testing campaign. For the SEB/SEGR characterization, the device was tested under enabled and disabled modes. The device was enabled/disabled by using the TP2 and forcing EN to either 5 V or 0 V using a E36311A power supply. The Chroma Load was connected even when the device was disabled to help differentiate if an SET momentarily activated the device under the heavy-ion irradiation. During the SEB/SEGR testing with the device in disabled mode, not a single V_{OUT} transient or input current event was observed.

For the SET characterization, the device was powered up to 5, 6, and 6.5 V with a VOUT of 1 V. The SET events were monitored using two National Instruments™ (NI) PXIe-5172 scope cards and one NI PXIe-5162 scope card. One 5172 scope was used to monitor V_{OUT} and Phase while triggering from V_{OUT}, using a window trigger around ±3% from the nominal output voltage. The second 5172 scope was used to monitor PGOOD and V_{OUT} while triggering from PGOOD at V_{IN} – 0.5 V using an edge/negative trigger. The PXIe-5162 scope was used to monitor and trigger from SS at 0.5 V using an edge/negative trigger. All three scopes were mounted on a NI PXIe-1095 chassis.

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 a MXI controller and NI PXIe-8381 remote control module.

Figure 6-1 shows a block diagram of the setup used for SEE testing of the TPS7H4003-SEP. Table 6-1 shows the connections, limits, and compliance values used during the testing. A die temperature of 125°C used for SEL was achieved with the use of a convection heat gun aimed at the die. For SET and SEB/SEGR testing, the device was tested at room temperature (no cooling or heating was applied to the DUT). The die temperature was monitored throughout testing by a T-Type thermocouple attached to the thermal pad vias (on the bottom side of the EVM) with thermal paste. The thermocouple was held in place by using high temperature tape (kapton-tape). Die-to-thermocouple temperature was verified using a IR-camera prior to the SEE testing campaign.

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Table 6-1. Equipment Set and Parameters Used for TPS7H4003-SEP SEE Testing

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
VIN	Agilent N6700 PS (Channel #3)	15 A	10 A	5, 6, 6.5, and 7 V
EN	Keysight E36311A PS (Channel #1)	5 A	100 mA	0 V (disabled) and 5 V (enabled)
Oscilloscope card on V_{OUT}	NI-PXIe 5172	100 MS/s	—	10 MS/s
Oscilloscope card on PGOOD	NI-PXIe 5172	100 MS/s	—	50 MS/s
Oscilloscope card on SS	NI-PXIe 5162	100 MS/s	—	50 MS/s
Load	Chroma-E3630-80-60 (Channel #1)	60 A	Range: High	18 A
Digital I/O	NI-PXIe 6589	—	—	Interrupt Based

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to ensure that the test system was stable under all bias and load conditions prior to being taken to the TAMU facility. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H4003-SEP device and set the external sourcing and monitoring functions of the external equipment. After functionality and stability were 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 output voltage exceeded the pre-defined ±3% window trigger, or when the PG signal changed from High to Low (using a negative edge trigger), a data capture was initiated. In addition to monitoring the voltage levels of the two scopes, VIN current and the +5-V signal from TAMU were monitored at all times. 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.

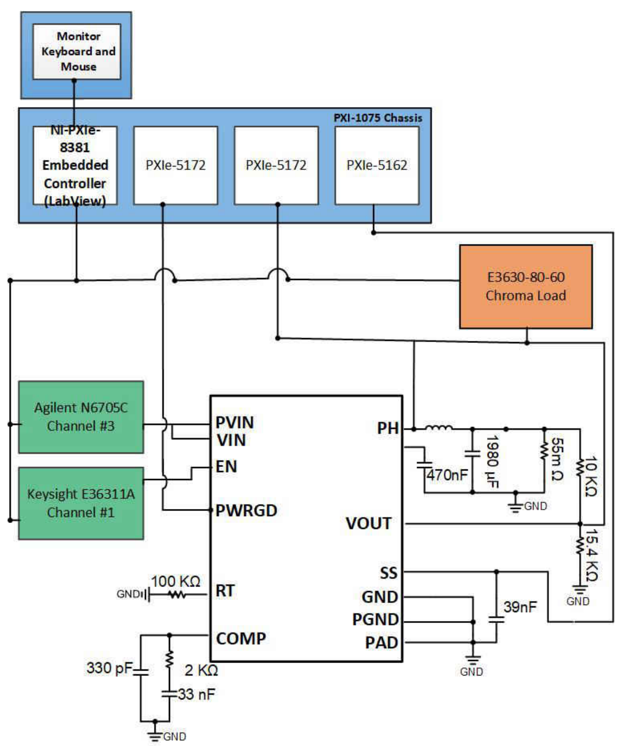

Figure 6-1. Block Diagram of SEE Test Setup With the TPS7H4003-SEP

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7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

During SEL characterization, the device was heated using forced hot air, maintaining the DUT temperature at 125°C. The die temperature was monitored during the testing using a T-Type thermocouple attached to the thermal pad vias (on the bottom side of the EVM) with thermal paste. The thermocouple was held in-place by using high temperature tape (kapton-tape). Die-to-thermocouple temperature was verified using a IR-camera.

The species used for the SEL testing was a silver (^{109}Ag) ion with an angle-of-incidence of 0° for an LET_{EFF} = 48.2 MeV·cm^2/mg (for more details refer to Section 5). The kinetic energy in the vacuum for this ion is 1.634 GeV (15-MeV/amu line). Flux of approximately 10^5 ions/cm^2·s and a fluence of approximately 10^7 ions/cm^2 were used for the five runs. Run duration to achieve this fluence was approximately 2 minutes. The three devices were powered up and exposed to the heavy-ions using 6.5 V and the maximum recommended voltage of 7 V and maximum load of 18 A. No SEL events were observed during all four runs, indicating that the TPS7H4003-SEP is SEL-free.Table 7-1 shows the SEL test conditions and results. Figure 7-1 shows a plot of the current vs time for run # 1.

Table 7-1. Summary of TPS7H4003-SEP SEL Test Condition and Results

RUN #	UNIT #	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	V_{IN} (V)
1	1	^{109}Ag	48.2	9.79×10^4	1×10^7	6.5
2	1	^{109}Ag	48.2	7.06×10^4	9.96×10^7	7
3	2	^{109}Ag	48.2	8.56×10^4	1×10^7	6.5
4	2	^{109}Ag	48.2	1.1×10^5	1×10^7	7
5	3	^{109}Ag	48.2	1.16×10^5	9.96×10^6	7

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluence of the five runs @ 125°C (5.00×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 7.38 \times 10^{-8}$ cm^2/device for LET_{EFF} = 48.2 MeV·cm^2/mg and T = 125°C.

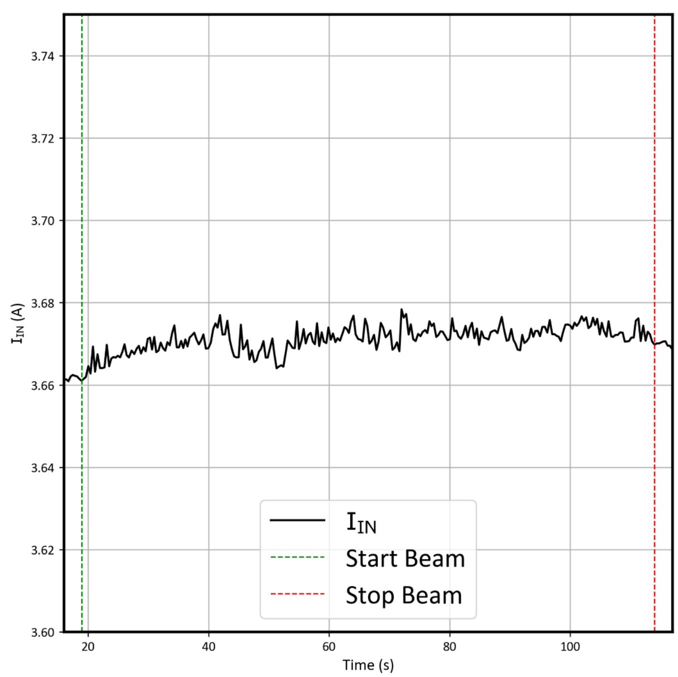

Figure 7-1. Current vs Time for Run # 1 of the TPS7H4003-SEP at T = 125°C

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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 ≈25°C. The die temperature was monitored during the testing using a T-Type thermocouple attached to the thermal pad vias (on the bottom side of the EVM) with thermal paste. The thermocouple was hold on place by using high temperature tape (kapton-tape). Die-to-thermocouple temperature was verified using a IR-camera.

The species used for the SEB/SEGR testing was a Silver (^{109}Ag) ion with an angle-of-incidence of 0° for an LET_{EFF} = 48.2 MeV·cm^2/mg (for more details refer to Section 5). The kinetic energy in the vacuum for this ion is 1.634 GeV (15-MeV/amu line). Flux of approximately 10^5 ions/cm^2·s and a fluence of approximately 10^7 ions/cm^2 were used for the six runs. Run duration to achieve this fluence was approximately 2 minutes. The three devices were powered up using the recommended maximum voltage of 7 V and the maximum load of 18 A. The TPS7H4003-SEP was tested under enabled and disabled modes, the device was disabled by using the TP2 and forcing EN to 5 V or 0 V, respectively, through channel one of an E36311A power supply. The Chroma Load was connected, even when the device was disabled, to help differentiate if a SET momentarily activated the device under the heavy-ion irradiation. During SEB/SEGR testing with the device *disabled*, no V_{OUT} transient or input current events were observed. No SEB/SEGR events were observed during all six runs, indicating that the TPS7H4003-SEP is SEB/SEGR-free up to LET_{EFF} = 48.7MeV·cm^2/mg and across the full electrical specifications.Table 7-2 shows the SEB/SEGR test conditions and results. Figure 7-2 shows a plot of the current vs time for run # 6 (Enabled) and Figure 7-3 for run # 7 (Disabled).

Table 7-2. Summary of TPS7H4003-SEP SEB/SEGR Test Condition and Results

RUN #	UNIT #	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	V_{IN} (V)	ENABLED STATUS
6	1	^{109}Ag	48.2	1.17×10^5	1×10^7	7	Enabled
7	1	^{109}Ag	48.2	1.15×10^5	9.98×10^6	7	Disabled
8	2	^{109}Ag	48.2	1.07×10^4	1×10^7	7	Enabled
9	2	^{109}Ag	48.2	1.07×10^5	1×10^7	7	Disabled
10	3	^{109}Ag	48.2	1.16×10^5	1×10^7	7	Enabled
11	3	^{109}Ag	48.2	1.45×10^5	9.97×10^6	7	Disabled

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the six runs @ 25°C (6.00×10^7), 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} = 48.2 MeV·cm^2/mg and T = 25°C.

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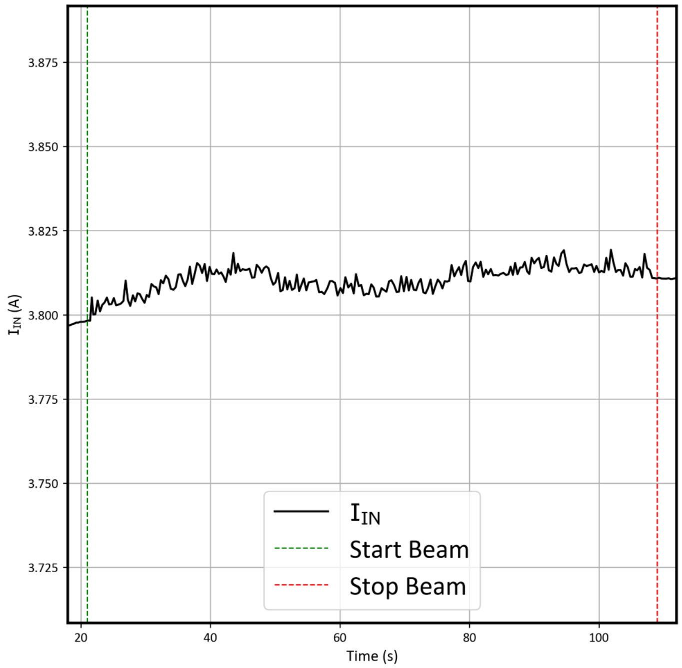

Figure 7-2. Current vs Time for Run # 6 (Enabled) for the TPS7H4003-SEP at T = 25°C

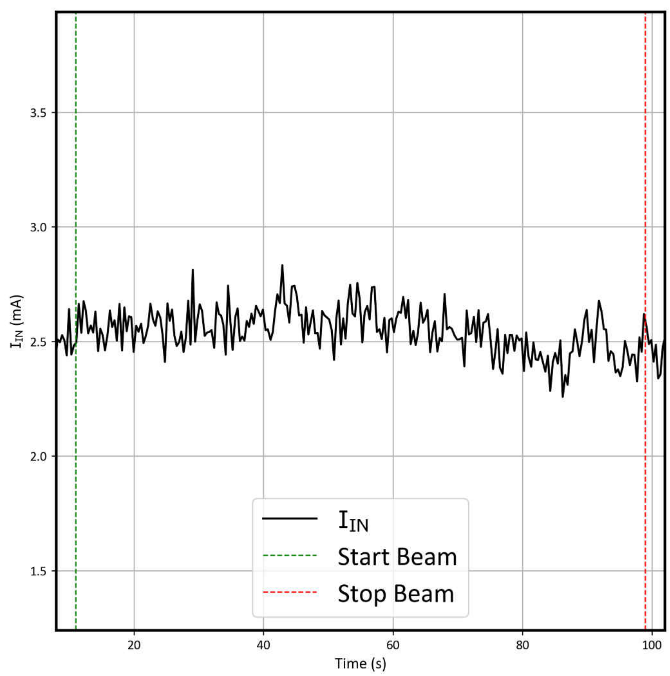

Figure 7-3. Current vs Time for Run # 7 (Disabled) for the TPS7H4003-SEP at T = 25°C

During the SEB On runs, there were recorded transients on V_{OUT} that were not seen during SET testing (i.e. Only at "worst case" V_{IN} voltages of 7-V). The following histograms and transient plot show the V_{OUT} transient information seen only during destructive testing.

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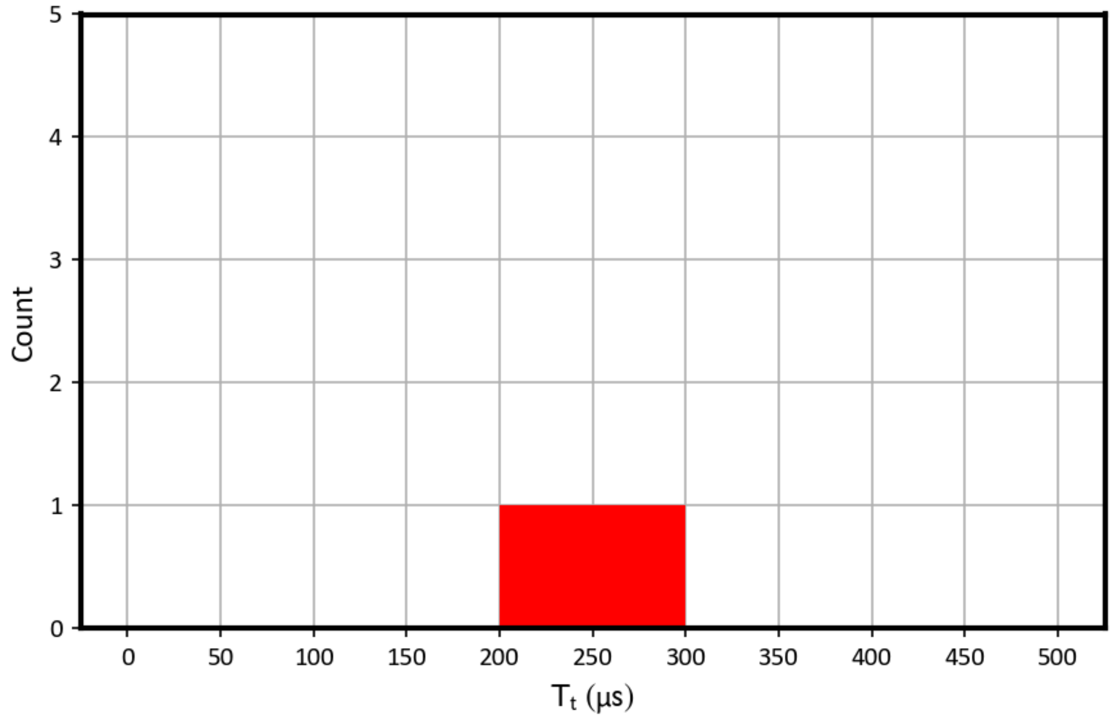

Figure 7-4. Histogram of the Transient Time for V_{OUT} SETs on Run # 6

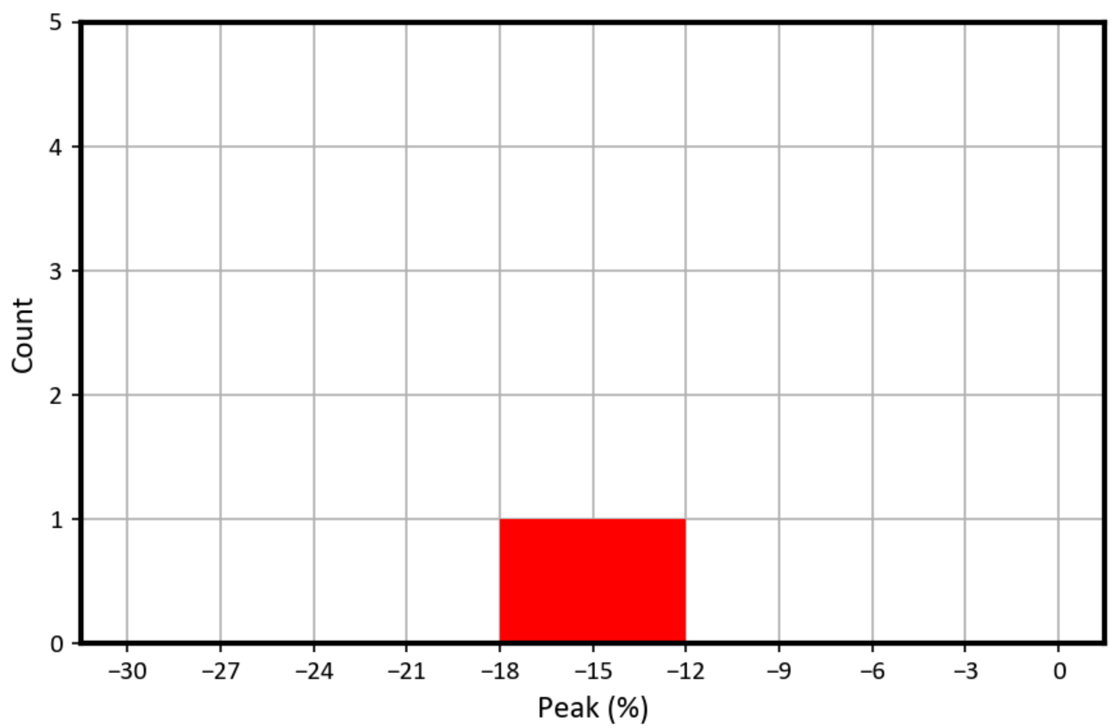

Figure 7-5. Histogram of the Normalized Amplitude for the Positive and Negative V_{OUT} SETs on Run # 6

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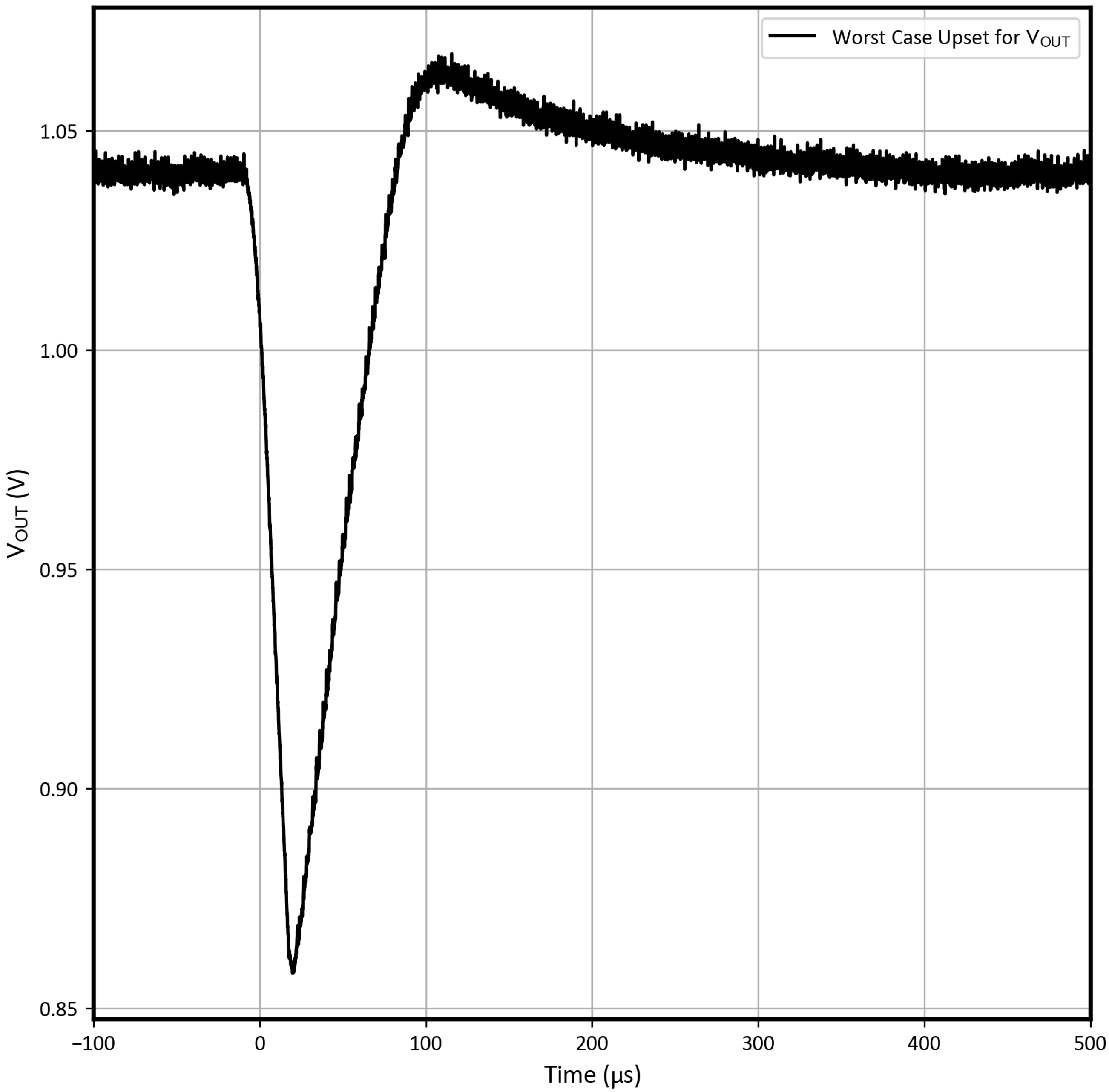

Figure 7-6. Worst Case Positive and Negative Polarity $VOUT_{SET}$ for Run # 6

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8 Single-Event Transients (SET)

SETs are defined as heavy-ion-induced transients upsets on the V_{OUT}, SS, and the PGOOD flag of the TPS7H4003-SEP. SET testing was performed at room temperature (no external temperature control applied). The species used for the SET testing was a Silver (^{109}Ag) ion with an angle-of-incidence of 0° for an LET_{EFF} = 48.2 MeV·cm^2/mg. For more details refer to Section 5. Flux of approximately 10^5 ions/cm^2·s and a fluence of approximately 1 × 10^7 ions/cm^2 were used for the seven SET runs.

V_{OUT} SETs were characterized using a window trigger of ±3% around the nominal output voltage (≈1 V). PGOOD SETs were characterized using a negative edge at V_{IN} – 0.5 V. The output load was set to 18 A for both runs by using Constant Resistance mode on a E36300 Chroma Load. To capture the SETs, two NI-PXIe-5172 scope card and one NI-PXIe-5162 were used to continuously monitor the V_{OUT}, SS, and PGOOD. Each scope was operated independently. The output voltage was monitored using the TP19 and GND test points on the EVM, SS was monitored using the TP5 and GND test points, and PGOOD was monitored using the TP7 and GND test points. The scope triggering from PGOOD also monitored the output voltage.

The scope triggering from V_{OUT} was programmed to record 20k samples with a sample rate of 5 MS/s samples per second (S/s) in case of an event (trigger). The scope triggering from PGOOD was programmed with 30k samples and 5 MS/s. The scope triggering from SS was programmed with 20k samples and 5 MS/s. All three scopes were programmed to record 20% of the data before the trigger happened.

Under heavy-ions, the TPS7H4003-SEP exhibited only a PGOOD transients that reached 0 V. All transients fully recovered in ≤ 300 μs without the need for external intervention.

Test conditions and results are summarized in Table 8-1.

Table 8-1. Summary of TPS7H4003-SEP SET Test Condition and Results

RUN #	UNIT #	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	V_{IN} (V)	$VOUT_{SET}$ (#) ≥ 3%	$VOUT_{SET}$ (#) ≤ –3%	SS_{SET} (#)	$PGOOD_{SET}$ ≤ V_{IN} – 0.5 V
12	2	^{109}Ag	48.2	1.09 × 10^5	9.98 × 10^6	5	0	0	0	19
13	2	^{109}Ag	48.2	1.09 × 10^5	9.97 × 10^6	6	0	0	0	19
14	3	^{109}Ag	48.2	1.09 × 10^5	1 × 10^7	5	0	0	0	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 for the different SETs as shown in Table 8-2.

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Table 8-2. Upper Bound Cross Section at 95% Confidence Interval and Room Temperature

To determine the upper bound cross section for *any* type of SET, the sum of the number of upsets for each type of SET and the sum of the fluence for the 6 runs was used for the calculation.

SET TYPE	V_{IN} (V)	# UPSETS	UPPER BOUND CROSS SECTION (cm^2/device)
$VOUT_{SET}$ ≥ |3%|	5	0	1.84×10^{-7}
	6	0	1.85×10^{-7}
PGOOD ≤ V_{IN} (0.5 – V)	5	67	4.25×10^{-6}
	6	59	3.81×10^{-6}

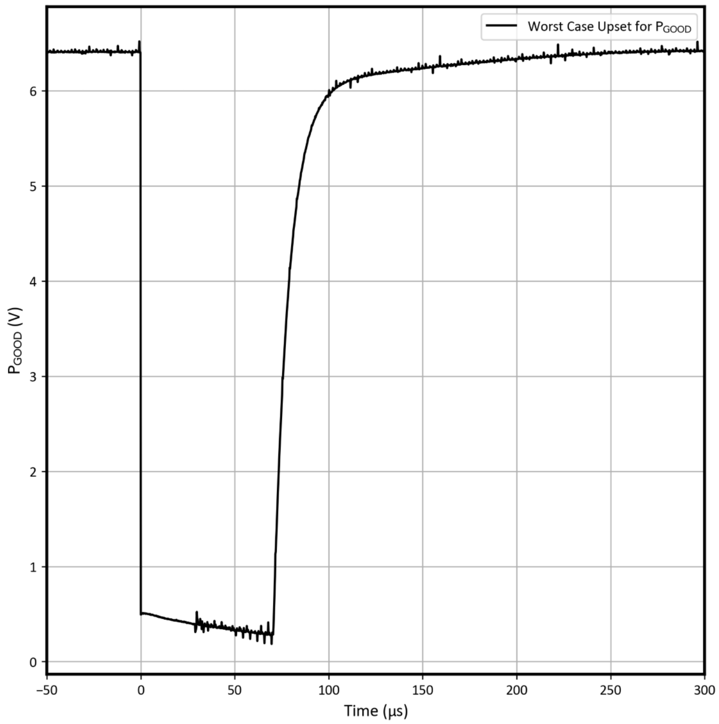

Figure 8-1. Worst Case $PGOOD_{SET}$ ≤ 0.9 V for Run # 13

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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

It is important to note that this number is for reference only. 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)	48.2	4.44×10^{-4}	7.38×10^{-8}	3.27×10^{-11}	1.36×10^{-3}	8.36×10^{7}
GEO		1.45×10^{-3}		1.07×10^{-10}	4.47×10^{-3}	2.55×10^{7}

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)	48.2	4.44×10^{-4}	6.15×10^{-8}	2.73×10^{-11}	1.13×10^{-3}	1.00×10^{8}
GEO		1.45×10^{-3}		8.94×10^{-11}	3.73×10^{-3}	3.06×10^{7}

Table 9-3. SET Event Rate Calculations for Worst-Week LEO and GEO Orbits

The even rate calculation for SET is based on the upper bound cross section for *any* type of SET.

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	48.2	4.44×10^{-4}	3.14×10^{-6}	1.39×10^{-9}	5.81×10^{-2}	1.96×10^{6}
GEO		1.45×10^{-3}		4.57×10^{-9}	1.90×10^{-1}	5.99×10^{5}

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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 TPS7H4003-SEP synchronous step-down POL converter. Heavy-ions with LET_{EFF} = 48.2 MeV·cm^2/mg were used for the SEE characterization campaign. Flux of 10^5 ions/cm^2·s and fluences of 1 × 10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H4003-SEP POL is free of destructive SEB events and SEL-free up to LET_{EFF} = 48.2 MeV·cm^2/mg and across the full electrical specifications. Transients at LET_{EFF} = 48.2 MeV·cm^2/mg on V_{OUT} and PGOOD are presented and discussed. CREME96-based worst-week event-rate calculations for LEO(ISS) and GEO orbits for the DSEE are presented for reference.

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A Appendix: Total Ionizing Dose From SEE Experiments

The production TPS7H4003-SEP POL is rated to a total ionizing dose (TID) of 20 krad(Si). In the course of the SEE testing, the heavy-ion exposures delivered ≈10 krad(Si) per 10^7 ions/cm^2 run. The cumulative TID exposure over all runs was determined to be between 3 krad(Si) to 20 krad(Si) for each device. All four production TPS7H4003-SEP devices used in the studies described in this report stayed within specification and were fully-functional after the heavy-ion SEE testing was completed.

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B Appendix: References

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C Revision History

Changes from Revision * (January 2022) to Revision A (May 2023)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document.................	3

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