Radiation Report

Single-Event Effects Test Report of the TPS7H4002-SP Synchronous Step-Down Converter

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation for the TPS7H4002-SP. Destructive single-event effects (DSEE) performance was verified up to an input voltage of 6 V, while single-event transients (SET) were characterized at the typical input voltage of 5 V, regulating to 2.5-V output at the maximum load of 3 A. Heavy ions with effective LET (LET_{EFF}) of 75 MeV·cm^2/mg were used to irradiate three production RHA devices. Flux of ≈10^5 and fluences of ≈10^7 ions/cm^2 per run were used for the characterization. The results demonstrate the TPS7H4002-SP is DSEE-free within the full electrical range of the device. SET performance at P_{VIN} = V_{IN} = 5 V, V_{OUT} = 2.5 V and 25°C showed only one upset ≥ |3%| from the nominal voltage, showing the transient robustness of the device to heavy ions.

Table of Contents

List of Figures

List of Tables

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

The TPS7H4002-SP is an space-grade, 3 to 5.5-V input, 3-A, synchronous buck point-of-load (POL) converter, which has been optimized for small designs with its high-efficiency operation and integration of the high-side and low-side power MOSFETs into a compact monolithic solution. Further space saving can be achieved through the use of the configurable switching frequency (0.1 to 1 MHz), which can reduce the output filter lumped components. Additional features are:

- 100-kHz to 1-MHz adjustable internal oscillator
- External sync capability: 100-kHz to 1-MHz
- Monotonic start-up into prebiased outputs
- Adjustable soft start
- Enable input and power-good output for power sequencing and power quality monitoring

Protection features include thermal shutdown and cycle-by-cycle current limiting (on high- and low-side MOSFET). The TPS7H4002-SP is offered in a thermally enhanced 20-pin ceramic, dual in-line flat-pack 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 TPS7H4002-SP product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H4002-SP
Orderable Number	5962R2021001VSC
Device Function	Point-of-load (POL) switching regulator
Technology	BiCMOS
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/nucleon)
Heavy Ion Fluence per Run	1 × 10^7 ions/cm^2
Irradiation Temperature	25°C (for SET and SEB/SEGR 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 TPS7H4002-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 TPS7H4002-SP, the CMOS circuitry introduces a potential for SEL susceptibility.

SEL can occur if excess current injection caused by the passage of an energetic ion is high enough to trigger the formation of a parasitic cross-coupled PNP and NPN bipolar structure (formed between the p-sub and n-well and n+ and p+ contacts) [1,2]. The parasitic bipolar structure initiated by a single-event creates a high-conductance path (inducing a steady-state current that is typically orders-of-magnitude higher than the normal operating current) between power and ground that persists (is "latched") until power is removed, the device is reset, or until the device is destroyed by the high-current state. The TPS7H4002-SP was tested for SEL at maximum recommended voltage of 5.5 V and also 6 V (+500-mV margin), at maximum load current of 3 A, and at V_{OUT} of 2.5 V. The device exhibited no SEL when exposed to heavy-ions with LET_{EFF} = 75 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.

Since this device is designed to conduct large currents (up to 3 A) and withstand up to 5.5 V during the off-state, the power LDMOS introduces a potential susceptibility for SEB and SEGR [3,4]. The TPS7H4002-SP was evaluated for SEB/SEGR at maximum recommended voltage of 5.5 V and also at 6 V (+500-mV margin) and at full load conditions of 3 A in both the enabled and disabled modes. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H4002-SP is SEB/SEGR-free up to LET_{EFF} = 75 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 ≈25°C. During the SEE testing campaign of the TPS7H4002-SP the heavy-ion used provided and LET_{EFF} of 75 MeV·cm^2/mg, at zero degrees of incidence.

The TPS7H4002-SP was characterized for SET at flux of ≈10^5 ions/cm^2·s, fluences of ≈10^7 ions/cm^2, and room temperature. The device was characterized at P_{VIN} = V_{IN} = 5 and V_{OUT} = 2.5 V at full load of 3 A, using a window trigger of ±3% around the nominal voltage. Under these conditions the device showed only one upset, across the three units.

3 Device and Test Board Information

The TPS7H4002-SP is packaged in a 20-pin thermally-enhanced dual ceramic flat pack package (HKH) as shown in Figure 3-1. The TPS7H4002EVM-CVAL evaluation board was used to evaluate the performance and characteristics of the TPS7H4002-SP 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 schematics. For more information about the evaluation board please see the user's guide on the TPS7H4002EVM-CVAL product page.

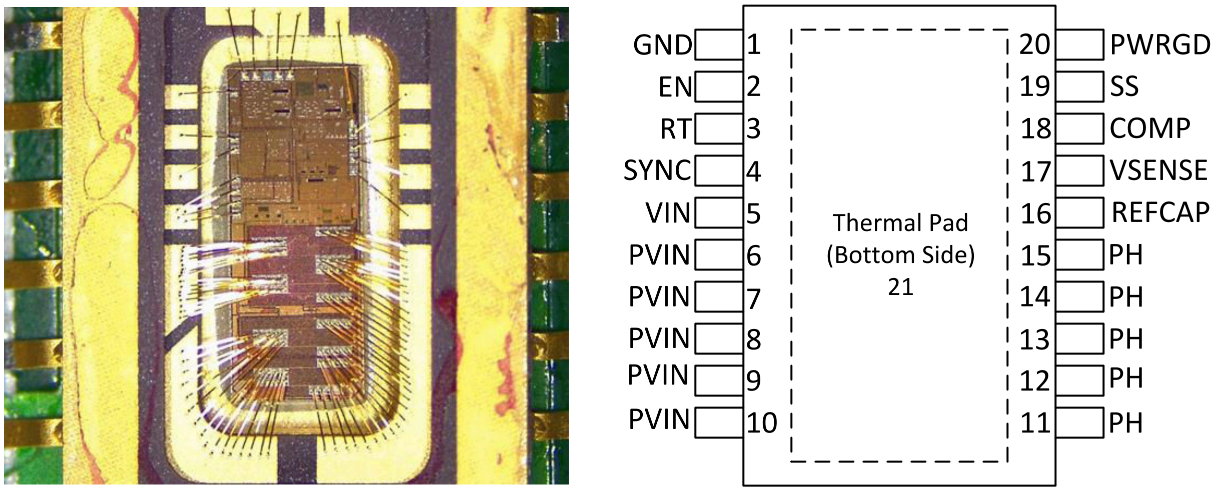

Figure 3-1. Photograph of Delidded TPS7H4002-SP [Left] and Pinout Diagram [Right]

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

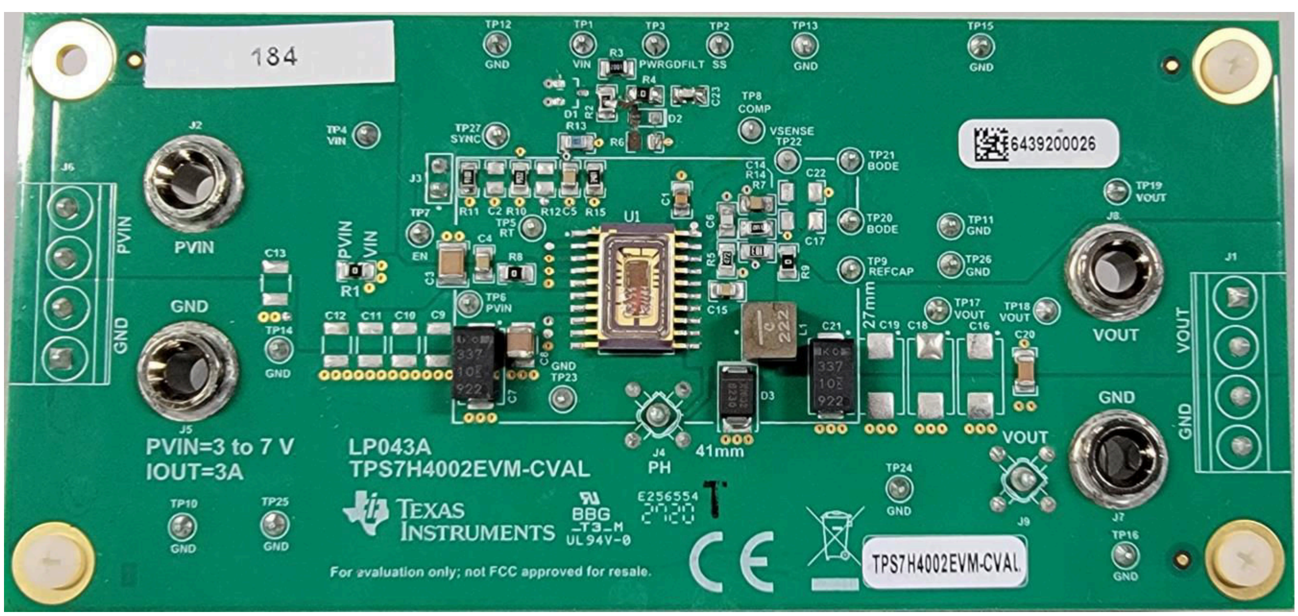

Figure 3-2. TPS7H4002-SP Board Top View

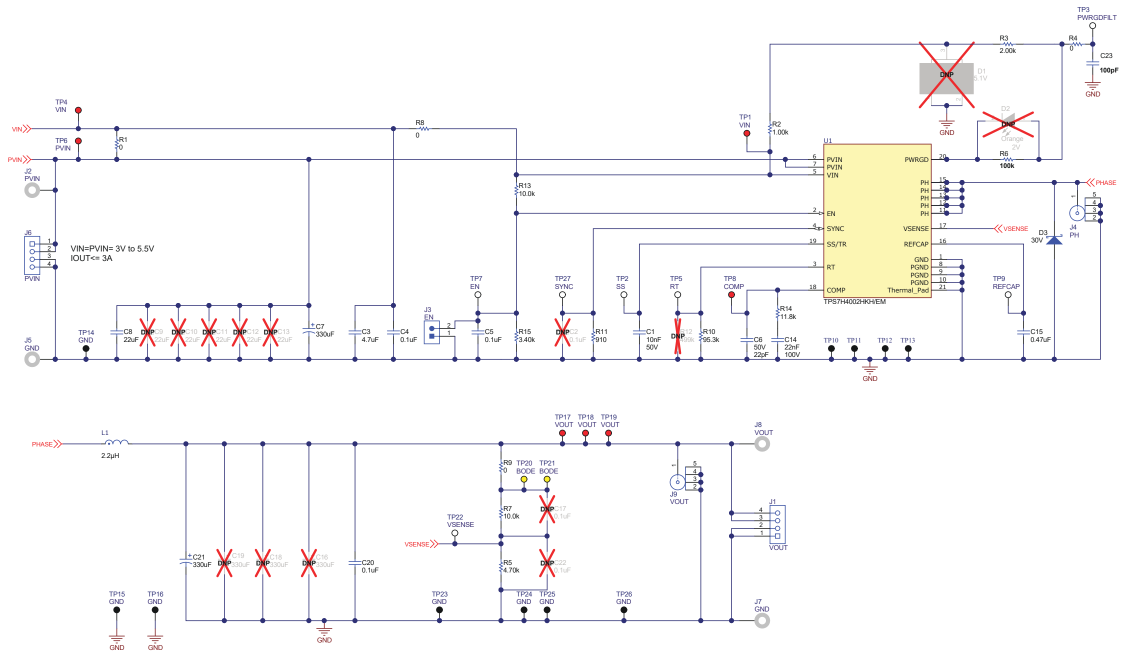

Figure 3-3. TPS7H4002EVM-CVAL Schematic

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 $\approx 10^5$ ions/cm^2·s were used to provide heavy-ion fluences of $\approx 10^7$ ions/cm^2.

For the experiments conducted on this report, Homium (^{165}Ho) at zero degrees of incidence, with an air distance of 30 mm was used. Under this condition the LET_{EFF} = 75 MeV·cm^2/mg. The total kinetic energy of ^{165}Ho in the vacuum is 2.47 GeV (15 MeV/nucleon). Ion uniformity for these experiments were between 90 and 96%.

Figure 4-1 shows the TPS7H4002EVM-CVAL 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 through-hole test points were soldered backwards for easy access of the signals while maintaining the air gap to 30 mm (distance from the nozzle to the die). The in-air gap between the device and the ion beam port window was maintained at 30 mm for all runs.

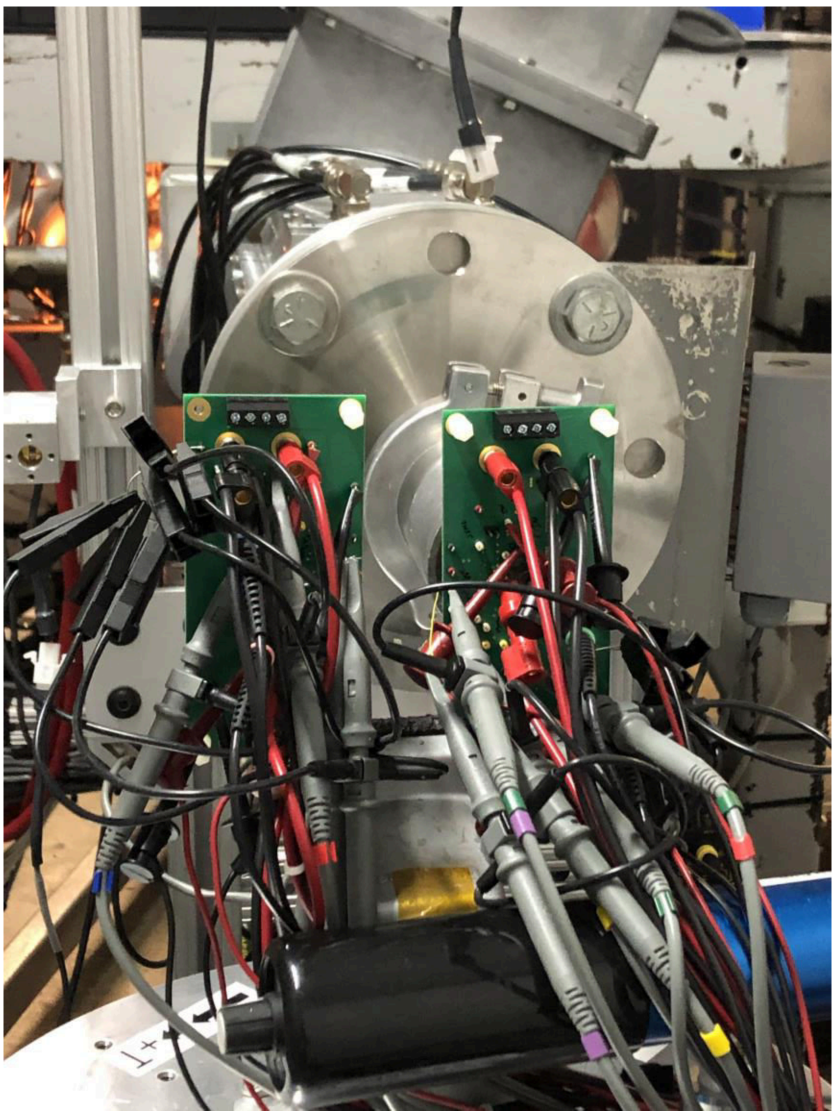

Figure 4-1. Photograph of the TPS7H4002-SP Evaluation Board Mounted in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 Depth, Range, and LET_{EFF} Calculation

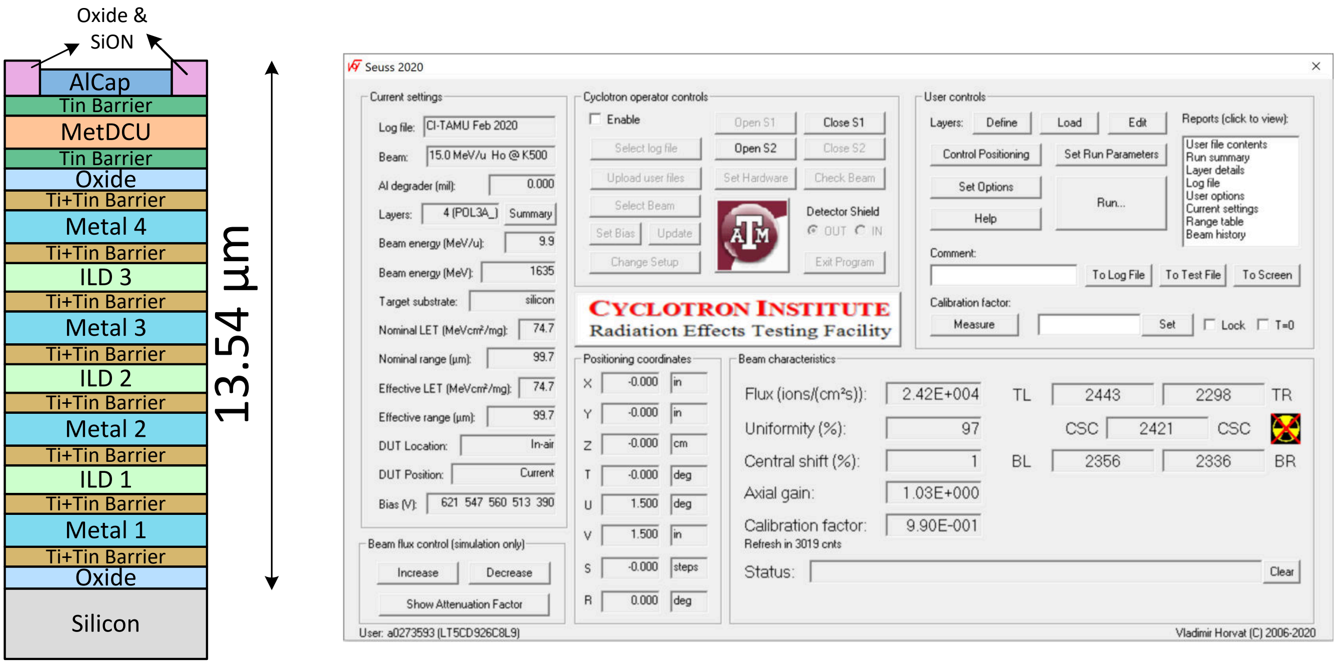

Figure 5-1. Generalized Cross Section of the BEOL Stack on the TPS7H4002A-SP [Left] and GUI of SEUSS 2020 Application Used to Determine the Ion Beam Parameters [Right]

The TPS7H4002-SP 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 metal on a 0.6-µm pitch. The total stack height from the surface of the passivisation 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 30-mm air gap, and the BEOL stack over the TPS7H4002-SP, the LET_{EFF} at the surface of the silicon substrate 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 $range_{EFF}$ for the ^{165}Ho heavy-ion is shown in 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. Homium Ion LET_{EFF} and $Range_{EFF}$ in Silicon

ION TYPE	ANGLE OF INCIDENCE (°)	$RANGE_{EFF}$ IN SILICON (µm)	LET_{EFF} ($MeV·cm^2/mg$)
^{165}Ho	0	99.7	74.7

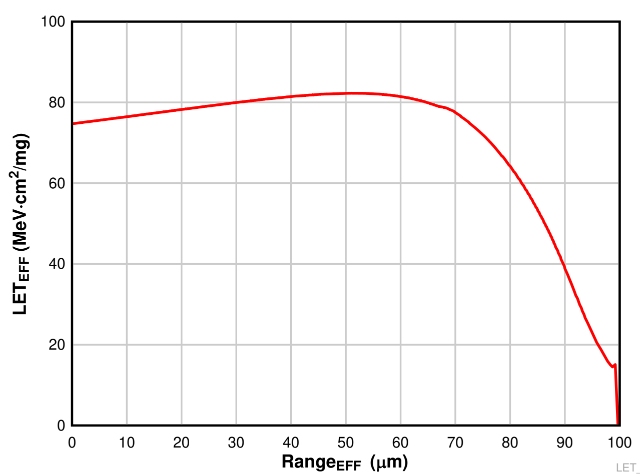

Figure 5-2. LET_{EFF} vs Range for ^{165}Ho at the Conditions Used for the SEE Test Campaign

6 Test Setup and Procedures

SEE testing was performed on a TPS7H4002-SP (5962R2021001VSC) device mounted on a TPS7H4002EVM-CVAL. The device power was provided using the J2 (PVIN) and J5 (GND) inputs with the N6765A PS Module mounted on a N6705 precision power supply in a 4-wire configuration. A chroma load model 63630-80-60 was used to load the device to 3 A for the SEE testing campaign. The chroma was operated on constant-current (CC) for all DSEE, and in constant-resistance (CR) for all SET testing campaign. The P_{VIN} and V_{IN} were tied together using the R1 resistor on the EVM.

For SEL, SEB, and SEGR testing (all DSEE), the device was powered up to the maximum recommended operating voltage of 5.5-V input while regulating to 2.5-V output, and loaded with the maximum load of 3 A. Two of the three tested devices were exposed to heavy-ions at P_{VIN} = V_{IN} = 6 V. These runs were intended to demonstrate the robustness of the device to DSEE.

For the SEB/SEGR characterization, the device was tested under enabled and disabled modes. The device was disabled by connecting a source measure unit (SMU) in the EN input such that the device could be enabled and disabled from the control room. The CC 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 enabled and disabled modes, not a single V_{OUT} transient or input current event was observed.

For the SET characterization, the device was powered to 5 V, regulating the output voltage to 2.5 V. The SET events were monitored using two National Instruments™ (NI) PXIe-5172 scope cards and one National Instruments (NI) PXIe-5162. The 5162 scope was used to monitor soft start and trigger from 1 V on the negative edge during SEL, SET, and enabled SEB. During disabled SEB, the trigger was set at the 0.5 V on the positive edge. One 5172 scope was used to monitor and trigger from V_{OUT} using a window trigger around ±3% from the nominal output voltage during SEL, SET, and enabled SEB. During the disabled SEB testing, V_{OUT} triggered from the positive edge at 0.5 V. The second 5172 scope was used to monitor and trigger from the PWRGD at V_{OUT} – 0.3 V, using an edge/negative trigger during SEL, SET, and enabled SEB. Like the other two values, PWRGD triggered at 0.5V on the positive edge during disabled SEB. Both 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 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 TPS7H4002-SP. Table 6-1 shows the connections, limits, and compliance values used during the testing. A die temperature of 125 ± 5°C was used for the SEL and was achieved by using a TDH35P10R0JE power resistor soldered to the GND plane from the bottom side of the EVM. An PXIe-4139 SMU was connected to the resistor to provide the power to be converted on heat. The temperature was confirmed by using a thermal infrared (IR) camera. Figure 6-2 shows an image of the die temperature during the SEL testing.

For the SEB/SEGR and SET testing, the device was tested at room temperature (no cooling or heating was applied to the DUT).

Table 6-1. Equipment Set and Parameters Used for SEE Testing the TPS7H4002-SP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
VIN	Agilen N6765A PS	15 A	3 A	5, 5.5, and 6 V
Oscilloscope Card on PWRGD	NI-PXIe 5172	100 MS/s	—	10 MS/s
Oscilloscope Card on V_{OUT}	NI-PXIe 5172	100 MS/s	—	10 MS/s
Oscilloscope on SS	NI-PXIe 5162	100 MS/s	—	2 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 TPS7H4002-SP device and set the external sourcing and monitoring functions of the external equipment. After functionality and stability was confirmed, the beam shutter was opened to expose the device to the heavy-ion beam. The shutter remained open until the target fluence was achieved (determined by external detectors and counters). During irradiation, the NI scope cards continuously and independently monitored the signals. When the output voltage exceeded the pre-defined 3% window trigger, or when the PG or SS 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, $P_{VIN} = V_{IN}$ current and the +5-V signal from TAMU were monitored at all times. No sudden increases in current outside of normal fluctuations were observed on any of the test runs and indicated that no SEL or SEB/SEGR events occurred during the tests.

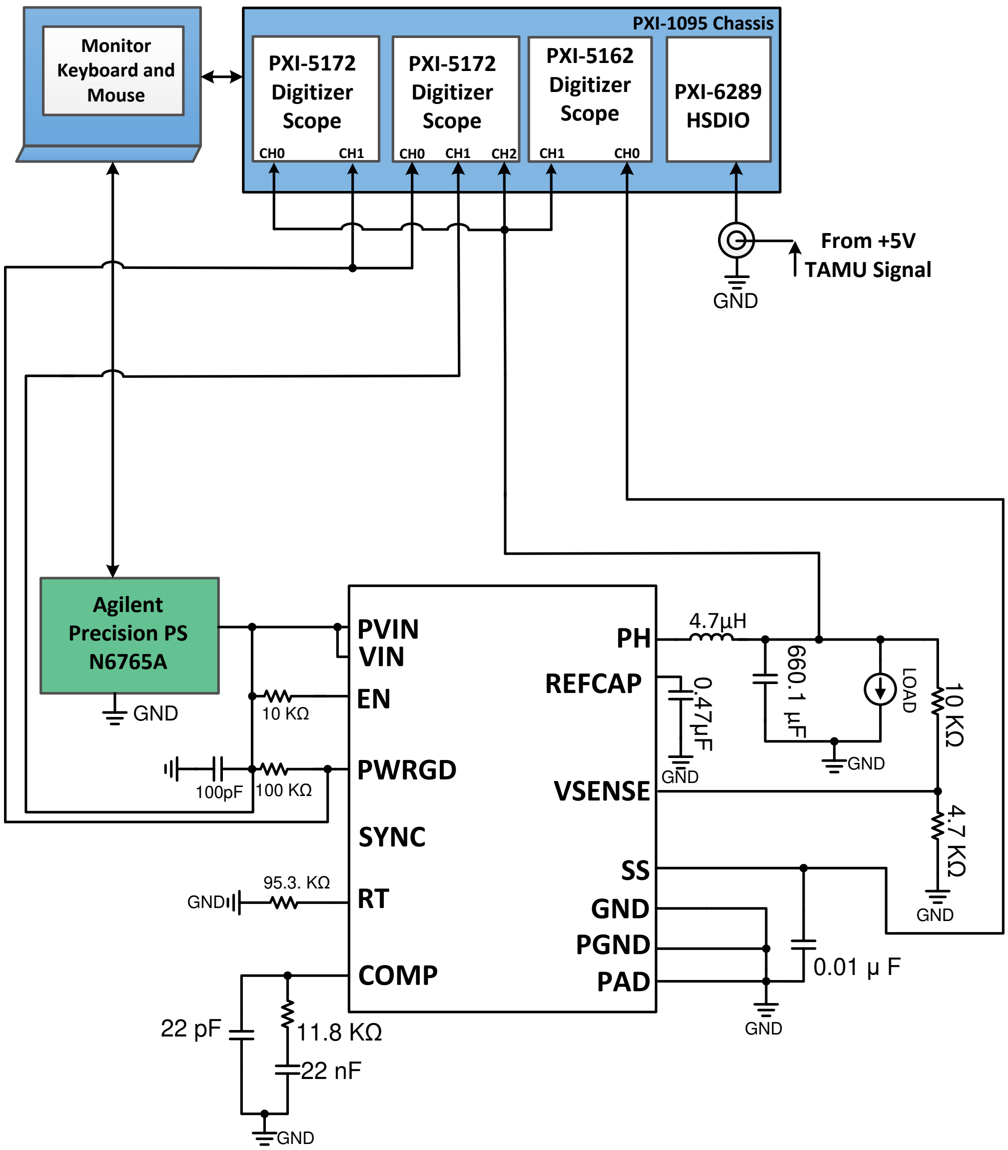

Figure 6-1. Block Diagram of SEE Test Setup for the TPS7H4002-SP

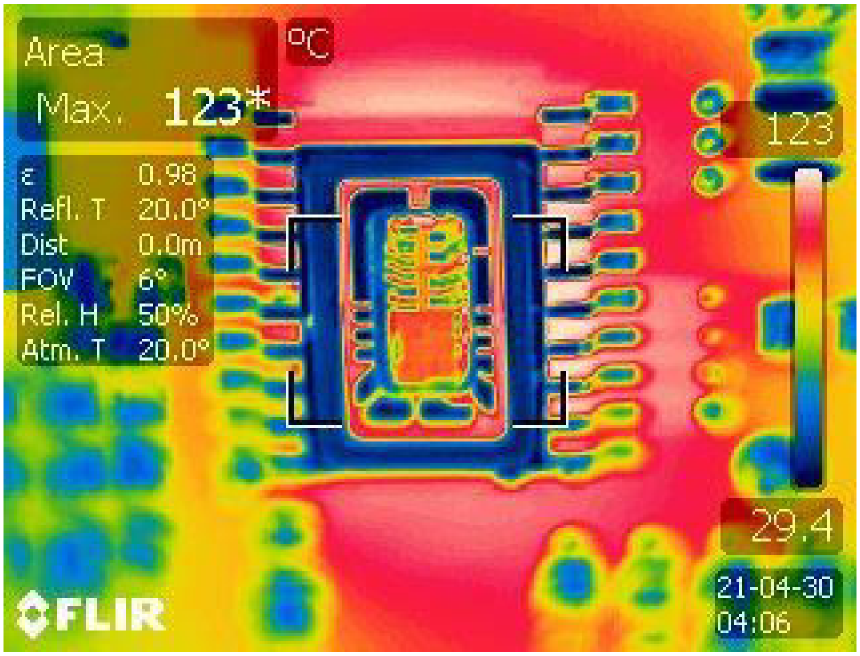

Figure 6-2. Die Temperature During the SEL Testing of the TPS7H4002-SP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

During SEL characterization, the device was heated using a TDH35P10R0JE power resistor soldered to the GND plane from the bottom side of the TPS7H4002-SP unit on the EVM. A PXIe-4139 SMU was used to provide the power to be dissipated across the resistor and converter to heat. The die temperature was confirmed previous to the heavy-ion exposure by using a FLIR™ IR camera.

The species used for the SEL testing was a Homium (^{165}Ho) ion with an angle of incidence of zero degrees for a LET_{EFF} = 75 MeV·cm^2/mg (for more details refer to Section 5). The kinetic energy in the vacuum for this ion is 2.47 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. All three devices were powered up and exposed to the heavy-ions using the maximum recommended voltage of 5.5 V and maximum load of 3 A. During run # 2 (unit # 1), the unit was exposed to heavy-ions while operating 500 mV above the recommended voltage of 5.5 V. This was done to demonstrate the robustness and margin of the TPS7H4002-SP to latch-up.

No SEL events were observed during all four runs, indicating TPS7H4002-SP 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 TPS7H4002-SP SEL Test Condition and Results

NOTE: The LET_{EFF} for all runs was 75 MeV·cm^2/mg, using ^{165}Ho heavy-ions at an angle of incidence of zero degrees.

RUN #	UNIT #	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	V_{IN} (V)	SS EVENTS	SEL?
1	1	1.07×10^5	9.97×10^6	5.5	0	No
2	1	1.05×10^5	9.97×10^6	6	0	No
3	2	9.96×10^4	9.99×10^6	5.5	0	No
4	3	1.06×10^5	9.99×10^6	5.5	0	No

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the 4 runs @ 125°C (3.99×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 9.24 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75 MeV·cm^2/mg and T = 125°C.

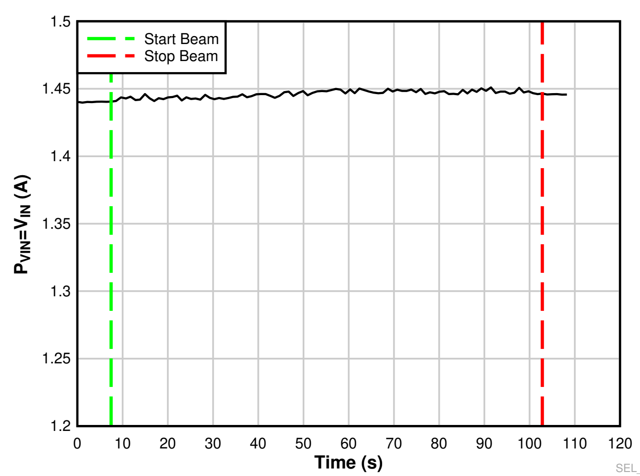

Figure 7-1. Current vs Time for Run # 2 of the TPS7H4002-SP at T = 125°C

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

For the SEB/SEGR characterization, the device was tested at room temperature (25°C). No external heating or cooling element. The species used for the SEB/SEGR testing was a Homium (^{165}Ho) ion with an angle-of-incidence of zero degrees for an LET_{EFF} = 75 MeV·cm^2/mg (for more details refer to Section 5). The kinetic energy in the vacuum for this ion is 2.47 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 using the recommended maximum voltage of 5.5 V and the maximum load of 3 A (using a chroma load on CC mode). For runs 6 and 10, the device was powered up and exposed to the heavy ions at 500 mV (6 V) above the recommended voltage of 5.5 V. This was done to demonstrate the robustness and margin of the TPS7H4002-SP to SEB/SEGR.

The TPS7H4002-SP was tested under enabled and disabled modes, the device was disabled and enabled by forcing 0 V and 2 V, on the EN input, respectively. The chroma load was present and all times 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 enabled and disabled, not a single V_{OUT} transient or input current event was observed. No SEB/SEGR events were observed during any of the eight runs, indicating that the TPS7H4002-SP is SEB/SEGR-free up to LET_{EFF} = 75 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 # 5 (Enabled) and Figure 7-3 for run # 6 (Disabled).

Table 7-2. Summary of TPS7H4002-SP SEB/SEGR Test Condition and Results

NOTE: The LET_{EFF} for all runs was 75 MeV·cm^2/mg, achieved using ^{165}Ho heavy-ions at an angle of incidence of zero degrees.

RUN #	UNIT #	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	V_{IN} (V)	ENABLED STATUS	V_{OUT} EVENTS ≥ |3%|
5	1	1.05×10^5	9.99×10^6	5.5	Enabled	0
6	1	1.01×10^5	9.96×10^6	6	Enabled	0
7	2	1.2×10^5	9.99×10^6	5.5	Enabled	0
8	3	1.14×10^5	9.98×10^6	5.5	Enabled	0
9	1	1.05×10^5	1.01×10^7	5.5	Disabled	0
10	1	1.07×10^5	9.97×10^6	6	Disabled	0
11	2	1.12×10^5	1×10^7	5.5	Disabled	0
12	3	1.14×10^5	9.95×10^6	5.5	Disabled	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the eight runs @ 25°C (7.99×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEB/SEGR} \leq 4.62 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75 MeV·cm^2/mg and T = 25°C.

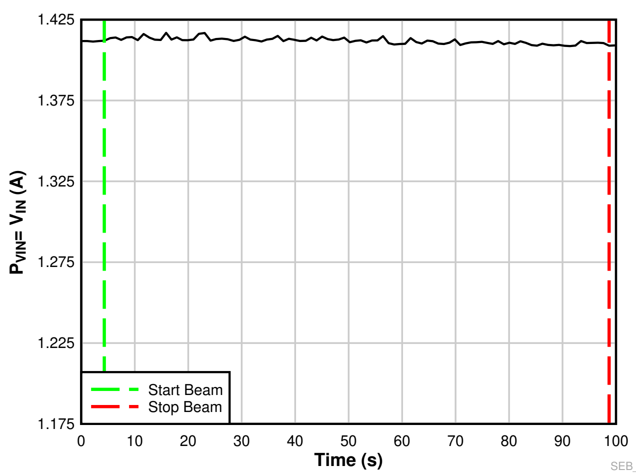

Figure 7-2. Current vs Time for Run # 5 (Enabled) for the TPS7H4002-SP at T = 25°C

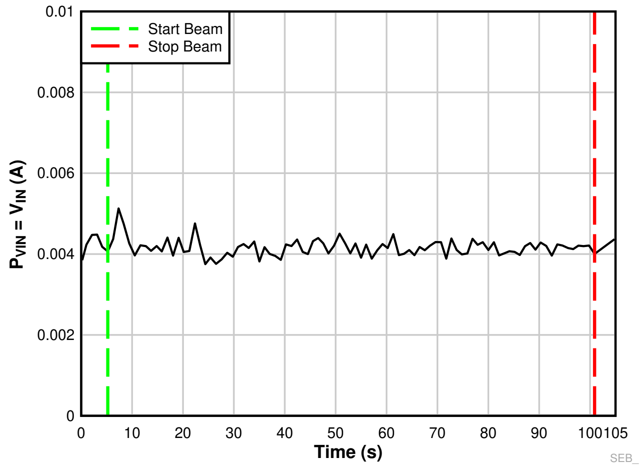

Figure 7-3. Current vs Time for Run # 6 (Disabled) for the TPS7H4002-SP at T = 25°C

8 Single-Event Transients (SET)

The SETs for the TPS7H4002-SP are defined here as heavy-ion-induced transient upsets on the SS, V_{OUT} , or the PWRGD flag of TPS7H4002-SP. SET testing was performed at room temperature (no external temperature control applied). The species used for the SET testing was Homium (^{165}Ho) ion with an angle-of-incidence of zero degrees for an LET_{EFF} = 75 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 10^7 ions/cm^2 were used for all SET runs.

V_{OUT} SETs were characterized using a window trigger of ±3% around the nominal output voltage (2.5 V). SS and PWRGD SETs were characterized using a negative edge trigger set at 1 V and VIN – 300 mV, respectively. The devices were characterized at P_{VIN} = V_{IN} of 5 V, while regulating to an output of 2.5 V. The output load was set to 3 A by using a chroma e-load on CR mode for all runs.

To capture the SETs, two NI-PXI-5172 and one NI-PXIe-5162 scope cards were used to continuously monitor the V_{OUT} , PWRGD, and SS (for more details refer to). Each scope's were operated independently from each other, capturing data when the trigger conditions set were satisfied.

The output voltage was monitored using the J9 cold nose probe on the EVM. For SS, the TP2 test point was used. Since a low pass filter was installed on PWRGD, the TP3 test point was used to monitor the signal after the filter. In order to monitor the PWRGD raw signal a cable was soldered directly to the pin by using the uninstalled D2 pad on the EVM.

The scope sample rate and record length for all the scopes is shown in Table 8-1 . All three scope were set to record 20% of the data pre-trigger. Under the test conditions shown on this report the TPS7H4002-SP *did not show* a single upset on the SS or the PWRGD (raw) signal. For the output voltage transients (V_{OUT}), only one upset ≥ |3%| at T = 25°C was observed (runs # 13-17), was observed. The summary for the SET test condition and results is shown on Table 8-2. Figure 8-1 shows the time domain plot for the only SET observed at T = 25 °C.

Table 8-1. Scope Data Capture Settings

SCOPE NAME	TRIGGER SIGNAL	RECORD LENGTH (kS)	SAMPLE RATE (MS/s)	TRIGGER VALUE
PXIe-5162	SS	2	20	0.6
PXIe-5172	V_{OUT}	25	10	± 3% from nominal (2.5 V)
PXIe-5172	PWRGD	5	10	VIN – 300 mV

Table 8-2. Summary of TPS7H4002-SP SET Test Condition and Results

NOTE: The LET_{EFF} for all runs was 75 MeV·cm^2/mg, achieved using ^{165}Ho heavy-ions at an angle of incidence of zero degrees.

RUN #	UNIT #	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	V_{IN} (V)	$VOUT_{SET}$ (#) ≥ |3%|	SS_{SET} ≤ 0.6V (#)	PWRDG SET ≤ 4.7-V
13	1	1.04 x 10^5	1 x 10^7	5	0	0	0
14	2	9.9 x 10^4	1 x 10^7	5	0	0	0
15	1	9.63 x 10^4	1 x 10^7	5	1	0	0
16	2	1.05 x 10^5	9.97 x 10^7	5	0	0	0
17	3	1.11 x 10^5	1 x 10^7	5	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 8-3.

Table 8-3. Upper Bound Cross Section for the SETs of the TPS7H4002-SP

NOTE: The upper bound cross section was calculated at 95% confidence interval, by adding all upsets and fluences for the given temperature condition.

SET TYPE	TEMPERATURE (°)	# OF UPSETS	TOTAL FLUENCE (# ions)	UPPER BOUND CROSS SECTION (cm^2/device)
$VOUT_{SET}$ ≥ |3%|	25	1	5×10^7	1.11×10^{-7}
SS_{SET}	25	0	1.7×10^8	2.17×10^{-8}
$PWRGD_{SET}$				

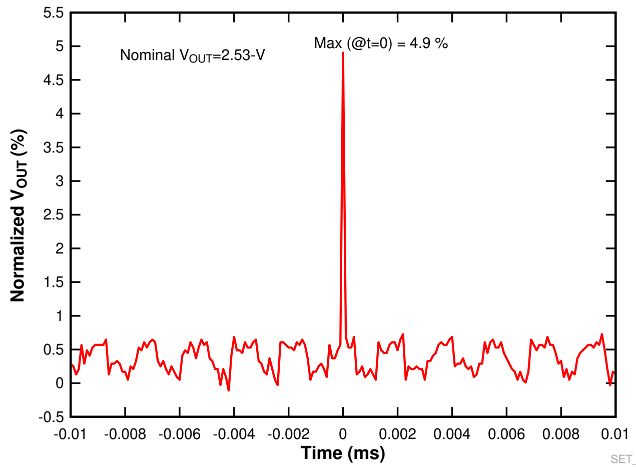

Figure 8-1. Only Observed SET ≥ 3% for Run # 15 at V_{IN} = P_{VIN} = 5 V, V_{OUT} = 2.5 V I_{LOAD} = 3 A and T = 25°C

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, SEB/SEGR, and the SETs the event rate calculation is shown inTable 9-1 to Table 9-2, respectively. *It is important to note that the numbers shown for the SEL and SEB/SEGR are for reference, since not a single DSEE was observed.*

Table 9-1. SEL Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	75	6.25×10^{-5}	9.24×10^{-8}	5.78×10^{-12}	2.41×10^{-4}	4.74×10^{8}
GEO		1.77×10^{-4}		1.64×10^{-11}	6.81×10^{-4}	1.68×10^{8}

Table 9-2. SEB/SEGR Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	75	6.25×10^{-5}	4.62×10^{-8}	2.89×10^{-12}	1.2×10^{-4}	9.49×10^{8}
GEO		1.77×10^{-4}		8.18×10^{-12}	3.41×10^{-4}	3.35×10^{8}

Table 9-3. PWRGD and SS 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)	75	6.25×10^{-5}	2.17×10^{-8}	1.36×10^{-12}	5.65×10^{-5}	2.02×10^{9}
GEO		1.77×10^{-4}		3.84×10^{-12}	1.6×10^{-4}	7.13×10^{8}

Table 9-4. V_{OUT} SET ≥ 3% at T = 25° C Event Rate Calculations for Worst-Week LEO and GEO Orbits

Based on the fact that the device show just one upset at 75 MeV·cm^2/mg, an educated guess of 70 MeV·cm^2/mg for the onset was used for the orbit rate calculation.

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)	70	8.62×10^{-5}	1.11×10^{-7}	9.57×10^{-12}	3.99×10^{-4}	2.86×10^{8}
GEO		2.45×10^{-4}		2.72×10^{-11}	1.13×10^{-3}	1.01×10^{8}

10 Summary

The purpose of this study was to characterize the effect of heavy-ion irradiation on the SEE performance of the TPS7H4002-SP synchronous step-down POL converter. Heavy-ions with LET_{EFF} = 75 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 TPS7H4002-SP POL is free of destructive SEB events and SEL up to LET_{EFF} = 75 MeV·cm^2/mg and across the full electrical specifications. SETs at room temperature were near-free by observing just one upset ≥ |3%| at T = 25°C. 154 V_{OUT} transients ≥ |3%| at T = 125°C were observed and described on the report for reference. CREME96-based worst-week event-rate calculations for LEO(ISS) and GEO orbits for the SEE are discussed for reference.

A Appendix A: Total Ionizing Dose from SEE Experiments

The production TPS7H4002-SP POL is rated to a total ionizing dose (TID) of 100 krad(Si). In the course of the SEE testing campaign, 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 47.6 krad(Si) to 108 krad(Si), per device. All three production TPS7H4002-SP 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 B: 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.