Radiation Report

TPS7H500X-SEP 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 TPS7H5005/6/7/8-SEP (referenced as TPS7H500x-SEP for the report). Destructive single-event-effects (DSEE) performance was verified at the maximum recommended voltage of 14-V. For the Single Event Transient (SET) characterization, the nominal input voltage of 12-V was used at the nominal switching frequency of F_{SW} = 500 kHz. Heavy-ions with LET_{EFF} of 30.5 to 47.8 MeV·cm^2/mg were used during the validation. A total of 4 devices were used for the data collection. Flux of ≈10^5 ions/cm^2·s and fluences of ≈10^7 ions/cm^2 per run were used for the characterization. The results demonstrated that the TPS7H500x-SEP is SEL and SEB/SEGR free up to 47.8 MeV·cm^2/mg, at T = 125°C and T = 25°C, respectively, and across the full electrical specifications. SET characterization is presented and discussed for a variety of different operating conditions.

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1 Introduction

The TPS7H500x-SEP series (consisting of TPS7H5005-SEP, TPS7H5006-SEP, TPS7H5007- SEP, and TPS7H5008-SEP) is a family of high speed, radiation-tolerant, PWM controllers in space enhanced plastic. **The TPS7H5005-SEP is the parent device with only interconnect differences to support the reduction of features for TPS7H5006/7/8-SEP.** The controllers provide a number of features that are beneficial for the design of DC-DC converter topologies intended for space applications. The controllers have a 0.613-V +0.7%/-1% accurate internal reference and configurable switching frequency up to 2 MHz. Each device offers programmable slope compensation and soft-start.

The TPS7H500x-SEP series can be driven using an external clock through the SYNC pin or by using the internal oscillator at a frequency programmed by the user. The controller family offers the user various options for switching outputs, synchronous rectification capability, dead time (fixed or configurable), leading edge blank time (fixed or configurable), and duty cycle limit. Each device in the TPS7H500x-SEP series has a 24-pin TSSOP package. General device information and test conditions are listed in Table 1-1. For more detailed technical specifications, user-guides, and application notes see theTPS7H5005-SEP product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H5005-SEP, TPS7H5006-SEP, TPS7H5007-SEP, TPS7H5008-SEP
Orderable Number	TPS7H5005MPWTSEP, TPS7H5006MPWTSEP, TPS7H5007MPWTSEP, TPS7H5008MPWTSEP
Device Function	2-MHz Current Mode PWM controller
Technology	Linear BiCMOS 7 (LBC7)
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (25 and 15 MeV/nucleon)
Heavy Ion Fluence per Run	$9.96 \times 10^6 – 1.00 \times 10^7$ 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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Each TPS7H500x-SEP device has a special set of outputs, configurations, and settings. From device to device, the number of outputs, dead-time and leading edge blank time configurability, and duty cycle limit options can vary. The table below gives a breakdown of each device in the TPS7H500x-SEP series.

Table 1-2. TPS7H500x-SEP Device Comparison Table

Device	Primary Outputs	Synchronous Rectifier Outputs	Dead-Time Setting	Leading Edge Blank Time Setting	Duty Cycle Limit Options
TPS7H5005-SEP	2	2	Resistor Programmable	Resistor Programmable	50%, 75%, 100%
TPS7H5006-SEP	1	1	Resistor Programmable	Resistor Programmable	75%, 100%
TPS7H5007-SEP	1	1	Fixed (50-ns typical)	Fixed (50-ns typical)	75%, 100%
TPS7H5008-SEP	2	0	Not Applicable	Resistor Programmable	50%

2 Single-Event Effects (SEE)

The primary concern for the TPS7H500x-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 TPS7H500x-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 TPS7H500x-SEP was tested for SEL at the maximum recommended voltage of 14-V. The device exhibited no SEL when heavy-ions with LET_{EFF} = 47.8 MeV·cm^2/mg at flux ≈10^5 ions/cm^2·s, fluences of ≈10^7 ions/cm^2, and a die temperature of 125°C.

The TPS7H500x-SEP was evaluated for SEB/SEGR at a maximum voltage of 14-V in the enabled and disabled mode. The device was tested at room temperature with no external thermal control device. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H5005-SEP is SEB/SEGR-free up to LET_{EFF} = 47.8 MeV·cm^2/mg at a flux of ≈10^5 ions/cm^2·s, fluence of ≈10^7 ions/cm^2, and a die temperature of ≈25°C.

The TPS7H500x-SEP was characterized for SET at flux of ≈10^5 ions/cm^2·s, fluence of ≈10^7 ions/cm^2, and at room temperature. The device was characterized at V_{IN} of 12-V. SET performance was verified at nominal F_{SW} = 500 kHz. Heavy-ions with LET_{EFF} of 30.5 to 47.8 MeV·cm^2/mg were used to characterize the transient performance. A total of 4 devices were used for the SET characterization. To see the SET results of the TPS7H500x-SEP, please refer to Section 8.

3 Device and Test Board Information

The TPS7H500x-SEP is packaged in a 24-pin TSSOP package as shown in Figure 3-1. To see specific pinout differences between TPS7H5005/6/7/8-SEP please refer to the TPS7H5005-SEP product page. A special test board designed specifically for radiation testing was used to evaluate the performance of the TPS7H500x-SEP under heavy-ions. The test board is shown in Figure 3-2. Board schematics are shown in Section 3.1.

Note

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

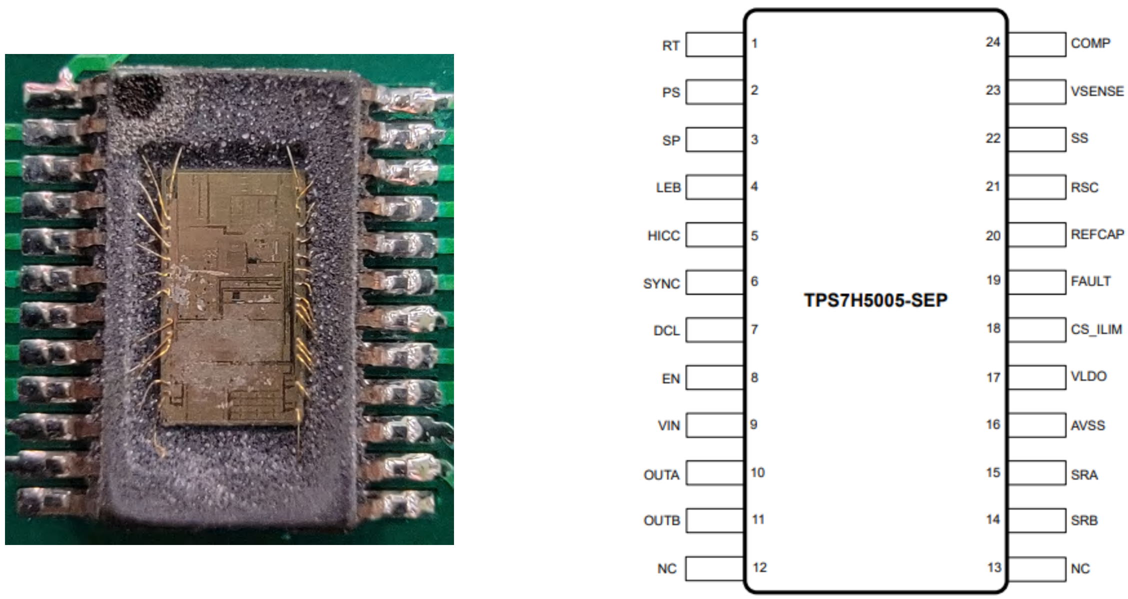

Figure 3-1. Photograph of Exposed TPS7H5005-SEP [Left] and Pinout Diagram [Right]

Note

The white wires were soldered down in order to access VSense. The specific wire used was soldered to the pad for R31.

Figure 3-2. TPS7H5005-SEP SEE Test Board Top View

3.1 TPS7H5005-SEP SEE Test Board Schematics

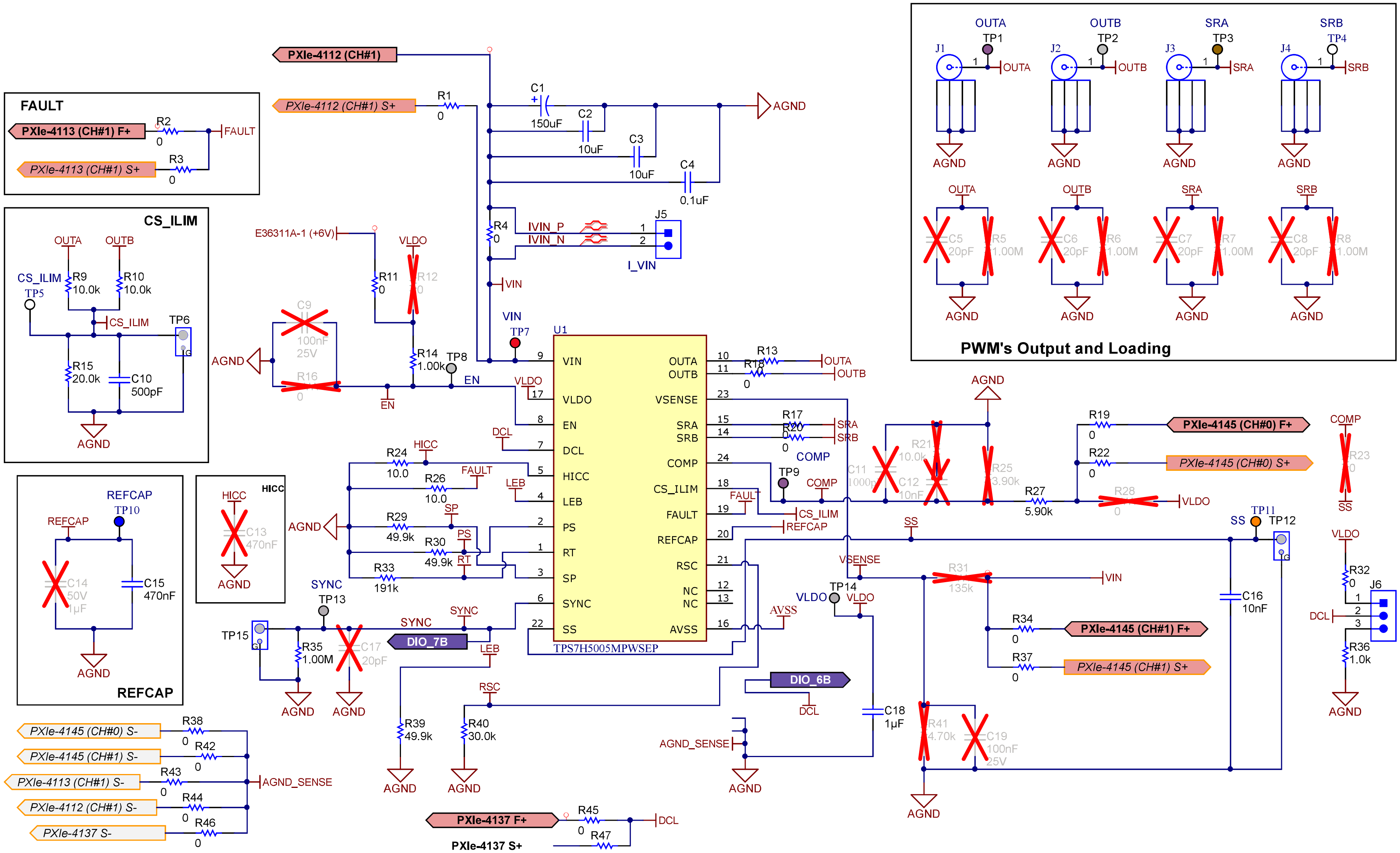

Figure 3-3. TPS7H5005-SEP SEE Test Board Schematics

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 these studies, ion flux of 9.00×10^4 to 1.46×10^5 ions/cm^2·s was used to provide heavy-ion fluence of 9.93×10^6 to 1.00×10^7 ions/cm^2.

For the experiments conducted on this report, there were 2 ions used: Krypton (Kr) and Silver (Ag). Kr was used to obtain LET_{EFF} of 30.5 MeV·cm^2/mg. Ag was used to obtain LET_{EFF} of 47.8 MeV·cm^2/mg. The total kinetic energy for each of the ions are shown in Table 4-1.

Table 4-1. Total Kinetic Energy for Ions Used

ION USED	ION UNIFORMITY RANGE
^{84}Kr = 2.081 GeV (15 MeV/nucleon)	93% to 97%
^{109}Ag = 1.634 GeV (15 MeV/nucleon)	88% to 94%

Figure 4-1 shows the TPS7H500x-SEP SEE Test Board used for the data collection 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. The in-air gap between the device and the ion beam port window was maintained at 40 mm for all runs.

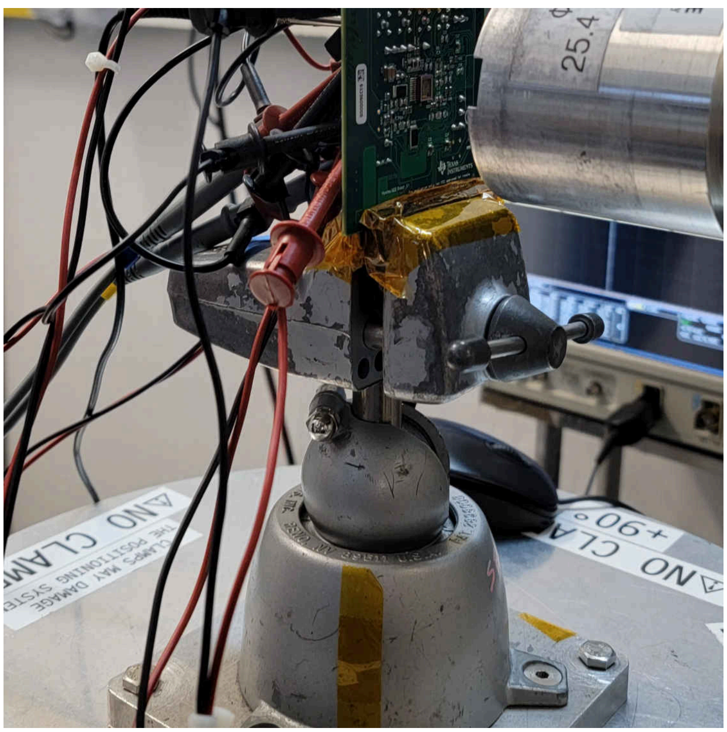

Figure 4-1. Photograph of the TPS7H500x-SEP SEE Test Board in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 Depth, Range, and LET$_{EFF}$ Calculation

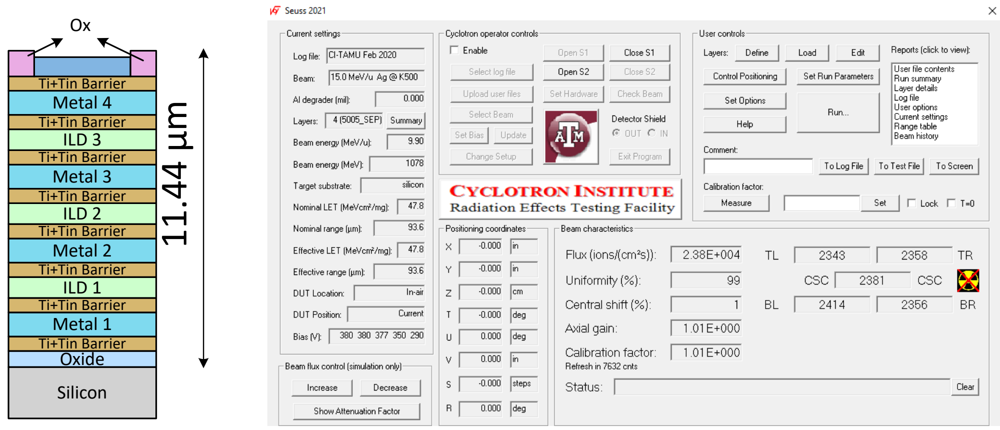

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H500x-SEP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right]

The TPS7H500x-SEP is fabricated in the TI Linear BiCMOS 250-nm process with a back-end-of-line (BEOL) stack consisting of 4 levels of standard thickness aluminum.The total stack height from the surface of the passivation to the silicon surface is 11.44 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 TPS7H500x-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 models[7]). The results are shown in Table 5-1. The LET$_{EFF}$ vs range for the used heavy-ion are shown inFigure 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. Ion LET$_{EFF}$, Depth, and Range in Silicon

ION TYPE	BEAM ENERGY (MeV/nucleon)	ANGLE OF INCIDENCE	RANGE IN SILICON (µm)	LET$_{EFF}$ (MeV·cm^2/mg)
^{84}Kr	15	0	111	30.5
^{109}Ag	15	0	92	47.8

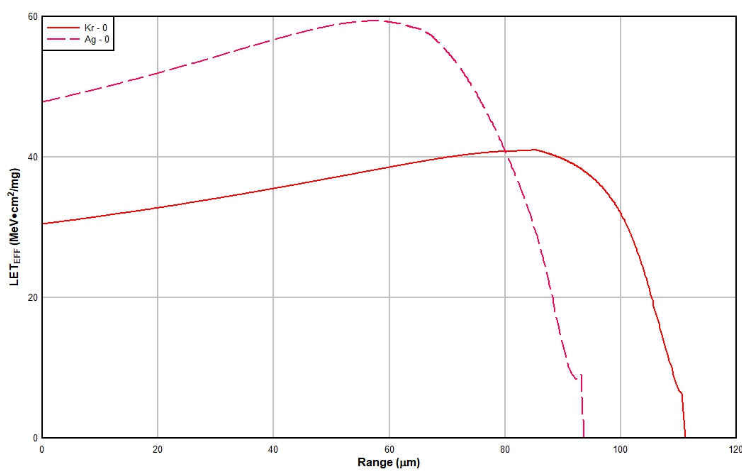

Figure 5-2. LET$_{EFF}$ vs Range for Used HeavyIons During the SEE Test Campaign

6 Test Setup and Procedures

The device power (V_{IN}) was provided using the Agilent N6705C Power supply in a four-wire configuration. For the validation the device was tested using an "open-loop" configuration, under this configuration the V_{SENSE} and V_{COMP} voltages were forced externally using Channel 0 (CH 0) of two PXIe-4139 SMU (mounted on a PXI-1085 Chassis). For most of the testing, V_{SENSE} was set to 500mV while V_{COMP} was set to 2V. To minimize transient filtering on the OUTX and SRX signals, the only loading on the signals was due to the probes used to monitored these signals (~11pF). DCL pin was connected to GND through a 1-kΩ pull-down for all testing.

For SEL, SEB, and SEGR testing, the device was powered up to the maximum recommended operating voltage of 14 V. During the SEL testing the device was heated to 125°C by using a TDH35P10R0JE discrete power resistor soldered under the thermal vias on the bottom layer of the coupon card. Using a PXIe-4139 SMU, a current of 1.2 A was forced into the power resistor elevating the die temperature to 125°C. The temperature of the die was verified using thermal camera. During the SEL testing not a single current event was observed.

For the SEB/SEGR characterization, the device was tested under the Enabled and Disabled modes. For the SEB-OFF mode the device was disabled using the EN pin by forcing 100mV (using CH 0 of a E36311A Keysight PS).When device was on, 5V was forced to the EN pin. During the SEB and SEGR testing with the device in both the Enabled and Disabled mode, not a single OUTA (only trigger signal used) transient or input current event was observed.

For the SET characterization, the device was powered up to V_{IN} of 12-V. Internal clocks configured to switch at 500 kHz were used for the validation. OUTX and SRX transients are presented and discussed

The SET events were monitored using one National Instruments™ scope and setup as described in the following:

- PXIe-5110 used to trigger from SRA or SRB using a outside pulse-width trigger at ±30%
- PXIe-5162 used to trigger from SS using a Negative Edge trigger at 0.6-V

In addition an Tektronix™ DPO7104C was used to trigger from OUTA. An outside pulse-width trigger at ±30% was used for the OUTA signal. For details on the SET testing, please refer to Section 8.

All equipment other than the DPO7104C 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. The DPO7104C manufacturer interface was used. The DPO was set to fast-frame for all SET data collection.

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 TPS7H5005-SEP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the TPS7H5005-SEP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{IN}	NI-PXIe4112 (CH 0)	60V, 1A	0.1A	4, 5, 7, 12, and 14 V
V_{COMP}	NI-PXIe 4139-1 (CH 0)	±6V, 0.5A	0.1 A	1.4, 1.7, and 2V
V_{SENSE}	NI-PXIe 4139-2 (CH 1)			0.5V
EN	E36311A (CH 0)	5V, 5A	0.1A	100mV, 5V
Heater	NI-PXIe-4113	60V, 3A	3	1.2A
SRX	NI-PXIe-5110	1 GS/s	—	100 MS/s
OUTX	DPO7104C	40 GS/s	—	2.5 and 5 GS/s
SS	NI-PXIe-5162	1.5 GS/s	—	2.5 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 TAMU facility. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H5005-SEP 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 pulse-width (OUTX and SRX) exceeded the pre-defined 30% pulse width trigger, a data capture was initiated. In addition to monitoring the time duration of the two scopes (OUTX and SRX), V_{IN} 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.

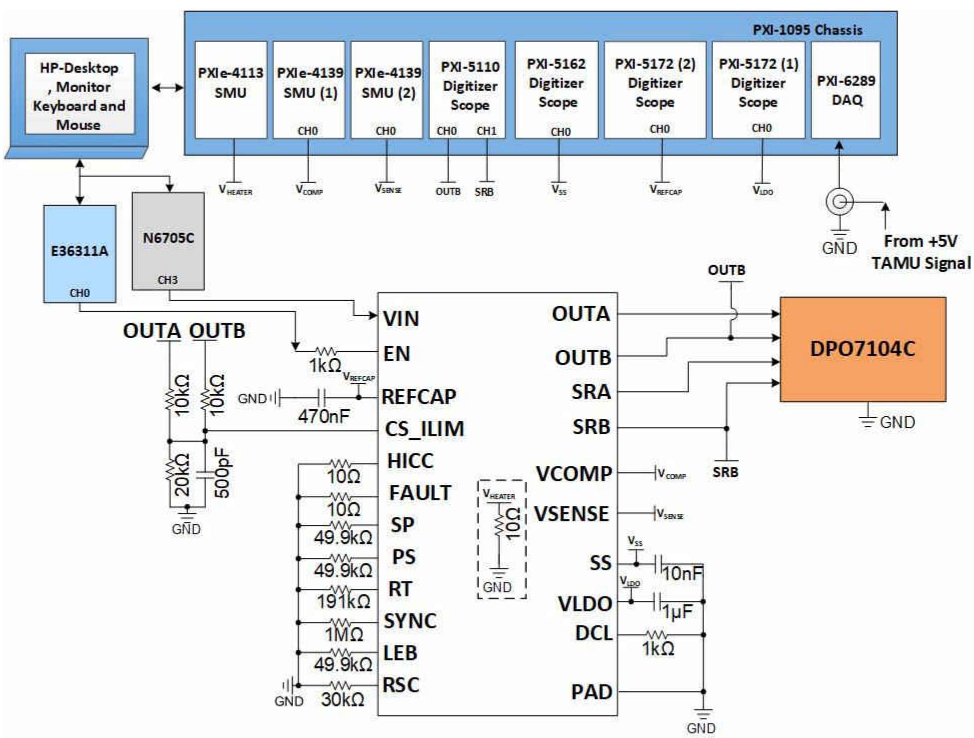

Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H5005-SEP

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 a TDH35P10R0JE discrete power resistor soldered right under the thermal vias on the bottom layer on the coupon card board. Using a PXIe-4113 SMU, a current of 1.2 A was forced into the power resistor elevating the die temperature to 125°C. The temperature of the die was verified using thermal camera.

The ion species used for the SEL testing was Silver (^{109}Ag @ 15 MeV/nucleon). An LET_{EFF} = 47.8 MeV·cm^2/mg was achieved, while an angle of incidence of 0°. Flux of approximately 10^5 ions/cm^2·s and a fluence of approximately 10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was approximately 2 minutes. The four devices were powered up and exposed to the heavy-ions using the maximum recommended voltage of 14V. No SEL events were observed during all four runs, indicating that the TPS7H5005-SEP is SEL-free up to 47.8 MeV·cm^2/mg. 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 TPS7H5005-SEP SEL Test Condition and Results

RUN #	Device	UNIT #	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions·cm^2/mg)	FLUENCE (ions·cm^2/mg)	SEL EVENTS
1	TPS7H5005	1	Ag	47.8	1.39×10^5	1×10^7	0
2	TPS7H5006	2	Ag	47.8	1.23×10^5	9.99×10^6	0
3	TPS7H5007	3	Ag	47.8	1×10^5	1×10^7	0
4	TPS7H5008	4	Ag	47.8	1.30×10^5	1×10^7	0

Using the MFTF method described in*Single-Event Effects (SEE) Confidence Interval Calculations* application note and combining (or summing) the fluences of the four runs @ 125°C (3.99×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 9.21 \times 10^{-8}$ cm^2/device for LET_{EFF} = 47.8 MeV·cm^2/mg and T = 125°C.

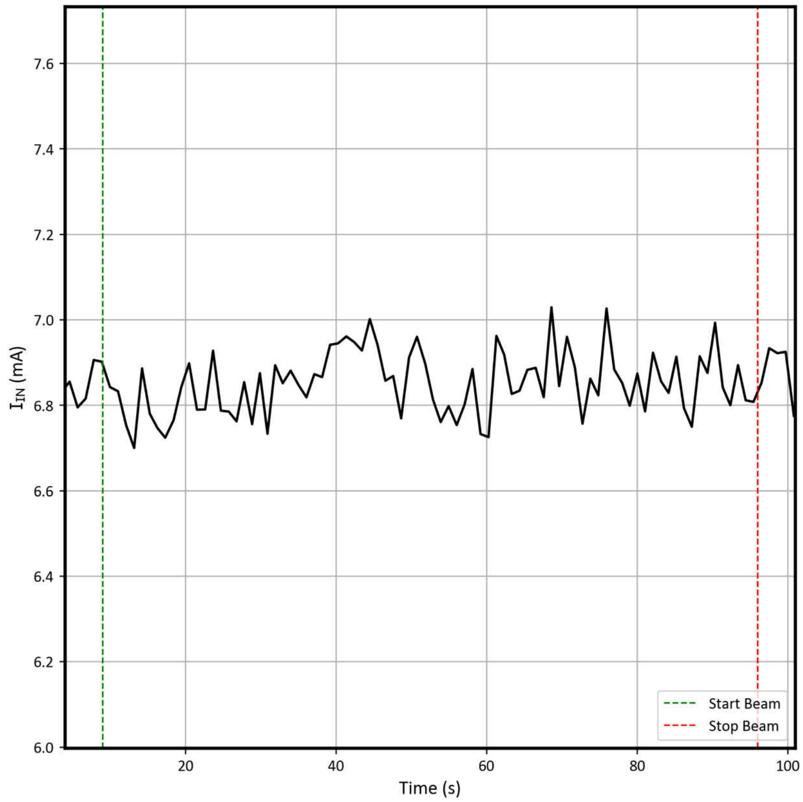

Figure 7-1. Current vs Time for Run #1 of the TPS7H5005-SEP at T = 125°C

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

During the SEB and SEGR characterization, the device was tested at room temperature or approximately 25°C. The device was tested under the Enabled and Disabled mode. For the SEB-OFF mode the device was disabled using the ENpin by forcing 100mV (using CH 0 of a E36311A Keysight PS). During the SEB and SEGR testing with the device in Disabled mode, not a single OUTA (only trigger signal used) transient or input current event was observed.

The species used for the SEB and SEGR testing was Silver (^{109}Ag) ion with an angle-of-incidence of 0°, for an LET_{EFF} = 47.8 MeV·cm^2/mg. 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 2 minutes. The device was powered up using the recommended maximum voltage of 14-V. No SEB and SEGR current events were observed during the 8 runs, indicating that the TPS7H500x-SEP is SEB and SEGR-free up to LET_{EFF} = 47.8 MeV·cm^2/mg and across the full electrical specifications. Table 7-2 shows the SEB and SEGR test conditions and results. Figure 7-2 shows the current versus time for run #5 (Disabled) and Figure 7-3 shows the current versus time for run #6 (Enabled).

Table 7-2. Summary of TPS7H500x-SEP SEB/SEGR Test Condition and Results

RUN #	Device	UNIT #	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	ENABLED STATUS
5	TPS7H5005-SEP	1	Ag	47.8	1.39×10^5	1×10^7	Disabled
6	TPS7H5005-SEP	1	Ag	47.8	1.39×10^5	1×10^7	Enabled
7	TPS7H5006-SEP	2	Ag	47.8	1.43×10^5	1×10^7	Disabled
8	TPS7H5006-SEP	2	Ag	47.8	1.34×10^5	9.97×10^6	Enabled
9	TPS7H5007-SEP	3	Ag	47.8	1.13×10^5	1×10^7	Disabled

Table 7-2. Summary of TPS7H500x-SEP SEB/SEGR Test Condition and Results (continued)

RUN #	Device	UNIT #	ION	LET_{EFF} (MeV·cm²/mg)	FLUX (ions·cm²/mg)	FLUENCE (# ions)	ENABLED STATUS
10	TPS7H5007-SEP	3	Ag	47.8	1.17×10^5	1×10^7	Enabled
11	TPS7H5008-SEP	4	Ag	47.8	9.96×10^4	9.97×10^6	Disabled
12	TPS7H5008-SEP	4	Ag	47.8	1.04×10^5	9.97×10^6	Enabled

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application note, the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEB} \leq 4.61\times 10^{-8}$ cm²/device for LET_{EFF} = 75 MeV·cm²/mg and T = 25°C.

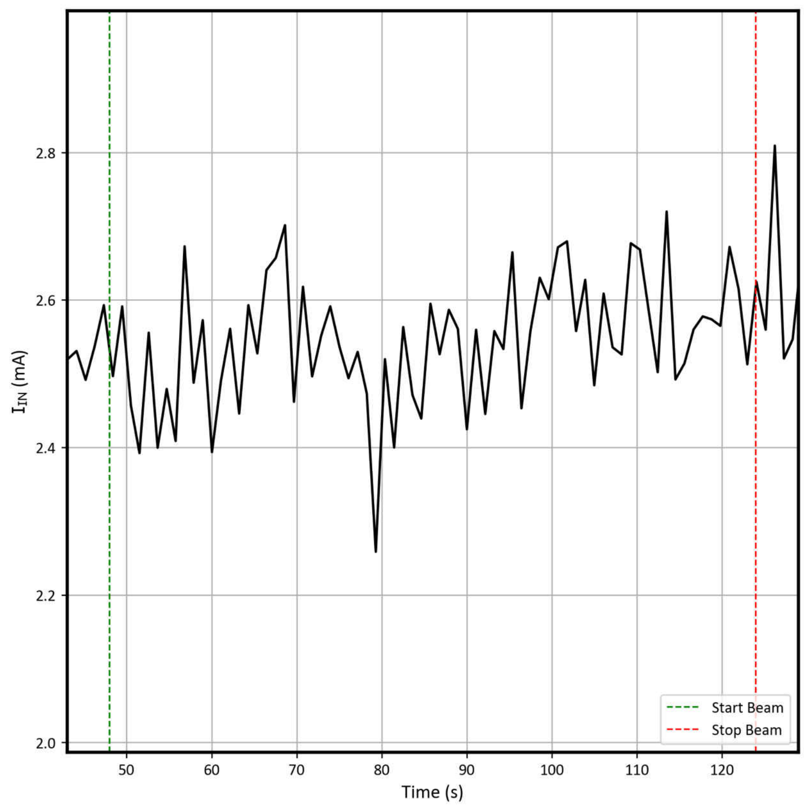

Figure 7-2. Current vs Time for Run #5 (Disabled) for the TPS7H5005-SEP at T = 25°C

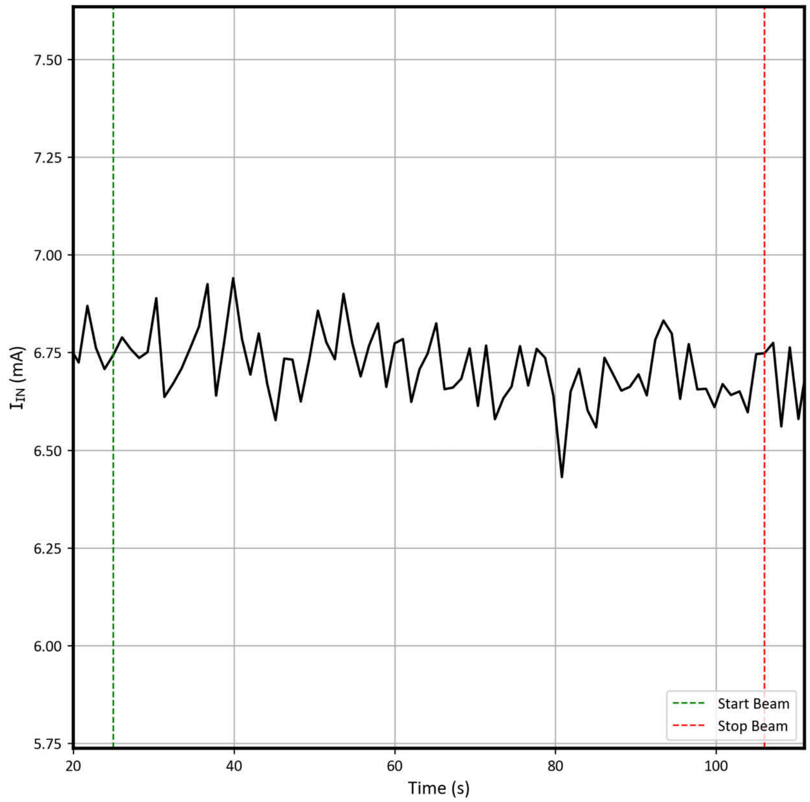

Figure 7-3. Current vs Time for Run #6 (Enabled) for the TPS7H5005-SEP at T = 25°C

8 Single-Event Transients (SET)

SET are defined as heavy-ion-induced transients upsets on the OUTX, SRX, and SS of the TPS7H5005-SEP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for the SET testing were Krypton (^{84}Kr) and Silver (^{109}Ag) for an LET_{EFF} = 30.5 to 47.8 MeV·cm^2/mg, for more details refer to Ion LET_{EFF}, Depth, and Range in Silicon. Flux of ≈10^5 ions/cm^2·s and a fluence ≈10^7 ions/cm^2, per run were used for the SET characterization. SET testing was done at V_{IN} =12V (nominal) at F_{SW} = 500 kHz.

Waveform size, sample rate, trigger type, value, and signal for all scopes used is presented in Table 8-1. **For SS, not a single capture was recorded under the conditions used for the data collection. For this reason, the data is not presented in the table.**

Table 8-1. Scope Settings

Note: Only one signal was used as a trigger source at a time, this table just presents all possible sources for a given scope, the same is valid for the trigger type. All percentage specified on the trigger value are deviation from the nominal value.

SCOPE MODEL	TRIGGER SIGNAL	TRIGGER TYPE	TRIGGER VALUE	RECORD LENGTH	SAMPLE RATE
DPO7104C	OUTA	Pulse-Width (Outside)	±30%	500 ns/div or 2μs/div	2.5 or 5 GS/s
	COMP	Window (Outside)	±10%		
	AND Gate (X-Conduction)	Edge-Positive	2.5V		
PXIe-5110	SRB	Pulse-Width (Outside)	±30%	4 kS	100 MS/s
PXIe-5162	SS	Edge/Negative	0.6	100 kS	2.5 MS/s

V_{IN} =12V (nominal) at F_{SW} = 500 kHz

For V_{IN} = 12V and switching frequency of 500 kHz, the results are presented in Table 8-2. The outside-pulse width trigger was set to 30% from the nominal pulse width for both the DPO7104C and the PXIe-5110. Upper-bound cross section at 95% confidence interval and based on SLVK047 are presented in Table 8-3 and Table 8-4. A typical time domain plot for OUTA is shown in Figure 8-1. Since the main concern for a DC/DC converter is the OUTX, (OUTA and OUTB have similar if not equal performance), the OUTA signal was used to characterize the Onset. Due to SRX performing worse behavior than OUTX, the onset was not found during testing.

Table 8-2. Summary of TPS7H5005-SEP SET Test Condition and Results V_{IN} = 12V

There is a greater focus on OUTX transients than on SRX transients because OUTX transients have more implication at a system level.

Run #	Device	Unit #	ION	LET_{EFF} (MeV·cm²/mg)	FLUX (ions·cm²/mg)	FLUENCE (# ions)	# DPO7104C ≥ 30% (OUTX)	# PXIe-5110 ≥ 30% (SRX)
13	TPS7H5005-SEP	1	^{109}Ag	47.8	1.45×10^5	1×10^7	31	398
14	TPS7H5006-SEP	2	^{109}Ag	47.8	1.30×10^5	1×10^7	9	419
15	TPS7H5007-SEP	3	^{109}Ag	47.8	1.32×10^5	9.98×10^6	1	430
16	TPS7H5008-SEP	4	^{109}Ag	47.8	1.28×10^4	1×10^7	14	N/A
17	TPS7H5005-SEP	1	^{84}Kr	30.5	9.56×10^4	1×10^7	0	207
18	TPS7H5006-SEP	2	^{84}Kr	30.5	9×10^4	9.96×10^6	0	221
19	TPS7H5007-SEP	3	^{84}Kr	30.5	1.46×10^5	9.99×10^6	0	215
20	TPS7H5008-SEP	4	^{84}Kr	30.5	1.42×10^5	1×10^7	0	N/A

Table 8-3. Upper Bound Cross Section for OUTX for V_{IN}=12-V and F_{SW} = 500 kHz

Upper Bound Cross Section was at 95% confidence interval and based on SLVK047.

LET_{EFF} (MeV·cm²/mg)	# of Upsets	Upper Bound X-Section (cm²)
30	0	9.22×10^{-8}
48	55	2.01×10^{-6}

Table 8-4. Upper Bound Cross Section for SRX for V_{IN}=12-V and F_{SW} = 500 kHz

Upper Bound Cross Section was calculated at 95% confidence interval and based on SLVK047.

LET_{EFF} (MeV·cm²/mg)	# of Upsets	Upper Bound X-Section (cm²)
30	643	2.31×10^{-5}
48	1,247	4.40×10^{-5}

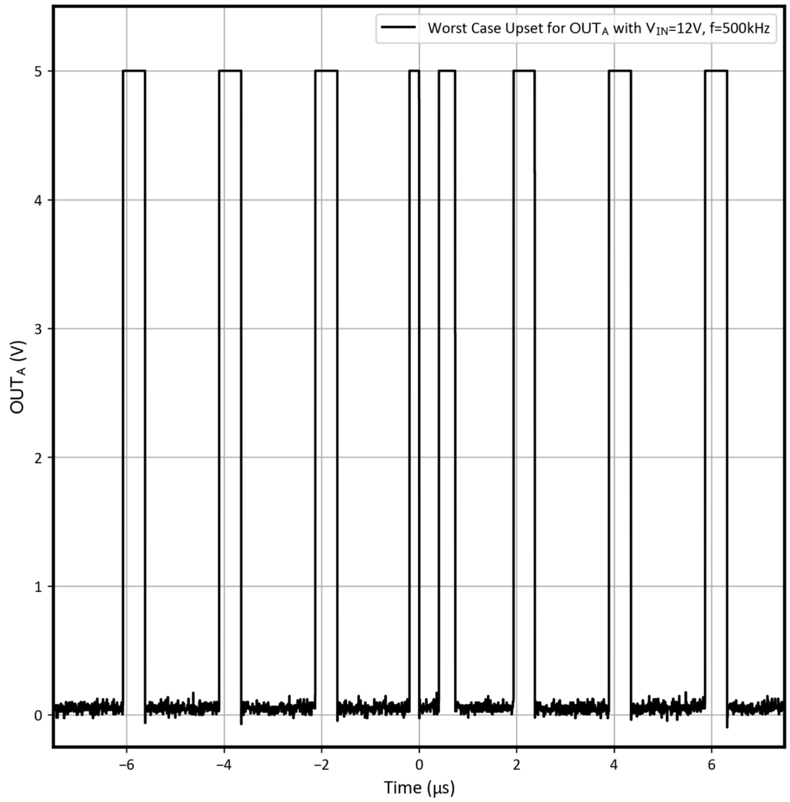

Figure 8-1. Worst Case OUTA Time Domain Upset (Run # 13)

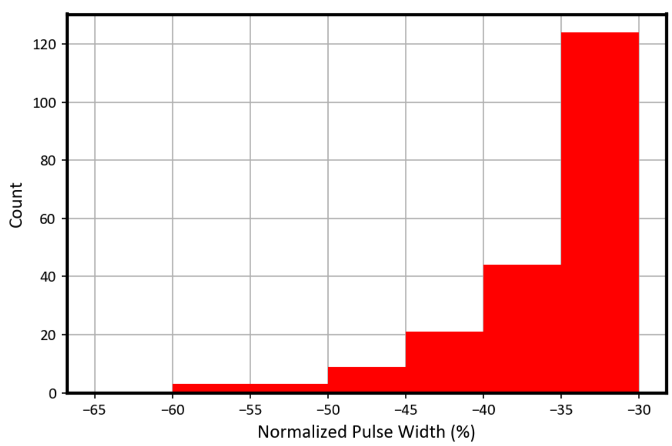

Figure 8-2. OUTA Normalized Percentage Pulse Width Deviation During Trigger

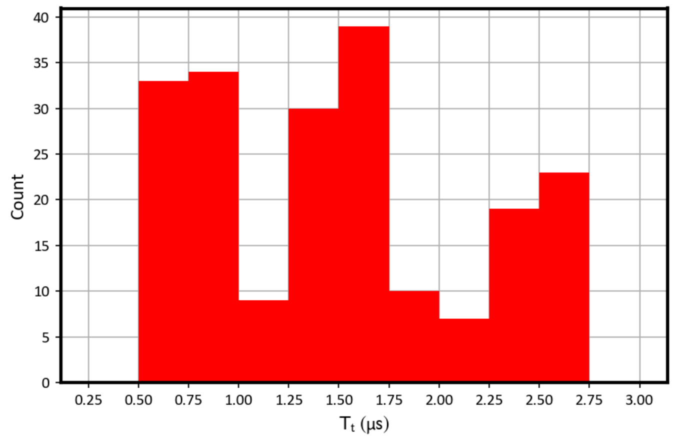

Figure 8-3. OUTA Duration of Triggers (µs)

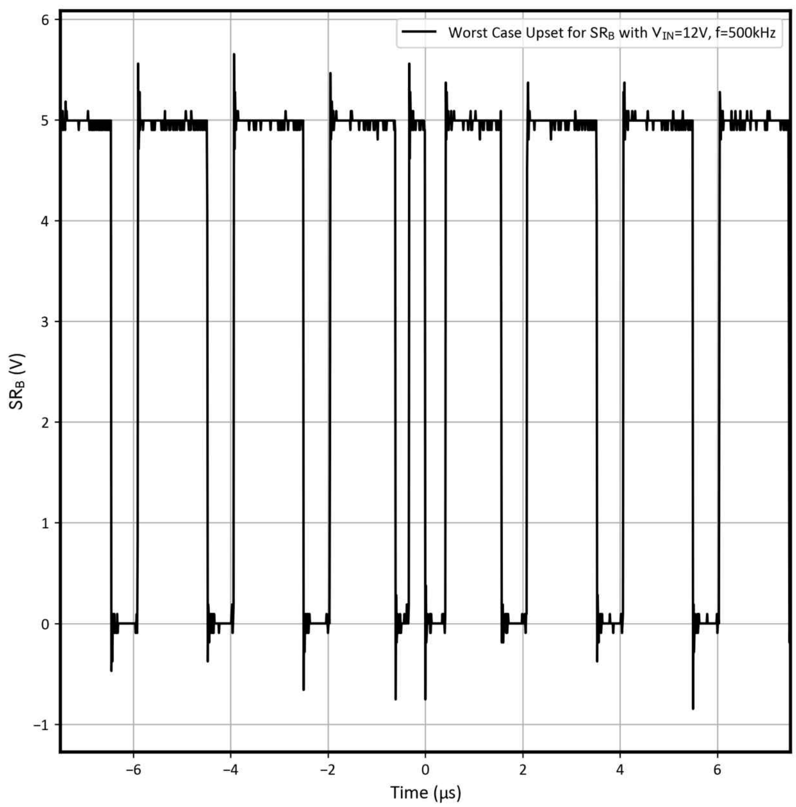

Figure 8-4. Worst Case SRB Time Domain Upset (Run#13)

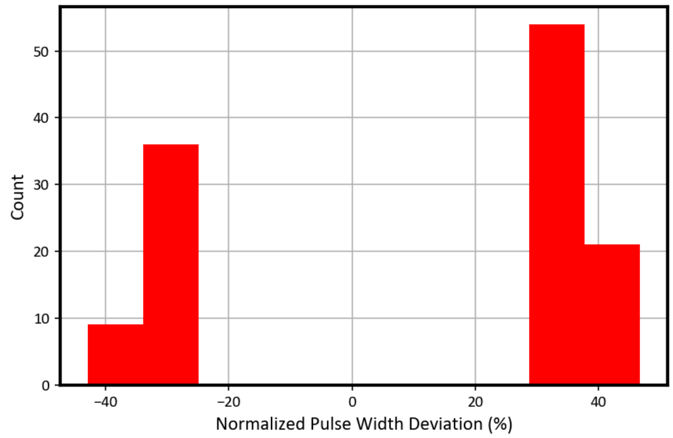

Figure 8-5. SRB Normalized Percentage Pulse Width Deviation During Trigger

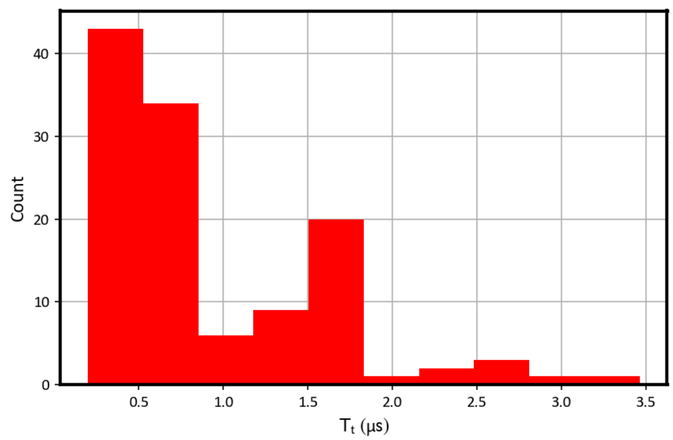

Figure 8-6. SRB Duration of Triggers (µs)

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. **It is important to note that this number is for reference since no SEL or SEB/SEGR events were observed.** SET orbit rate for OUTA at V_{IN}=12-V and F_{SW} = 500 kHz is presented on SEB/SEGR Event Rate Calculations for Worst-Week LEO and GEO Orbits.

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)	47.8	4.56×10^{-4}	9.21×10^{-8}	4.20×10^{-11}	1.75×10^{-3}	6.52×10^{7}
GEO		1.50×10^{-3}		1.38×10^{-10}	5.75×10^{-3}	1.99×10^{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)	47.8	4.56×10^{-4}	4.61×10^{-8}	2.10×10^{-11}	8.76×10^{-4}	1.30×10^{8}
GEO		1.50×10^{-3}		6.90×10^{-11}	2.88×10^{-3}	3.97×10^{7}

Table 9-3. SET (OUTA @ V_{IN}=12-V , F_{SW}=500 KHz at Upsets ≥ 30 %) Event Rate Calculations for Worst-Week LEO and GEO Orbits

The cross section of 2.01 x 10^{-6} is based on the Onset LET_{EFF} of 30.5 MeV-cm^2/mg found in table 8-3.

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)	30.5	6.14 x 10^{-3}	2.01×10^{-6}	1.23×10^{-8}	5.14×10^{-1}	2.22×10^{5}
GEO		3.59 x 10^{-2}		7.21×10^{-8}	3.00×10^{0}	3.80×10^{4}

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 TPS7H5005-SEP Si and GaN Dual Output Controller. Heavy-ions with LET_{EFF} = 30 to 48 MeV·cm^2/mg were were used for the SEE characterization campaign. Flux of 9 x 10^4 to 1.46 x 10^5 ions/cm^2·s and fluences ranging from 9.96 × 10^6 to 1 × 10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H500x-SEP is free of destructive SEL,SEB and cross conduction up to LET_{EFF} = 48 MeV·cm^2/mg and across the full electrical specifications. Transients at LET_{EFF} = 30 to 48MeV·cm^2/mg on OUTX, SRX, and SS are presented and discussed. CREME96-based worst-week event-rate calculations for LEO(ISS) and GEO orbits for the DSEE and SET (at V_{IN}=12-V and F_{SW}=500 KHz) are presented for reference.

A Total Ionizing Dose from SEE Experiments

The production TPS7H500x-SEP is rated to a total ionizing dose (TID) of 30 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 was controlled below 100krad (Si) per unit. All ten TPS7H500x-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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