Radiation Report

TPS7H1210-SEP Single-Event Effects (SEE) Test Report

ABSTRACT

The purpose of this study is to characterize the single-event-effects (SEE) performance due to heavy-ion irradiation of the TPS7H1210-SEP. SEE performance was verified at two common output voltage rails of –5 V and –12 V, as well as min voltage, or V_{FB} = –1.182 V. Heavy-ions with LET_{EFF} of 47.8 MeV·cm^2/mg were used to irradiate 6 production devices. 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 TPS7H1210-SEP is single-event latch-up (SEL), single-event burnout (SEB), and single-event gate rupture (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. Single event transient (SET) performance for output voltage excursions ≥ |3%| from the nominal voltage are discussed.

Table of Contents

List of Figures

List of Tables

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

The TPS7H1210-SEP is a space-enhanced-plastic, –3-V to –16.5-V input, 1-A, low-noise negative voltage regulator. The device provides an adjustable output from V_{FB} (–1.182) to –15 V and is designed for low noise and high-precision where clean voltage rails are critical to system performance. The regulator includes a CMOS logic level compatible enable pin (EN) to allow for user-customizable power management schemes. Because of its power management schemes, low noise, and high accuracy, it is ideal for:

- Powering op amps, ADCs, DACs, and other high-performance technology
- Post DC-DC converter regulation
- Sensitive devices and RF applications

Protection features include a built in current limit and thermal shutdown to protect the device and system during fault conditions. The device is offered in a 20-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 please go to TPS7H1210-SEP product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H1210-SEP
Orderable Number	TPS7H1210MRGWSEP
Device Function	Low-noise negative voltage regulator
Technology	BICOM3XHV
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/nucleon)
Heavy Ion Fluence per Run	9.96×10^6 – 1×10^7 ions/cm^2
Irradiation Temperature	25°C (for SEB/SEGR and SET testing), and 125°C (for SEL testing)

(1) TI may provide technical, applications or design advice, quality characterization, and reliability data or service, providing these items shall not expand or otherwise affect TI's warranties as set forth in the Texas Instruments Incorporated Standard Terms and Conditions of Sale for Semiconductor Products and no obligation or liability shall arise from Semiconductor Products and no obligation or liability shall arise from TI's provision of such items.

2 Single-Event Effects (SEE)

The primary concern for the TPS7H1210-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 TPS7H1210-SEP, the CMOS circuitry introduces a potential for SEL susceptibility.

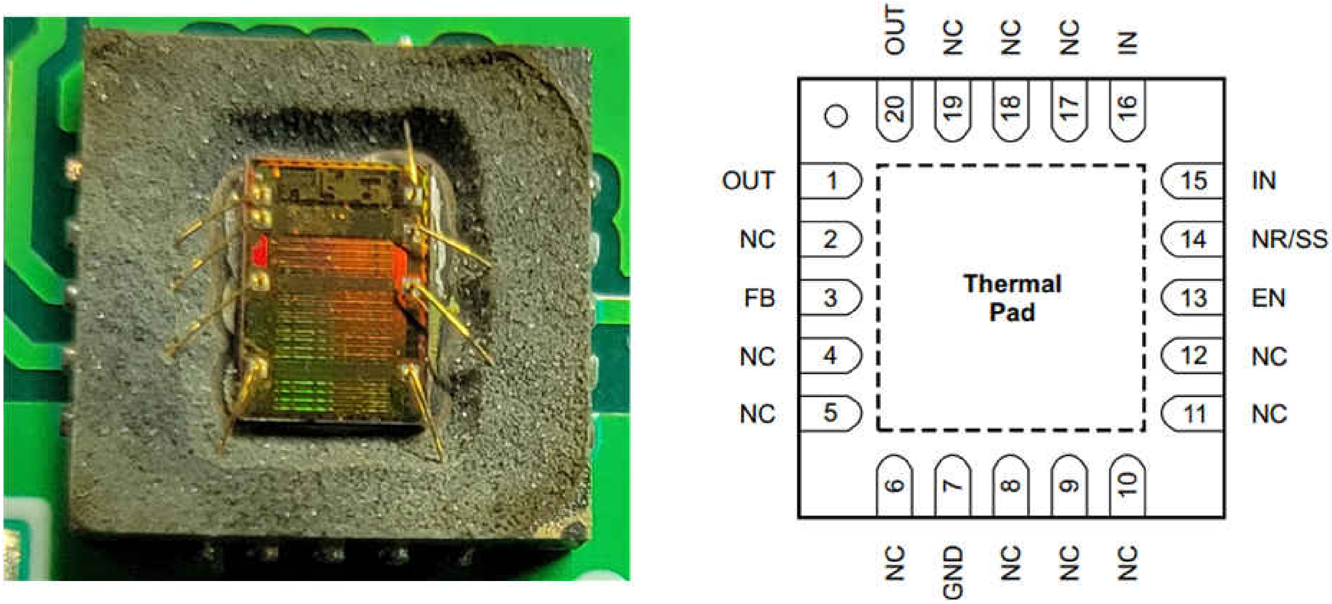
SEL can occur if excess current injection caused by the passage of an energetic ion is high enough to trigger the formation of a parasitic cross-coupled PNP and NPN bipolar structure (formed between the p-sub and n-well and n+ and p+ contacts) [1,2]. The parasitic bipolar structure initiated by a single-event 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 TPS7H1210-SEP was tested for SEL at a maximum input voltage of –16.5 V, a varying load current, and V_{OUT} of –1.182 V, –5 V, and –12 V. Testing was done with a varying load current in order to ensure the device reached 125°C and did not trip thermal protection. During the V_{OUT} case of –1.182 V the input voltage was incremented from –12 V to –16.5 V in an experiment to determine the max V_{IN} to V_{OUT} (drop-out) delta. For this specific device, we did not experience any damage during any of the runs conducted. The device exhibited no SEL under any of the tested V_{OUT} conditions, when heavy-ions with LET_{EFF} = 47.8 MeV·cm^2/mg, flux ≈10^5 ions/cm^2·s and fluences of ≈10^7 ions/cm^2, and a die temperature of 125°C were used.

Since this device is designed to conduct a current up to 1 A and withstand up to –16.5 V during the off-state, the power pass element introduces a potential susceptibility for SEB and SEGR [2]. The TPS7H1210-SEP was evaluated for SEB/SEGR at various load conditions of 0.15 A to 0.385 A in order to keep die temperature <50°C, and a voltage of –16.5 V. The device was tested under enabled and disabled modes. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H1210-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, fluences of ≈10^7 ions/cm^2, and a die temperature of ≈50°C.

The TPS7H1210-SEP was characterized for SET at flux of ≈10^5 ions/cm^2·s, fluences of ≈10^7 ions/cm^2, and a die temperature of about 50°C. The device was characterized at V_{IN} = –6 V, –12 V, and –15 V to V_{OUT} = –5 V and V_{IN} = –12.7 and –15-V to V_{OUT} = –12-V with varying loads. Under these conditions all V_{OUT} voltage excursions self-recover with no external intervention.

3 Device and Test Board Information

The TPS7H1210-SEP is packaged in a 20-pin VQFN plastic package as shown in Figure 3-1. The TPS7H1210 SEE daughter card was used to evaluate the performance and characteristics of the TPS7H1210-SEP under heavy-ions. Figure 3-2 shows the top view of the board used for the radiation testing. Figure 3-3 shows the board schematics used for the heavy-ion testing campaign.



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

Figure 3-1. Photograph of Delidded TPS7H1210-SEP [Left] and Pinout Diagram [Right]

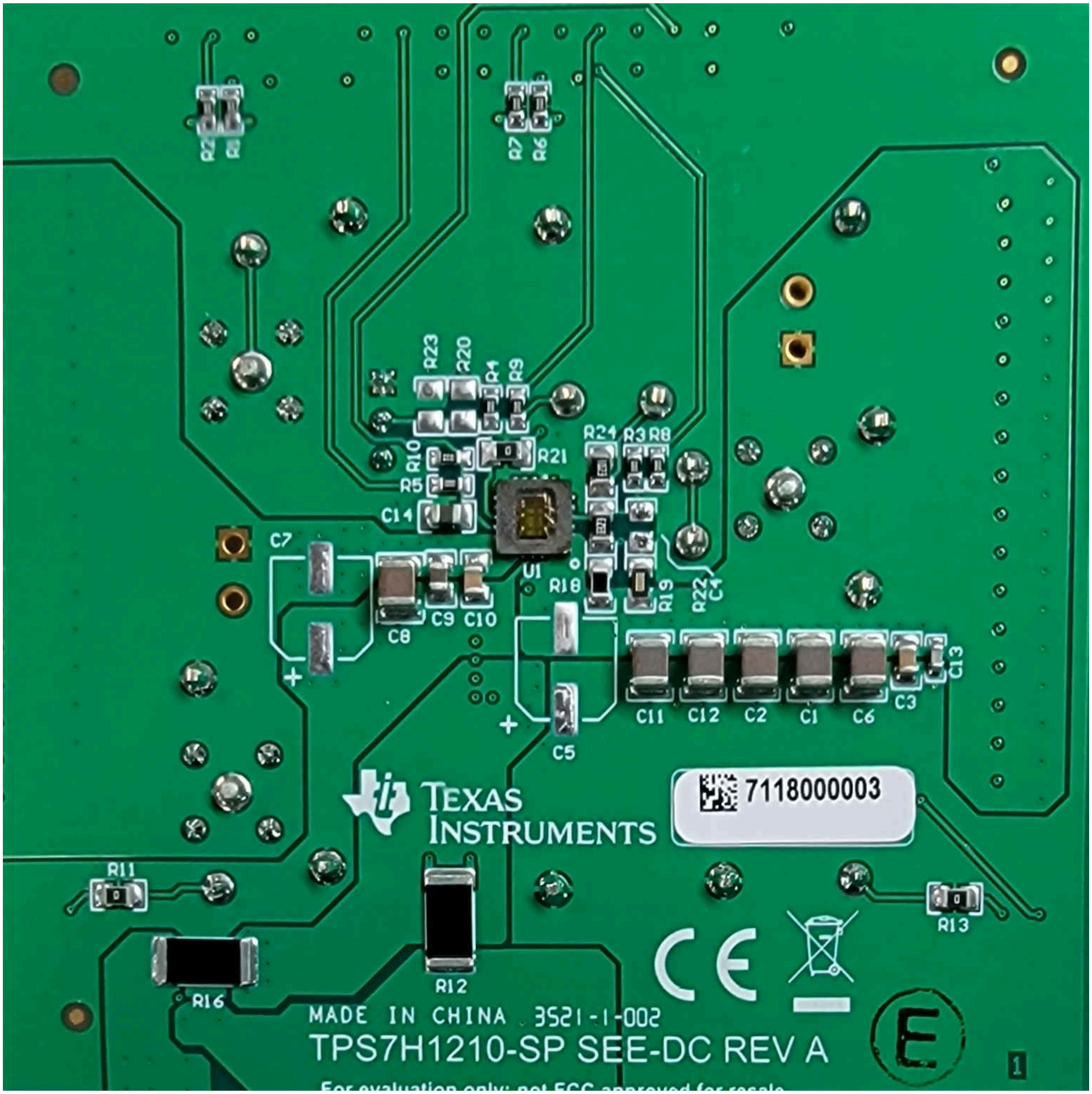


Figure 3-2. TPS7H1210-SEP Board Top View

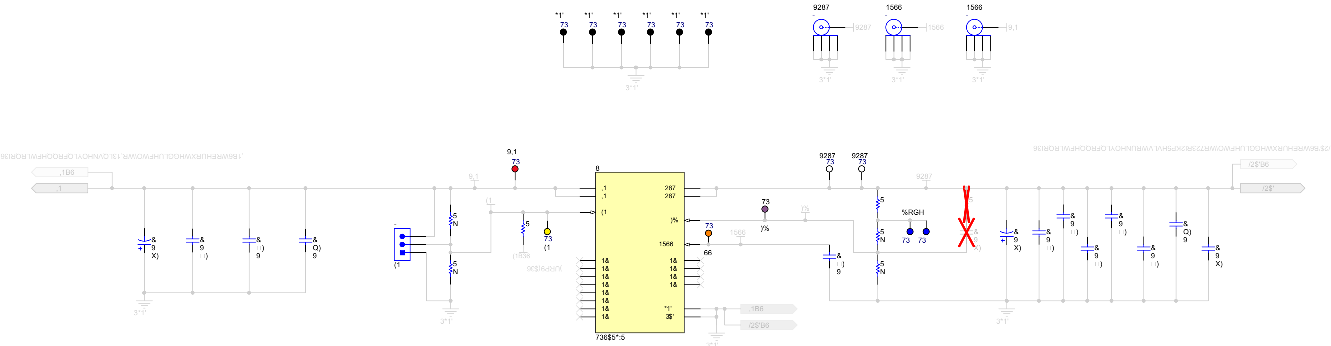


Figure 3-3. TPS7H1210EVM Schematic

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 fluences of ≈10^7 ions/cm^2.

For the experiments conducted on this report, ^{109}Ag ions at angle of incidence of 0° for an LET_{EFF} of 47.8 MeV·cm^2/mg were used. The total kinetic energy of ^{109}Ag in the vacuum is 1.634GeV (15 MeV/nucleon). Ion uniformity for these experiments was between 92 and 97%.

Figure 4-1 shows the backside of the TPS7H1210-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.

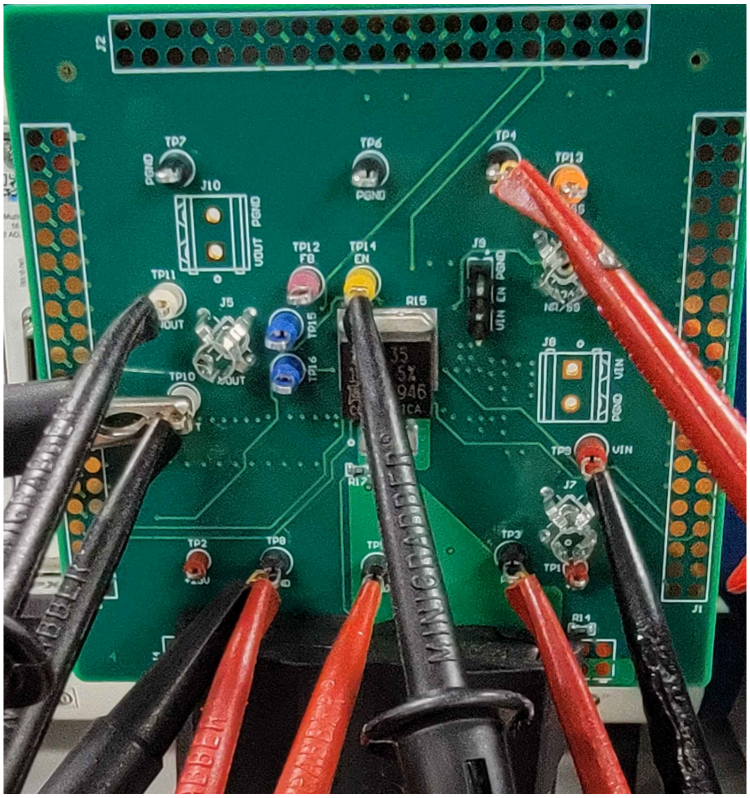
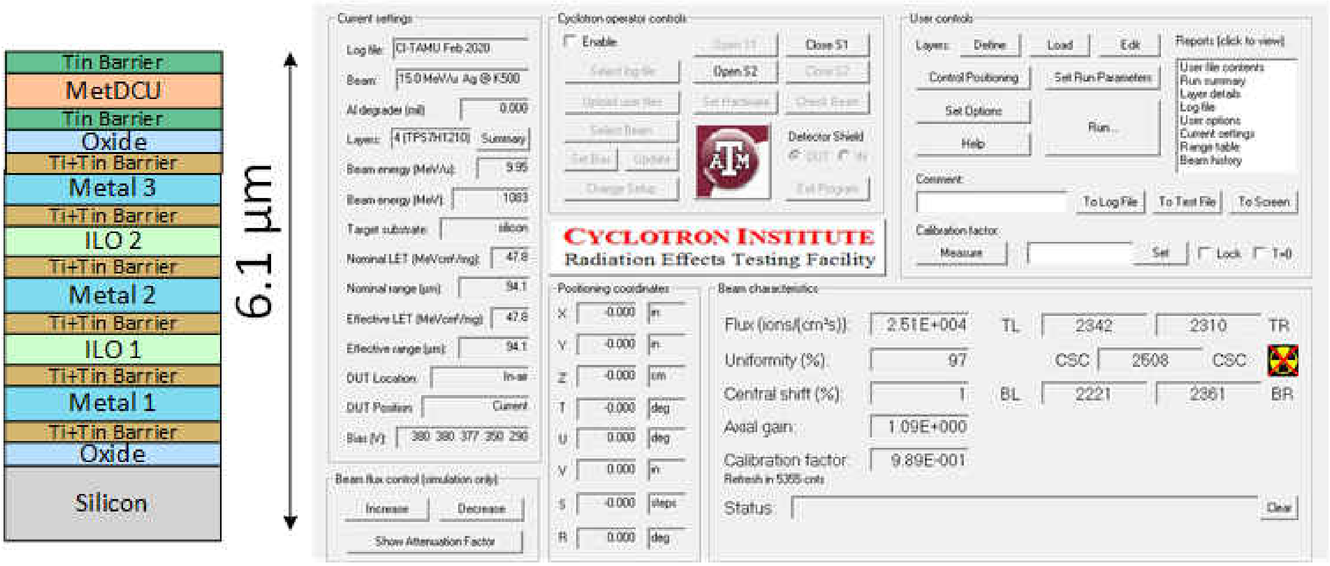


Figure 4-1. Photograph of the TPS7H1210-SEP Evaluation Board at the Texas A&M Cyclotron

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



Log file: CI-TAMU Feb 2020
Beam: 15.0 MeV/u Ag @ K500
Al degrader (mil): 0.000
Layers: 4 (TPS7H1210)
Beam energy (MeV/u): 9.95
Beam energy (MeV): 1083
Target substrate: silicon
Nominal LET (MeV/cm²/mg): 47.8
Nominal range (µm): 94.1
Effective LET (MeV/cm²/mg): 47.8
Effective range (µm): 94.1
DUT Location: In-air
DUT Position: Current
Bias (V): 380 380 377 350 298

X: -0.000 in
Y: -0.000 in
Z: -0.000 cm
T: -0.000 deg
U: 0.000 deg
V: 0.000 in
S: -0.000 steps
R: 0.000 deg

Flux (ions/(cm²s)): 2.51E+004
Uniformity (%): 97
Central shift (%): 1
Axial gain: 1.09E+000
Calibration factor: 9.89E-001
TL: 2342
TR: 2310
CSC: 2608
BL: 2221
BR: 2361

Figure 5-1. Generalized Cross-Section of the BICOM3XHV Technology BEOL Stack on the TPS7H1210-SEP [Left] and SEUSS 2021 Application Used to Determine Key Ion Parameters [Right]

The TPS7H1210-SP is fabricated in the TI BICOM3XHV process with a back-end-of-line (BEOL) stack consisting of 3 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 6.1 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 TPS7H1210-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. Krypton Ion LET$_{EFF}$, Depth, and Range in Silicon

ION TYPE	ANGLE OF INCIDENCE	DEGRADER STEPS (#)	DEGRADER ANGLE	RANGE IN SILICON	LET$_{EFF}$ (MeV·cm^2/mg)
^{109}Ag	0	0	0	93.6	47.8

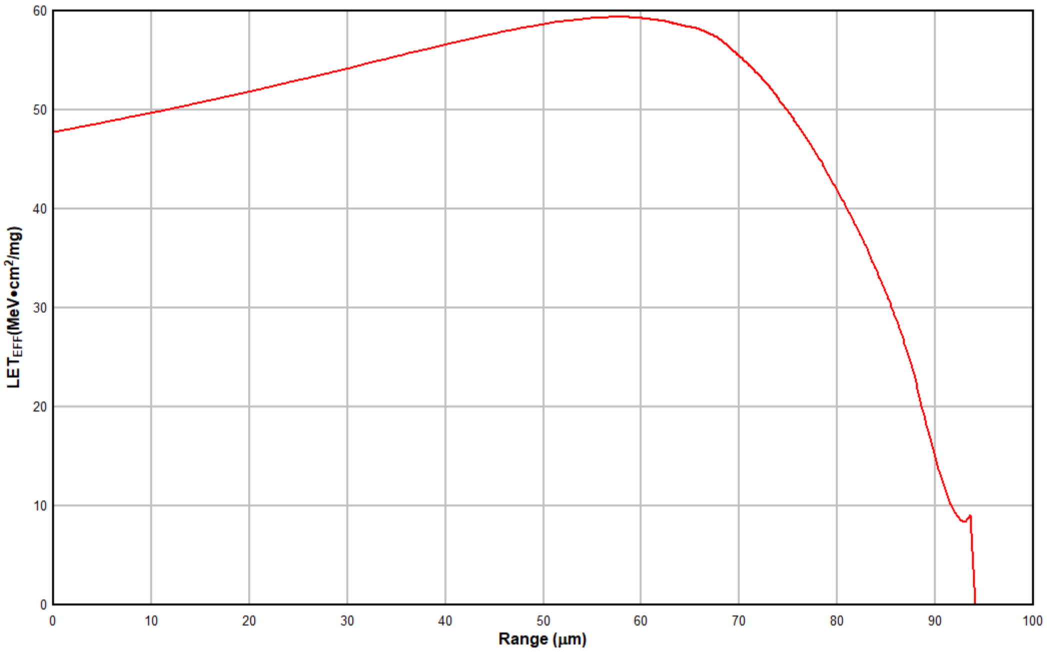


Figure 5-2. LET_{EFF} vs Range for ^{109}Ag at the Conditions Used for the SEE Test Campaign

6 Test Setup and Procedures

SEE testing was performed on a TPS7H1210-SEP device mounted on a board designed for SEE testing. The device power was provided using the TP9 (VIN) and (GND) inputs with the N6766A PS Module mounted on a N6705 precision power supply. A Chroma E-Load in constant current (CC) mode was used to load the device using TP10 and TP11 (V_{OUT}).

For SEL, SEB, and SEGR testing, the device was powered up to an operating voltage of –16.5 V and biased under the following conditions:

- SEL: V_{OUT} = 5 V, I_{OUT} = 0.385 A
- SEL: V_{OUT} = 12 V, I_{OUT} = 0.9 A
- SEB/SEGR: V_{OUT} = 5 V, I_{OUT} = 0.15 A
- SEB/SEGR: V_{OUT} = 12 V, I_{OUT} = 0.385 A

For the SEB/SEGR characterization, the device was tested under enabled and disabled modes. The device was disabled by using the TP14 (EN) pin, forcing 0 V using a PXIe-4139. The Chroma (E-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 in the following configurations:

- V_{IN} = 15 V, V_{OUT} = 5 V, I_{OUT} = 0.2 A
- V_{IN} = 12 V, V_{OUT} = 5 V, I_{OUT} = 0.35 A
- V_{IN} = 6 V, V_{OUT} = 5 V, I_{OUT} = 1 A
- V_{IN} = 15 V, V_{OUT} = 12 V, I_{OUT} = 0.575 A
- V_{IN} = 12.7 V, V_{OUT} = 12 V, I_{OUT} = 1 A

The SET events were monitored using a National Instruments™ (NI) PXIe-5172 scope card. The scope was used to monitor and trigger from V_{OUT}, using a window trigger around ±3% from the nominal output voltage. The scope was 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 an 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 TPS7H1210-SEP. Table 6-1 shows the connections, limits, and compliance values used during the testing. A die temperature of 125°C was used for SEL, the temperature was controlled by dissipating ≈4 W across the pass element. For the SEB/SEGR and SET characterization, the devices were tested at room temperature (no cooling or heating was applied to the DUT). The die temperature was verified using a IR-camera prior to the SEE test campaign.

Table 6-1. Equipment Set and Parameters Used for SEE Testing the TPS7H4010-SEP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
VIN	Agilent N6766A PS	15 A	10 A	5, 12, and 16.5 V
Oscilloscope Card on V_{OUT}	NI-PXIe 5172	100 MS/s	—	2.5 MS/s
Chroma E-Load on V_{OUT}	E36300-80-60	80 A	High Range	0.150 to 1 A

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 TPS7H1210-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 the output voltage exceeded the pre-defined ±3% window trigger a data capture was initiated. In addition to monitoring the output voltage, 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.

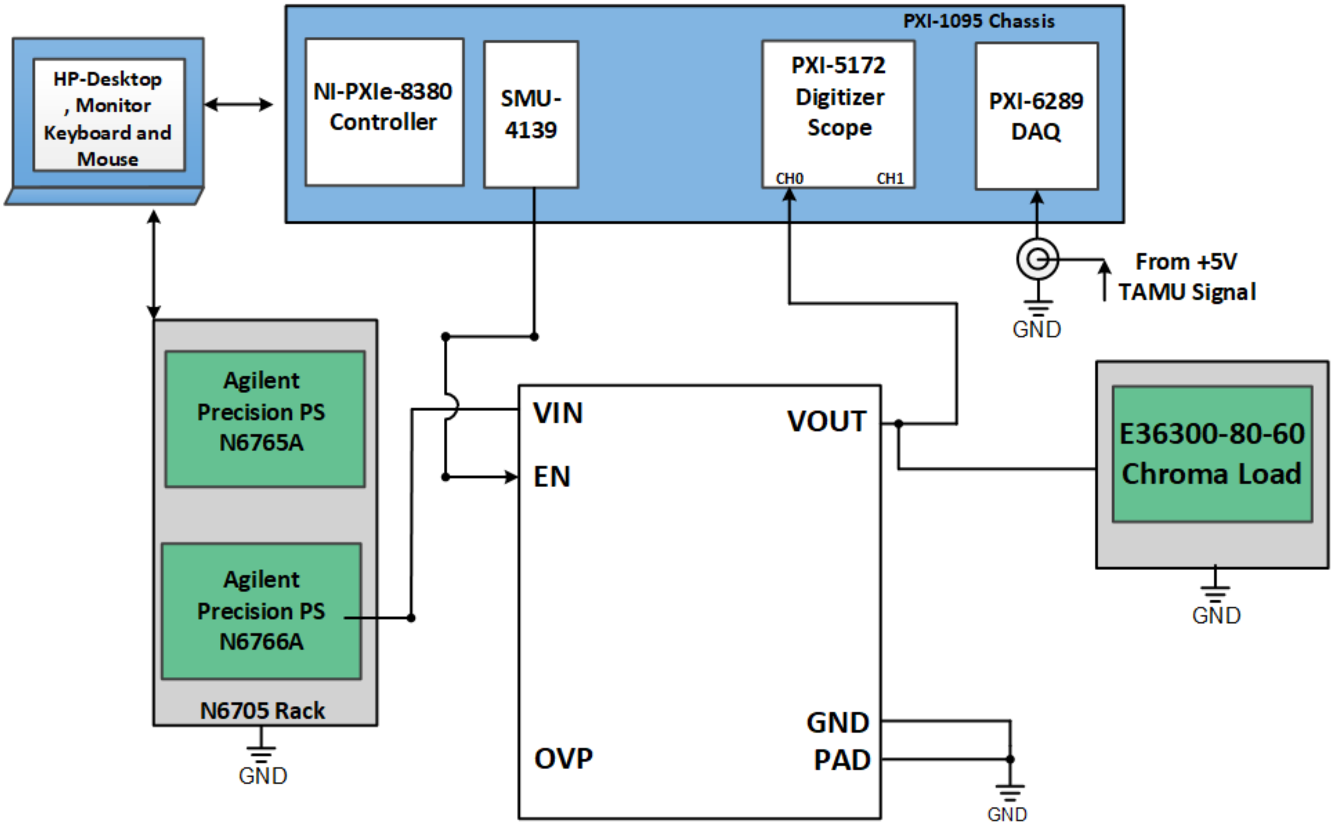


Figure 6-1. Block Diagram of SEE Test Setup With the TPS7H1210-SEP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

During SEL characterization, the device was heated using a varying forced load current, maintaining the DUT temperature at 125°C. The die 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} = 47.8 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 four runs. 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 –16.5 V and different loads depending on the output voltage such that the power dissipation across the pass element was ≈4 W. The specific V_{IN}, V_{OUT} and I_{LOAD} run conditions are shown in the summary of results table. From run # 4 to 14 (unit # 4) the device was operated at the minimum output voltage of –1.182 while the input voltage was incremented. During these runs the power dissipation was maintained constant at around 4 W. This experiment was conducted to determine if permanent damage occurred while operating the device with high drop-out voltage. No destructive damage was observed.

No SEL events were observed during all fourteen runs, indicating that the TPS7H1210-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 TPS7H4010-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)	V_{OUT} (V)	LOAD (A)
1	1	^{109}Ag	47.8	9.20×10^4	9.96×10^6	–16.5	–5	0.385
2	2	^{109}Ag	47.8	1.06×10^5	1×10^7	–16.5	–12	0.900
3	2	^{109}Ag	47.8	9.87×10^4	1×10^7	–16.5	–12	0.900
4	3	^{109}Ag	47.8	9.31×10^4	1×10^7	–16.5	–5	0.385
5	4	^{109}Ag	47.8	1.01×10^5	9.98×10^6	–12	–1.182	0.372
6	4	^{109}Ag	47.8	9.47×10^4	9.96×10^6	–12.5	–1.182	0.355
7	4	^{109}Ag	47.8	8.03×10^4	1×10^7	–13	–1.182	0.340
8	4	^{109}Ag	47.8	7.84×10^4	9.98×10^6	–13.5	–1.182	0.326
9	4	^{109}Ag	47.8	9.13×10^4	1×10^7	–14	–1.182	0.314
10	4	^{109}Ag	47.8	7.53×10^4	9.96×10^6	–14.5	–1.182	0.302
11	4	^{109}Ag	47.8	6.78×10^4	9.99×10^6	–15	–1.182	0.291
12	4	^{109}Ag	47.8	9.25×10^4	9.98×10^6	–15.5	–1.182	0.281
13	4	^{109}Ag	47.8	8.20×10^4	1×10^7	–16	–1.182	0.272
14	4	^{109}Ag	47.8	9.11×10^4	1×10^7	–16.5	–1.182	0.263

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences for the five runs at VIN = –16.5 V @ 125°C (5×10^7), 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} = 47.8 MeV·cm^2/mg and T = 125°C.

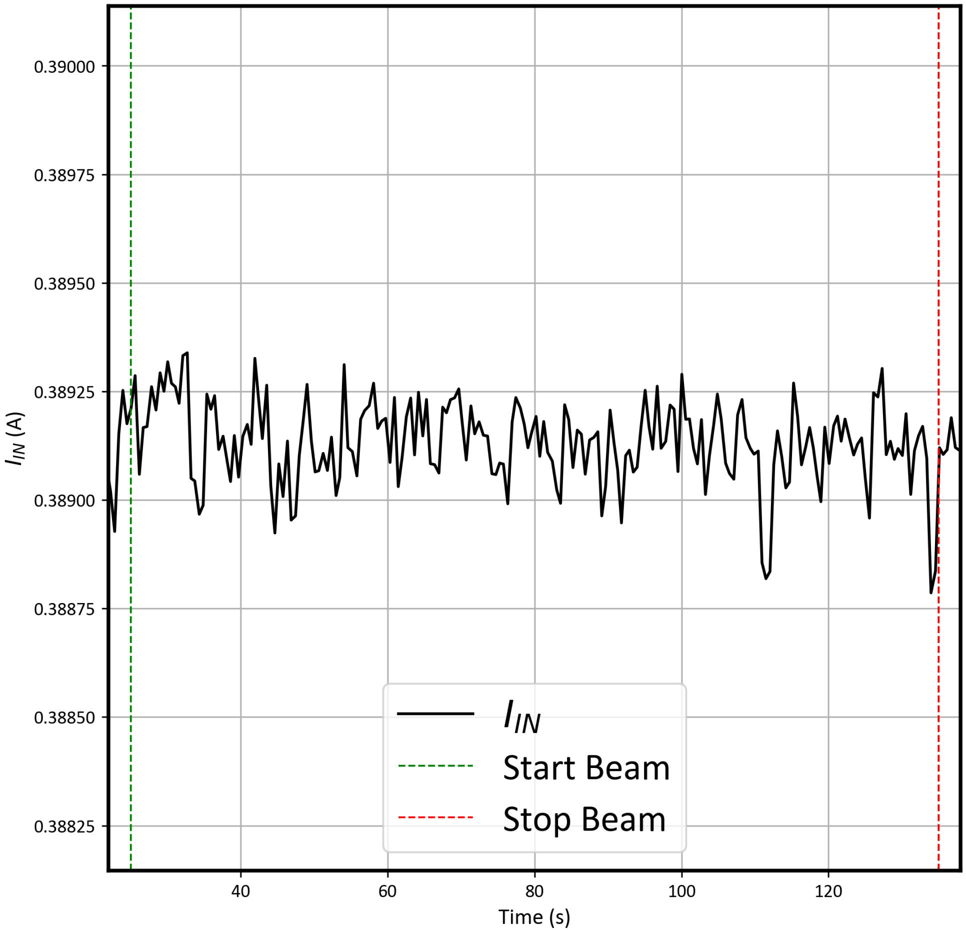


Figure 7-1. Current vs Time for Run # 1 of the TPS7H1210-SEP at T = 125°C

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

During the SEB/SEGR characterization, the device was tested at around 50°C. The die 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} = 47.8 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 minimum (maximum negative) voltage of –16.5 V and varying loads based on the output voltage, while ensuring the die was temperature was not beyond 50°C. Specific V_{IN} to V_{OUT} and I_{LOAD} run conditions are shown in the summary table Table 7-2. The TPS7H1210-SEP was tested under enabled and disabled modes, the device was disabled by using the EN pin forcing EN to 0 V through the PXIe-4139 SMU. The Chroma E-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 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 four runs, indicating that the TPS7H1210-SEP is SEB/SEGR-free up to LET_{EFF} = 47.8 MeV·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 # 15 (Enabled) and Figure 7-3 for run # 16 (Disabled).

Table 7-2. Summary of TPS7H1210-SEP SEL Test Condition and Results

RUN #	UNIT #	ION	LET_{EFF} (MeV·cm²/mg)	FLUX (ions·cm²/mg)	FLUENCE (# ions)	V_{IN} (V)	V_{OUT} (V)	LOAD (A)	ENABLED STATUS
15	1	^{109}Ag	47.8	8.67×10^4	1×10^7	–16.5	–5	0.150	Enabled
16	1	^{109}Ag	47.8	8.12×10^4	1×10^7	–16.5	0	0.150	Disabled
17	2	^{109}Ag	47.8	8.94×10^4	1×10^7	–16.5	–12	0.385	Enabled
18	2	^{109}Ag	47.8	9.69×10^4	1×10^7	–16.5	0	0.385	Disabled
19	3	^{109}Ag	47.8	9.75×10^4	9.95×10^6	–16.5	–5	0.150	Enabled
20	3	^{109}Ag	47.8	1.06×10^5	1×10^7	–16.5	0	0.150	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 @ 50°C (6×10^7), the upper-bound cross section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 6.15 \times 10^{-8}$ cm²/device for LET_{EFF} = 47.8 MeV·cm²/mg and T ≤ 50°C.

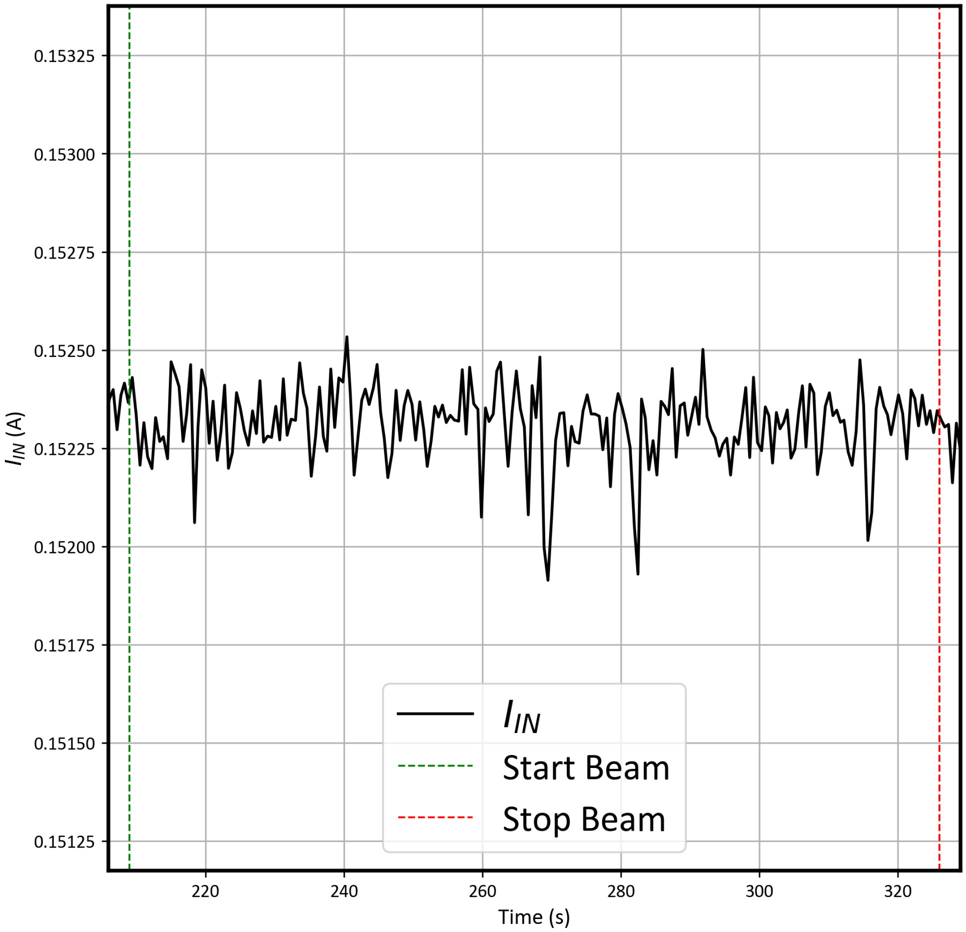


Figure 7-2. Current vs Time for Run # 15 (Enabled) for the TPS7H1210-SEP at T = 50°C

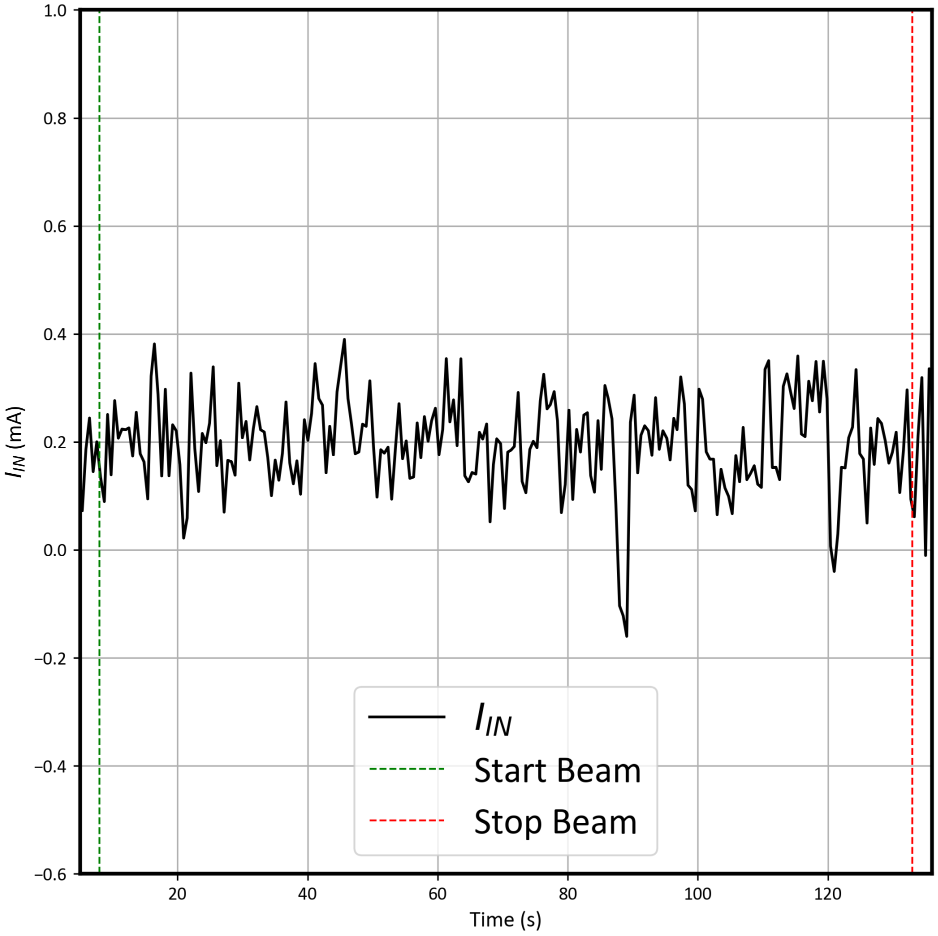


Figure 7-3. Current vs Time for Run # 16 (Disabled) for the TPS7H1210-SEP at T = 50°C

8 Single-Event Transients (SET)

SETs are defined as heavy-ion-induced transients upsets on V_{OUT} of the TPS7H1210-SEP. SET testing was performed at around 50°C. The species used for the SET testing was a Silver (^{109}Ag) ion with an angle-of-incidence of 0° for an LET_{EFF} = 47.8 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 eight SET runs.

V_{OUT} SETs were characterized using a window trigger of ±3% around the nominal output voltage (≈–5 and –12 V). The devices were characterized at V_{IN} = –6, –12, and –15 V (for VOUT = –5 V) and V_{IN} = –12.7 and –15 V (for V_{OUT} = –12 V). The output load was set to various loads to ensure the die temperature did not rise beyond 50°C, specific test conditions are in Table 8-1. To capture the SETs an NI-PXIe-5172 scope card was used to continuously monitor the V_{OUT}. The output voltage was monitored by using the TP1 and the TP15 test points on the EVM.

The scope triggering from V_{OUT} was programmed to record 100k samples with a sample rate of 2.5 M samples per second (S/s) in case of an event (trigger). The scope was programmed to record 20% of the data before (pre) the trigger. The captured data was stored as the absolute value of the measured voltage. Thus the output waveforms show positive voltages.

Under heavy-ions, the TPS7H1210-SEP exhibits transient upsets that were fully recoverable without the need for external intervention. With the exception of one upset all observed transient voltages were negative polarity, indicating decreasing potential relative to ground.

Test conditions and results are summarized in Table 8-1. Histograms for the $VOUT_{SET}$ peak percentage and the transient time are shown from Figure 8-1 to Figure 8-3. Figure 8-5 to Figure 8-7 show typical time domain plots for all the different types of the observed SETs for V_{OUT} = –5 V and V_{OUT} = –12 V. All peaks of the transients were within 70% of the nominal value and returned to nominal within 700 µs, showing no issues with device operation throughout the duration of the runs.

Table 8-1. Summary of TPS7H1210-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)	V_{OUT} (V)	LOAD (A)	P_D (W)	$VOUT_{SET}$ (#) ≥ ±3%
21	1	^{109}Ag	47.8	8.40×10^4	9.98×10^6	–15	–5	0.2	2	26
22	1	^{109}Ag	47.8	8.74×10^4	9.96×10^6	–12	–5	0.35	2.45	23
23	1	^{109}Ag	47.8	9.25×10^4	1×10^7	–6	–5	1	1	79
24	2	^{109}Ag	47.8	1.11×10^5	1×10^7	–15	–12	0.575	1.725	24
25	2	^{109}Ag	47.8	9.33×10^4	9.99×10^6	–12.7	–12	1	0.7	3
26	3	^{109}Ag	47.8	1.051×10^5	1×10^7	–15	–5	0.2	2	27
27	3	^{109}Ag	47.8	1.08×10^5	1×10^7	–12	–5	0.35	2.1	27
28	3	^{109}Ag	47.8	1.04×10^5	9.97×10^6	–6	–5	1	1	66

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 and Table 8-3.

Table 8-2. Upper Bound Cross Section for V_{OUT} = –5 V at 95% Confidence Interval

SET TYPE	# UPSETS	UPPER BOUND CROSS SECTION (cm^2/device)
$VOUT_{SET}$ ≥ |3%|	248	4.69×10^{-6}

Table 8-3. Upper Bound Cross Section for V_{OUT} = –12 V at 95% Confidence Interval

SET TYPE	# UPSETS	UPPER BOUND CROSS SECTION (cm^2/device)
$VOUT_{SET}$ ≥ |3%|	27	1.97×10^{-6}

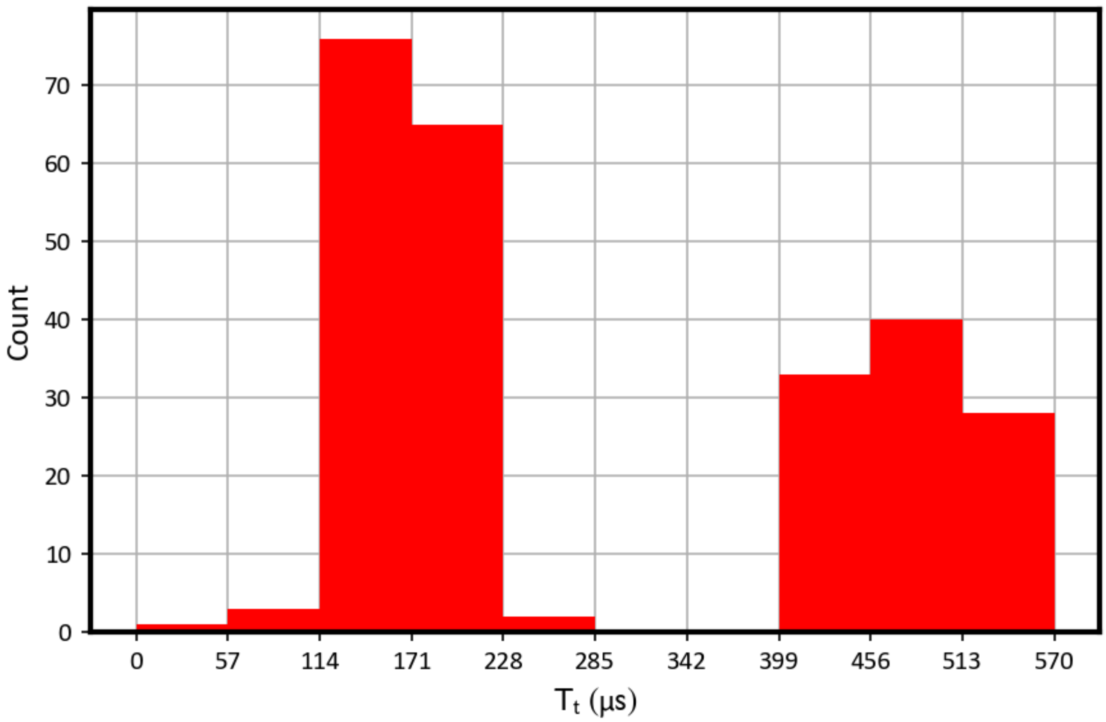


Figure 8-1. Histogram of the Transient Time for V_{OUT} SETs for V_{OUT} = 5 V

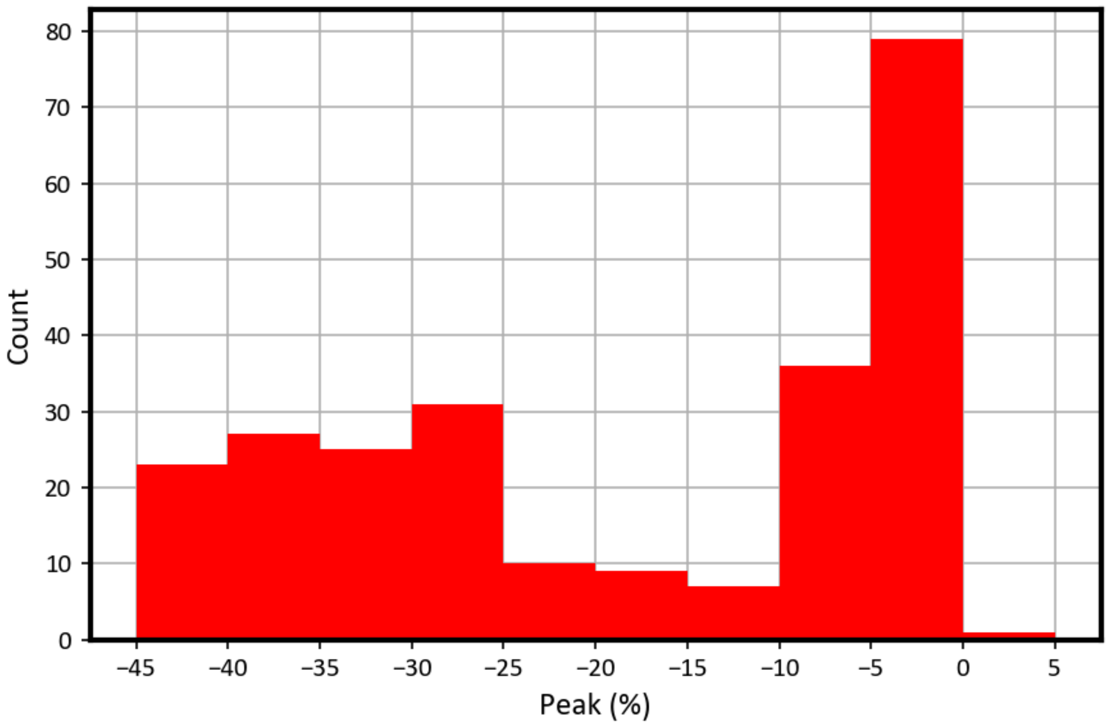


Figure 8-2. Histogram of the Peak Percentage for V_{OUT} SETs for V_{OUT} = 5 V

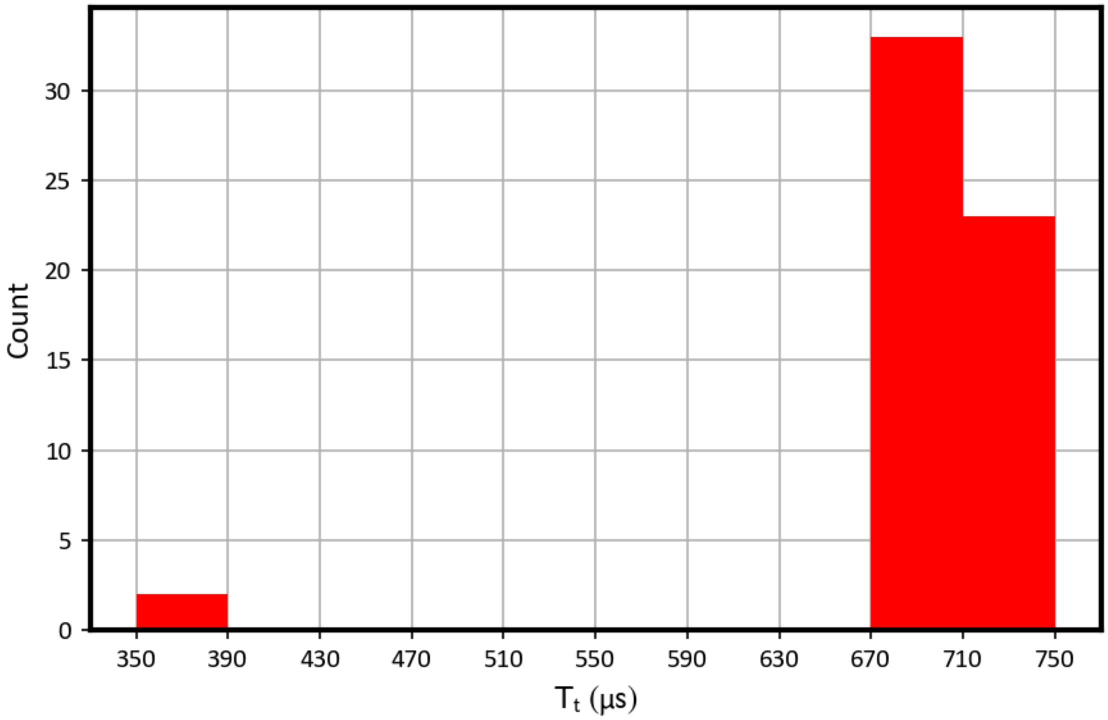


Figure 8-3. Histogram of the Transient Time for V_{OUT} SETs for V_{OUT} = 12 V

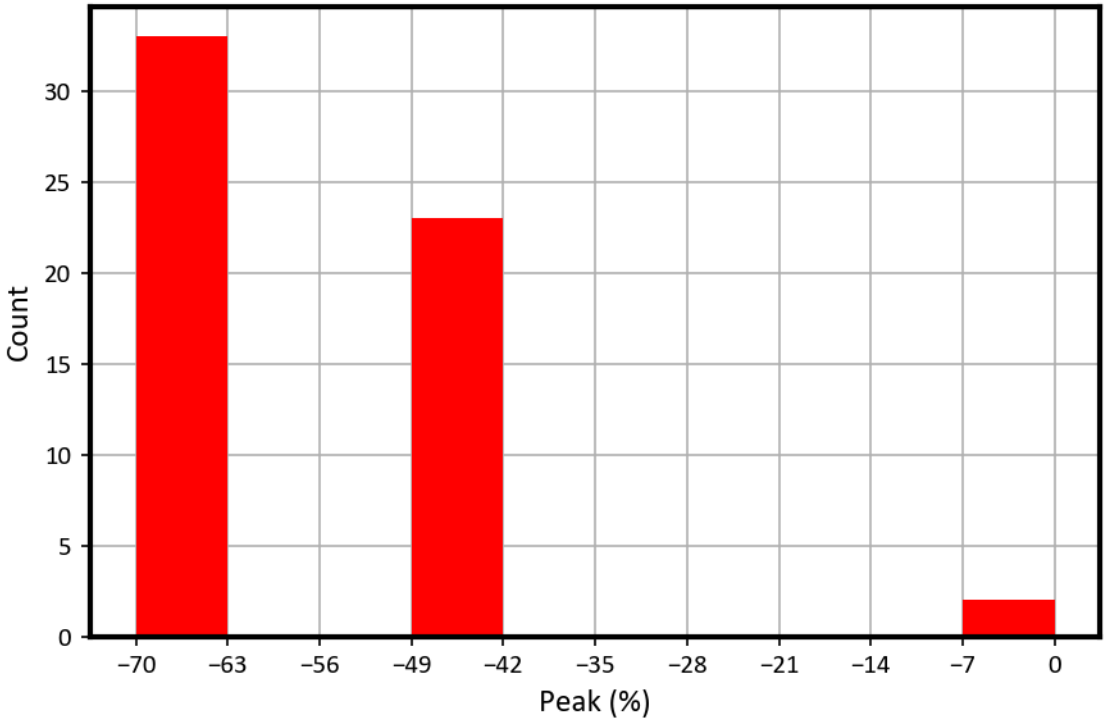


Figure 8-4. Histogram of the Peak Percentage for V_{OUT} SETs for V_{OUT} = 12 V

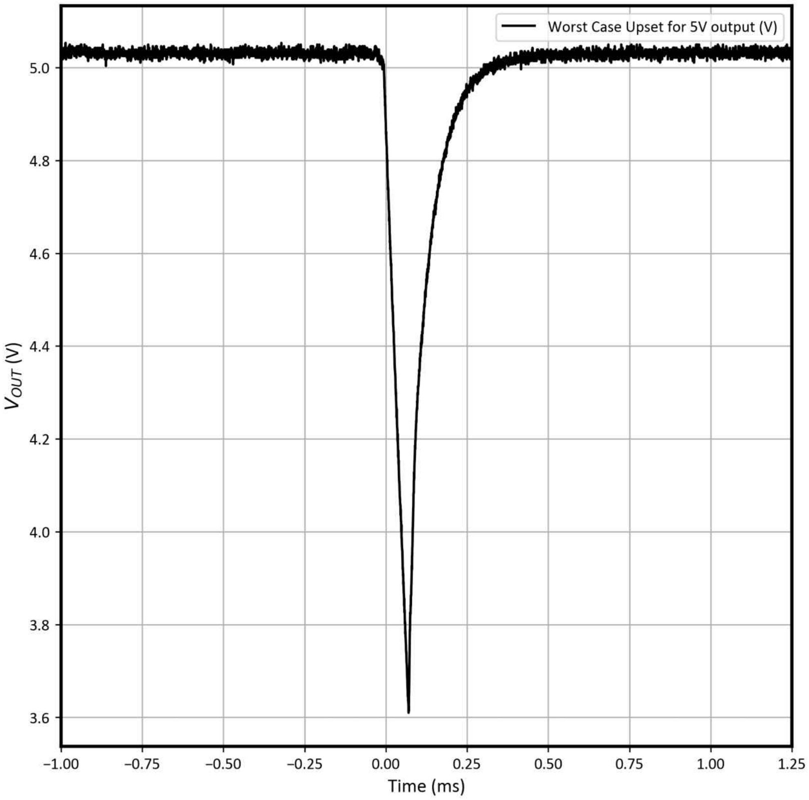


Figure 8-5. Worst Case VOUT$_{SET}$ for Run # 21

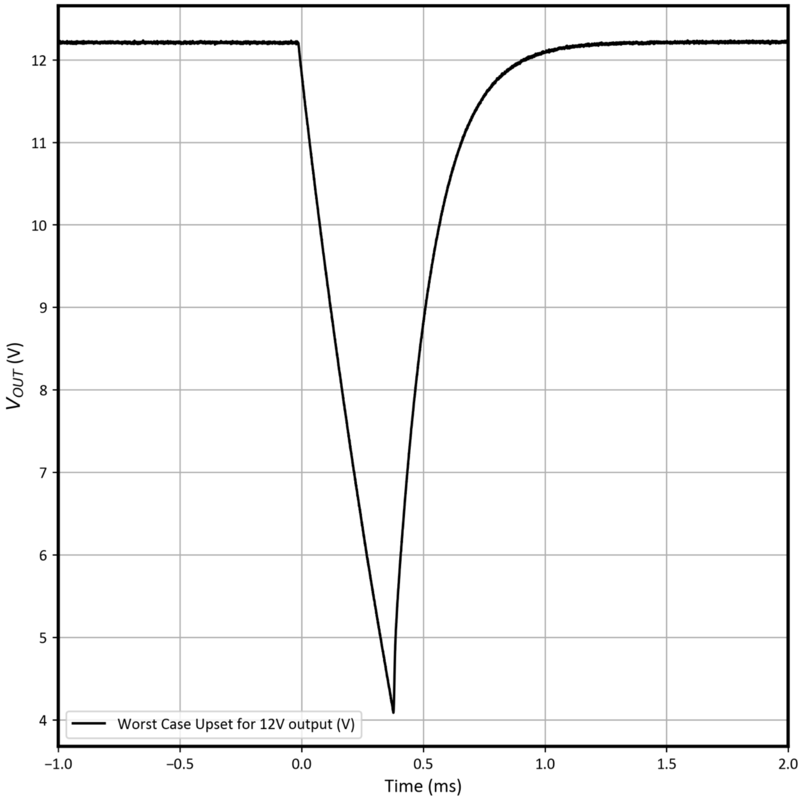


Figure 8-6. Worst Case VOUT$_{SET}$ for Run # 24

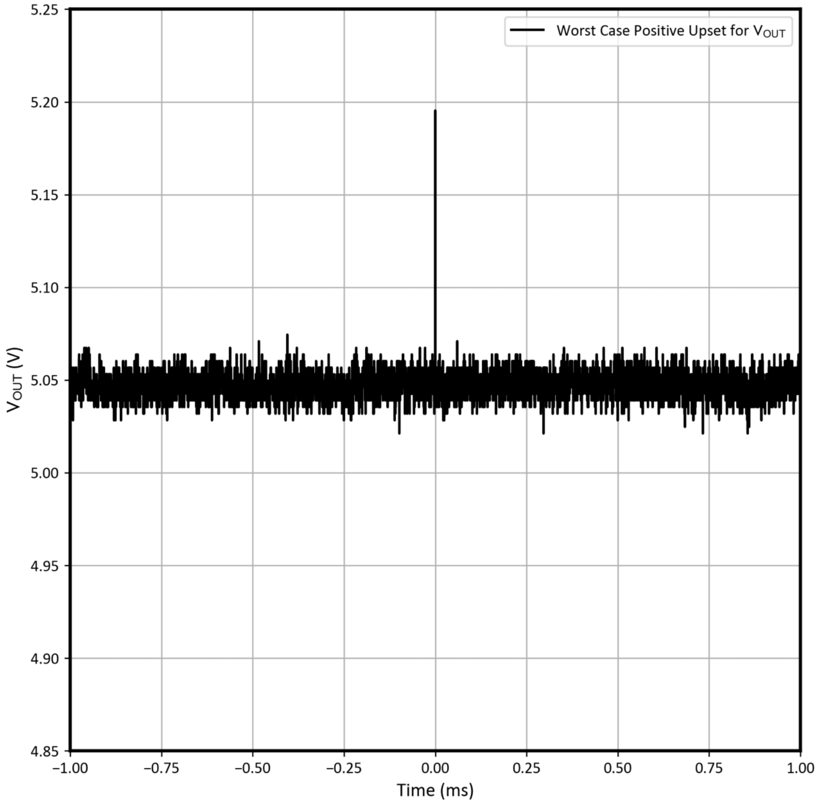


Figure 8-7. Worst Case Positve $VOUT_{SET}$

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.**

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}	7.38×10^{-8}	3.367×10^{-11}	1.403×10^{-3}	8.137×10^{7}
GEO		1.497×10^{-3}		1.105×10^{-10}	4.605×10^{-3}	2.479×10^{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}	6.15×10^{-8}	2.806×10^{-11}	1.169×10^{-3}	9.764×10^{7}
GEO		1.497×10^{-3}		9.209×10^{-11}	3.837×10^{-3}	2.975×10^{7}

Table 9-3. –5-V SET 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}	4.69×10^{-6}	2.14×10^{-9}	8.92×10^{-2}	1.28×10^{6}
GEO		1.497×10^{-3}		7.02×10^{-9}	2.93×10^{-1}	3.90×10^{5}

Table 9-4. –12-V SET 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}	1.97×10^{-6}	8.99×10^{-10}	3.75×10^{-2}	3.05×10^{6}
GEO		1.497×10^{-3}		2.95×10^{-9}	1.23×10^{-1}	9.29×10^{5}

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 TPS7H1210-SEP low noise negative voltage regulator. Heavy-ions with LET_{EFF} = 47.8 MeV·cm^2/mg were were used for the SEE characterization campaign. Flux of 10^5 ions/cm^2·s and fluences up to 1 × 10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H1201-SEP negative LDO is free of destructive SEB events and SEL-free up to LET_{EFF} = 47.8 MeV·cm^2/mg and across the full electrical specifications. Transients at LET_{EFF} = 47.8 MeV·cm^2/mg on V_{OUT} are presented and discussed. CREME96-based worst-week event-rate calculations for LEO(ISS) and GEO orbits for the DSEE are presented for reference.

A Appendix: Total Ionizing Dose from SEE Experiments

The production TPS7H1210-SEP Negative LDO is radiation lot acceptance tested (RLAT) to a total ionizing dose (TID) of 20 krad(Si) (characterized to 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 over all runs was determined to be between 3 krad(Si) to 20 krad(Si), for each device. All 4 production TPS7H1210-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.

B Appendix: References

1. M. Shoga and D. Binder, "Theory of Single Event Latchup in Complementary Metal-Oxide Semiconductor Integrated Circuits", *IEEE Trans. Nucl. Sci., Vol. 33(6)*, Dec. 1986, pp. 1714-1717.
2. G. Bruguier and J. M. Palau, "Single particle-induced latchup", *IEEE Trans. Nucl. Sci., Vol. 43(2)*, Mar. 1996, pp. 522-532.
3. G. H. Johnson, J. H. Hohl, R. D. Schrimpf and K. F. Galloway, "Simulating single-event burnout of n-channel power MOSFET's," in IEEE Transactions on Electron Devices, vol. 40, no. 5, pp. 1001-1008, May 1993.
4. J. R. Brews, M. Allenspach, R. D. Schrimpf, K. F. Galloway,J. L. Titus and C. F. Wheatley, "A conceptual model of a single-event gate-rupture in power MOSFETs," in IEEE Transactions on Nuclear Science, vol. 40, no. 6, pp. 1959-1966, Dec. 1993.
5. G. H. Johnson, R. D. Schrimpf, K. F. Galloway, and R. Koga,“Temperature dependence of single event burnout in n-channel power MOSFETs [for space application],” IEEE Trans. Nucl. Sci., 39(6), Dec. 1992, pp.1605-1612.
6. TAMU Radiation Effects Facility website. http://cyclotron.tamu.edu/ref/
7. "The Stopping and Range of Ions in Matter" (SRIM) software simulation tools website. www.srim.org/index.htm#SRIMMENU
8. D. Kececioglu, “Reliability and Life Testing Handbook”, Vol. 1, PTR Prentice Hall, New Jersey,1993, pp. 186-193.
9. ISDE CRÈME-MC website.https://creme.isde.vanderbilt.edu/CREME-MC
10. A. J. Tylka, J. H. Adams, P. R. Boberg, et al.,"CREME96: A Revision of the Cosmic Ray Effects on Micro-Electronics Code", *IEEE Trans. on Nucl. Sci., Vol. 44(6)*, Dec. 1997, pp. 2150-2160.
11. A. J. Tylka, W. F. Dietrich, and P. R. Boberg, "Probability distributions of high-energy solar-heavy-ion fluxes from IMP-8: 1973-1996", *IEEE Trans. on Nucl. Sci.,Vol. 44(6)*, Dec. 1997, pp. 2140-2149.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2022, Texas Instruments Incorporated