Radiation Report

Single-Event Effects (SEE) Radiation Report of the TPS7H4102-SEP

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TPS7H4102-SEP including a Safe-Operating-Area (SOA) design of experiments (DOE) for both the TPS7H4104-SP/SEP and TPS7H4102-SP/SEP. Heavy-ions with LET_{EFF} of 48 MeV·cm^2/mg were used to irradiate 4 devices. Flux of ≈10^5 ions/cm^2/s and fluence of ≈10^7 ions/cm^2 per run were used for the characterization. The results demonstrated that the TPS7H4102-SEP is SEL-free up to 48 MeV·cm^2/mg at T = 125°C and SEB/SEGR free up to 48 MeV·cm^2/mg at T = 25°C while operating within the SOA bias conditions. SET transients performance for output voltage excursions ≥ |3%| from the nominal voltage was monitored on all four outputs. Throughout all test runs, no transients were recorded on any of the device outputs, indicating the TPS7H4102-SEP is SET and SEFI free at 48 MeV·cm^2/mg.

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1 Introduction

The TPS7H4104 and TPS7H4102 are 7V, 3A per channel, multichannel, peak-current mode, synchronous buck converters optimized for use in area sensitive, space environment applications. The device incorporates four (TPS7H4104) or two (TPS7H4102) identical channels that can be use to step down the power input voltage into independent voltages up to 3A per phase or interleaved to increment the output current up to 12A (TPS7H4104) or 6A (TPS7H4102).

Each channel incorporates:

- High and low side power MOSFETs with programmable soft-start and slope compensation
- Power-good flags and enable signaling

The device also offers:

- An EN_SEQ input to create a sequential power up and reverse sequence power down
- Current limit mechanisms for robust current limiting during fault conditions
- Thermal shutdown to disable the device if the die temperature exceeds the thermal limit

The device is offered in a 64-pin plastic package. General device information and test conditions are listed in the overview information table. For more detailed technical specifications, user-guides, and application notes please go to device product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H4102-SEP
Orderable Part Number	TPS7H4102MPAPTSEP
Device Function	Multichannel Synchronous Buck Converter
Technology	LBC7 (Linear BiCMOS 7)
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/nucleon) and Facility for Rare Isotope Beams, K500 Cyclotron (KSEE), Michigan State University (19.5 MeV/nucleon)
Heavy Ion Fluence per Run	1.00×10^7 ions/cm^2
Irradiation Temperature	25°C (for SEB/SEGR testing and SET testing), and 125°C (for SEL testing)

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2 Single-Event Effects (SEE)

The primary concern for the TPS7H4102-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 TPS7H4102-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 TPS7H4102-SEP was tested for SEL at the maximum recommended operating conditions based on a SOA (safe operating area) design of experiments (DOE) of V_{IN} of 6.5V and 3A/channel in the "high current case" and a V_{IN} of 7V and 1.5A/channel in the "high voltage case". Output conditions were tested in two different configurations, either with each channel configured to output 1.2V or each channel configured to output 1.8V. During testing of the 4 devices, the TPS7H4102-SEP did not exhibit any SEL with heavy-ions with LET_{EFF} = 48 MeV·cm^2/mg at flux ≈10^5 ions/cm^2/s, fluence of ≈10^7 ions/cm^2, and a die temperature of 125°C while maintaining operating conditions within the SOA. The full SOA consisting of both TPS7H4104 and TPS7H4102 across multiple LET_{EFF} is presented in Section 7.1.

The TPS7H4102-SEP was evaluated for SEB/SEGR at the maximum recommended input conditions based on the SOA in the enabled and disabled mode. Because it has been shown that the MOSFET susceptibility to burnout decrement with temperature [5], the device was evaluated while operating under room temperatures. The device was tested with no external thermal control device. During the SEB/SEGR testing, not a single current event was observed demonstrating that the TPS7H4102-SEP is SEB/SEGR-free up to LET_{EFF} = 48 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 while maintaining operating conditions within the SOA. The full SOA consisting of both TPS7H4104 and TPS7H4102 across multiple LET_{EFF} is presented in Section 7.1.

The TPS7H4102-SEP 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 V_{IN} of 3.3V for the V_{OUT} case of 1.2V and V_{IN} of 5V for the V_{OUT} case of 1.8V. During all runs each channel was loaded to 3A. Heavy-ions with LET_{EFF} of 48 MeV·cm^2/mg were used to characterize the transient performance. During all testing, there were no transients recorded on any of the outputs with the trigger window set to > |3%|. For futher detail, please refer to Section 8.

3 Device and Test Board Information

The TPS7H4102-SEP is packaged in a 64-pin plastic package as shown in Figure 3-1. The TPS7H4102EVM was used to evaluate the performance and characteristics of the TPS7H4102-SEP under heavy ion radiation. The TPS7H4102EVM is shown in Figure 3-2. The schematic is shown in Figure 3-3. For further detail please reference the TPS7H4102EVM User's Guide.

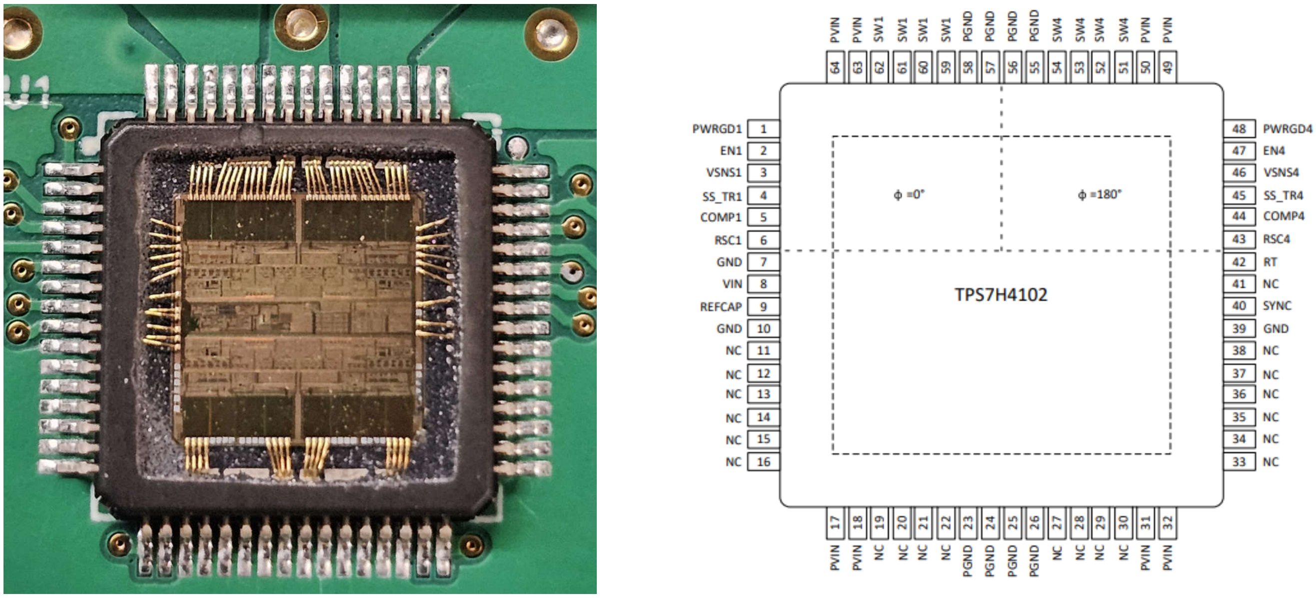

Figure 3-1. Photograph of Delidded TPS7H4102-SEP [Left] and Pinout Diagram [Right]

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

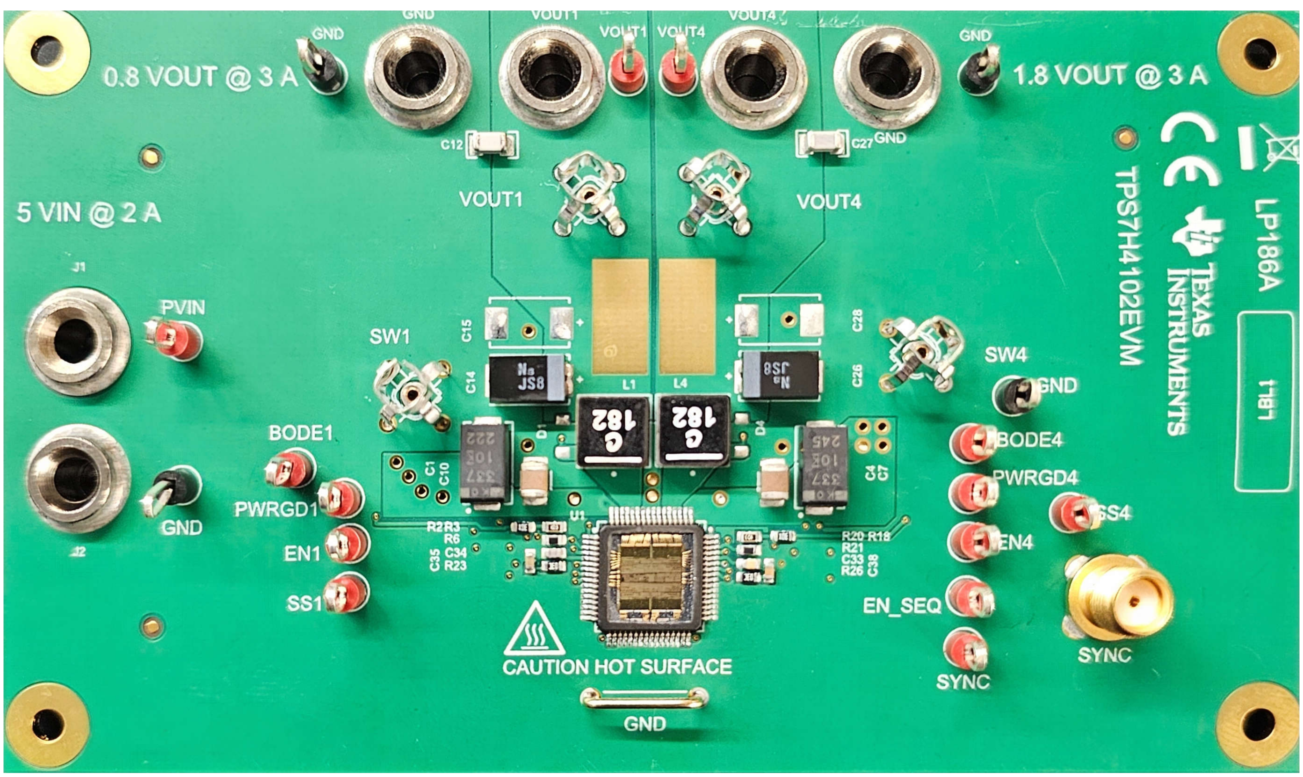

Figure 3-2. TPS7H4102-SEP EVM Top View

Note for the V_{OUT}=1.2V case both outputs were configured similar to VOUT1 and for the V_{OUT}=1.8V case both outputs were configured similar to VOUT4. Please refer to Table 6-2 for a breakdown of component values.

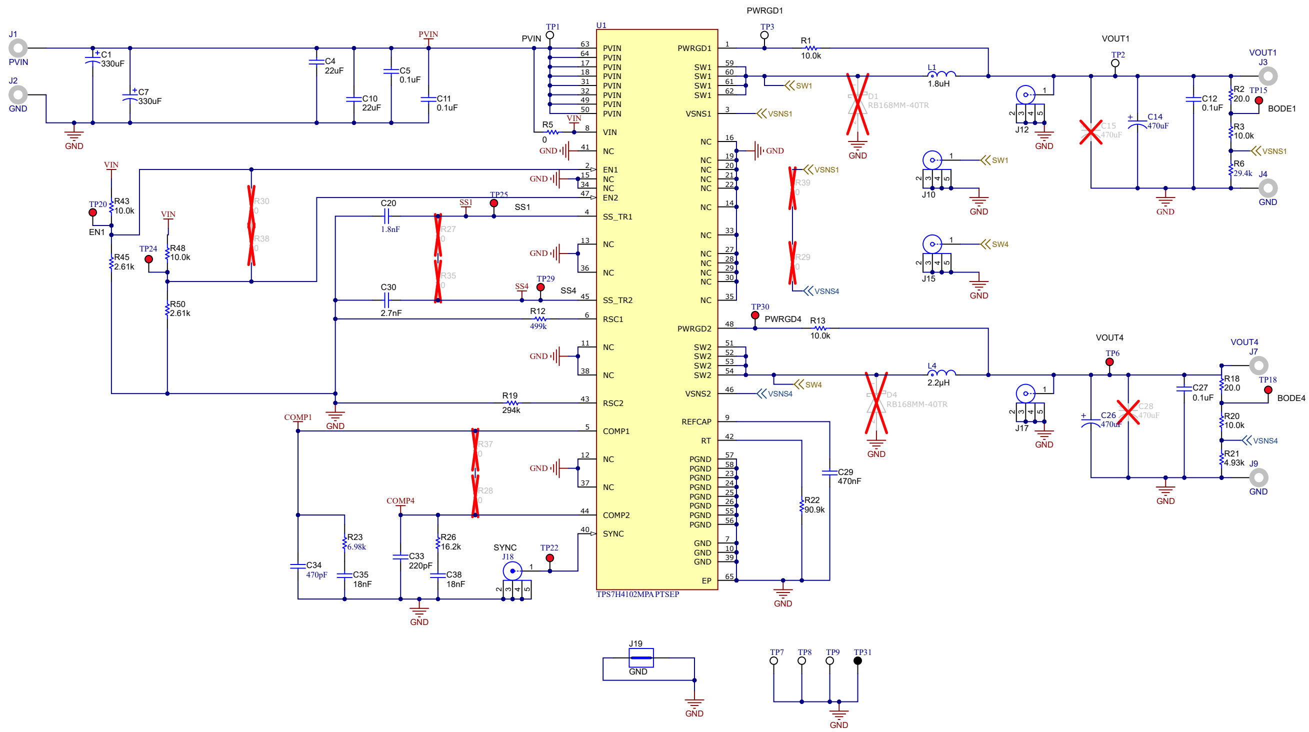

Figure 3-3. TPS7H4102-SEP EVM Schematics

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by:

- Texas A&M University (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 1.10 to 1.22 x 10^5 ions/cm^2/s was used to provide heavy-ion fluences of 1.00 x 10^7 ions/cm^2. The TAMU facility uses a beam port that has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.
- Michigan State University (MSU) Facility for Rare Isotope Beams (FRIB) using a K500 superconducting cyclotron (KSEE) and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity as the beam is collimated to a maximum of 40mm × 40mm square cross-sectional area for the in-air and vacuum scintillators. Uniformity is achieved by scattering on a Cu foil and then performing magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of ≈10^5 ions/cm^2/s was used to provide heavy-ion fluences of 1.00 × 10^7 ions/cm^2. The KSEE facility uses a beam port that has a 3-mil polyethylene naphthalate (PEN) window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 50mm for all runs. The KSEE facility was used to collect partial data for the SOA.

For the experiments conducted on this report, including the SOA, there were 3 ions used, ^{109}Ag,^{165}Ho, and ^{169}Tm. ^{109}Ag was used to obtain LET_{EFF} of 48 MeV·cm^2/mg. ^{165}Ho and ^{169}Tm were used to obtain LET_{EFF} of 75 MeV·cm^2/mg, depending on the test facility. The total kinetic energies for each of the ions were:

- ^{109}Ag (TAMU) = 1.634GeV (15 MeV/nucleon)
  - Ion uniformity for these experiments was ≈91%
- ^{109}Ag (MSU) = 2.125GeV (19.5 MeV/nucleon)
  - Ion uniformity for these experiments was ≈91%
- ^{165}Ho (TAMU) = 2.474GeV (15 MeV/nucleon)
  - Ion uniformity for these experiments was ≈90%
- ^{169}Tm (MSU) = 3.295GeV (19.5 MeV/nucleon)
  - Ion uniformity for these experiments was ≈90.5%

Figure 4-1 shows the TPS7H4102EVM used for the data collection at the TAMU cyclotron facility.

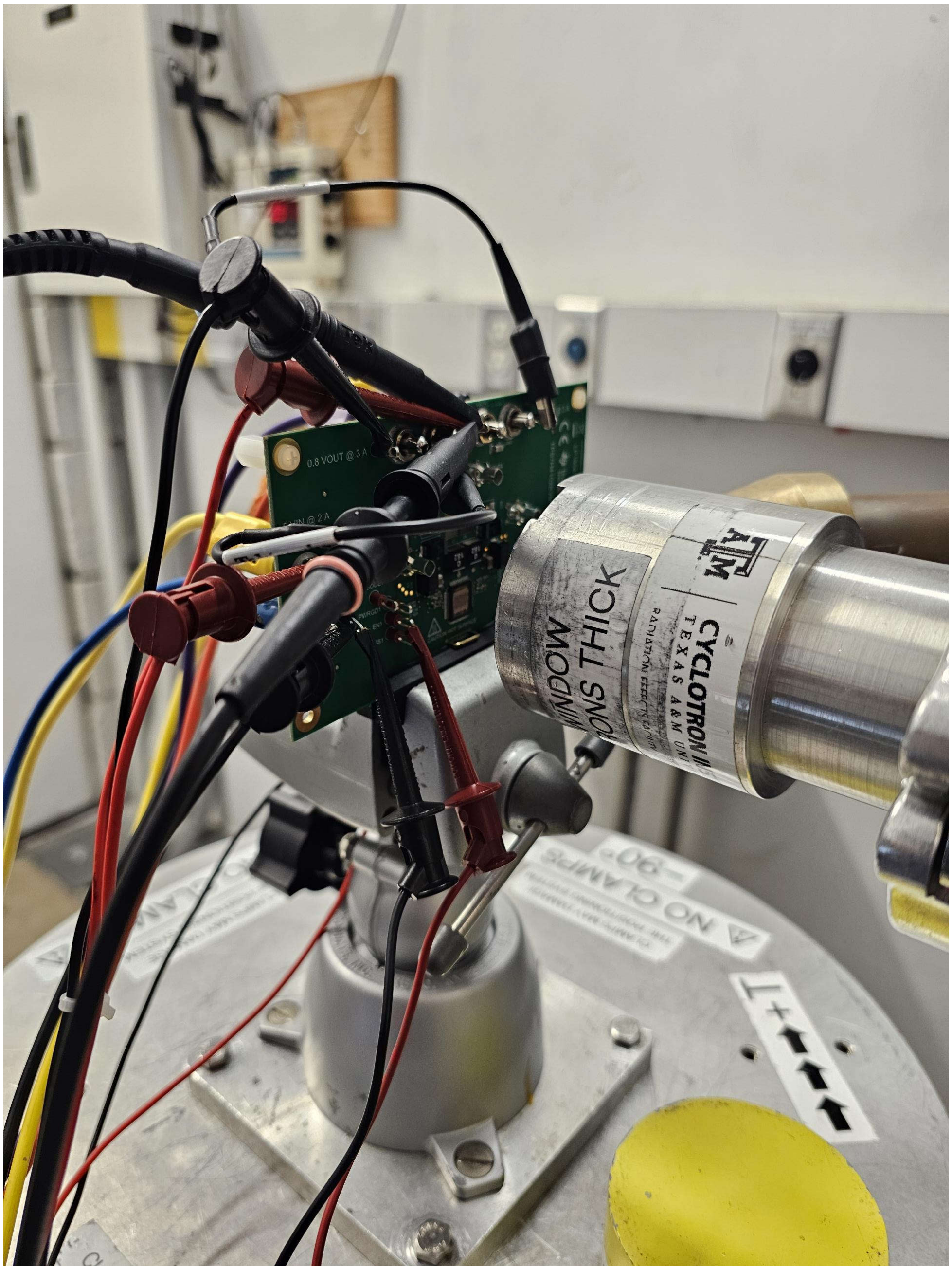

Figure 4-1. Photograph of the TPS7H4102-SEP EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 LET_{EFF} and Range Calculation

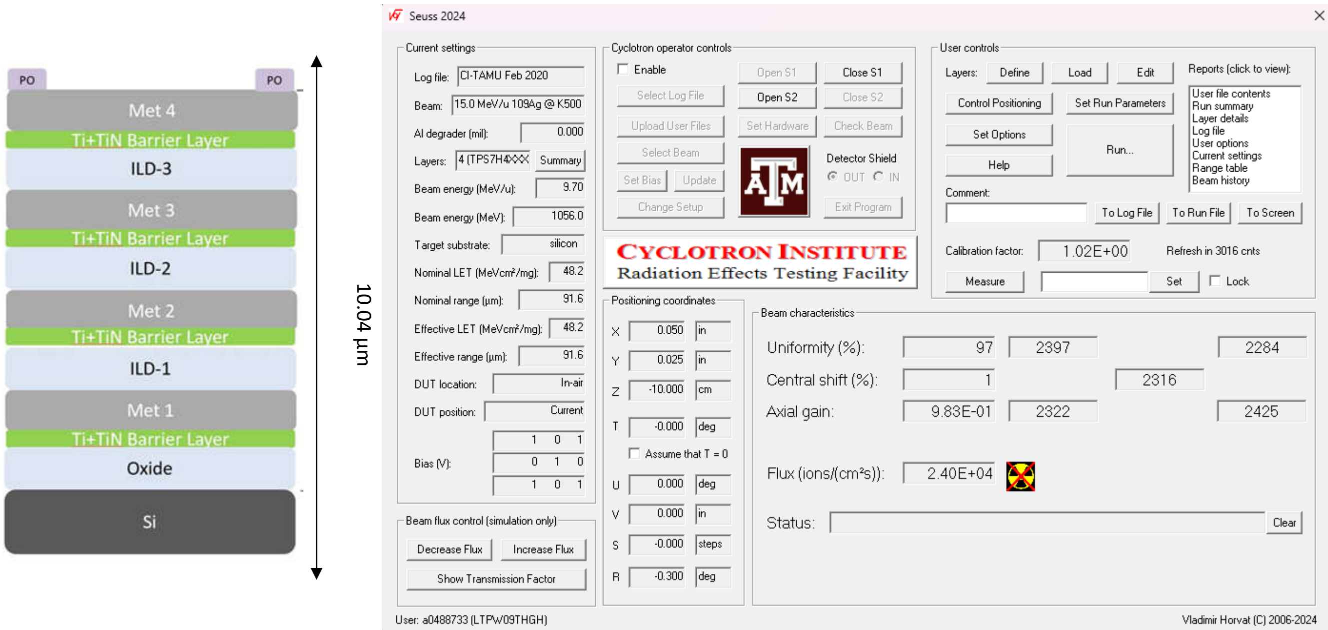

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H4102-SEP [Left] and SEUSS 2024 Application Used to Determine Key Ion Parameters [Right]

The TPS7H4102-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 10.04μm based on nominal layer thickness as shown in Figure 5-1. Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the TPS7H4102-SEP, the effective LET (LET_{EFF}) at the surface of the silicon substrate and the range was determined with:

- SEUSS 2024 software (provided by TAMU and based on the latest SRIM-2013 [7] models).
- MSU Stack-Up Calculator (provided by MSU FRIB and based on latest SRIM-2013 [7] models).

The results are shown in Table 5-1.

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

Facility	ION TYPE	Beam Energy (MeV/nucleon)	ANGLE OF INCIDENCE	DEGRADER STEPS (#)	DEGRADER ANGLE	Copper Foil Width (µm)	Beam Port Window	RANGE IN SILICON (µm)	LET_{EFF} (MeV·cm^2/mg)
TAMU	^{109}Ag	15	0	0	0	-	1-mil Aramica	95.1	48
TAMU	^{165}Ho	15	0	0	0	-	1-mil Aramica	93.9	75
KSEE	^{109}Ag	19.5	0	0	0	5	3-mil PEN	89.3	48
KSEE	^{169}Tm	19.5	0	0	0	5	3-mil PEN	90	75

6 Test Setup and Procedures

There were three input supplies used to power the TPS7H4102-SEP which provided V_{IN} and EN for each channel. The V_{IN} for the device was provided via Ch. 3 of an N6705C power module and ranged from 3.3 to 5V for SET and 6.5 to 7V for SEL and SEB/SEGR. Each channel's EN was provided from channels 1 and 2 of an E36311A power supply and were forced to either 0V for SEB Off or 5V for SET and other DSEE testing.

The primary signal monitored on the EVM was the V_{OUT} of each channel and this was done using two distinct NI PXIe-5172 scope cards which were set to trigger on a 3% window based on the nominal value of the channel's V_{OUT}. All SEB On, SEL, and SET testing used these conditions with only the SEB Off testing having different conditions. The conditions for SEB Off were a positive edge trigger at 0.5V which would check to see if the device ever incorrectly turned on while it was disabled.

To load each channel of the device either a Chroma 63600 E-load was attached to a channel in Constant Resistance (CR) mode in order to achieve either a 1.5A or 3A load.

All equipment was controlled and monitored using a custom-developed LabVIEW™ program (PXI-RadTest) running on a HP-Z4 desktop computer. The computer communicates with the PXI chassis via an MXI controller and NI PXIe-8381 remote control module.

Table 6-1 shows the connections, limits, and compliance values used during the testing. Figure 6-1 shows a block diagram of the setup used for SEE testing of the TPS7H4102-SEP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the TPS7H4102-SEP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{IN}	N6705C(CH # 3)	60V, 17A	5A	3.3 to 7V
EN_X	E36311A (CH # 1/2)	5V,5A	0.1A	0V, 5V
V_{OUTX}	PXIe-5172 (1-2)	100 MS/s	—	100 MS/s
V_{OUTX}	Chroma 63600 E-load	80A	Medium	0.4Ω to 1.2Ω

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to maintain that the test system was stable under all bias and load conditions prior to being taken to the radiation test facilities. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H4102-SEP device and set the sourcing and monitoring functions of the external equipment. After functionality and stability was confirmed, the beam shutter was opened to expose the device to the heavy-ion beam. The shutter remained open until the target fluence was achieved (determined by external detectors and counters). During irradiation, the NI scope cards continuously monitored the signals. When the output exceeded the pre-defined 3% window trigger, a data capture was initiated. No sudden increases in current were observed (outside of normal fluctuations) on any of the test runs and indicated that no SEL or SEB/SEGR events occurred during any of the tests when operating within the SOA.

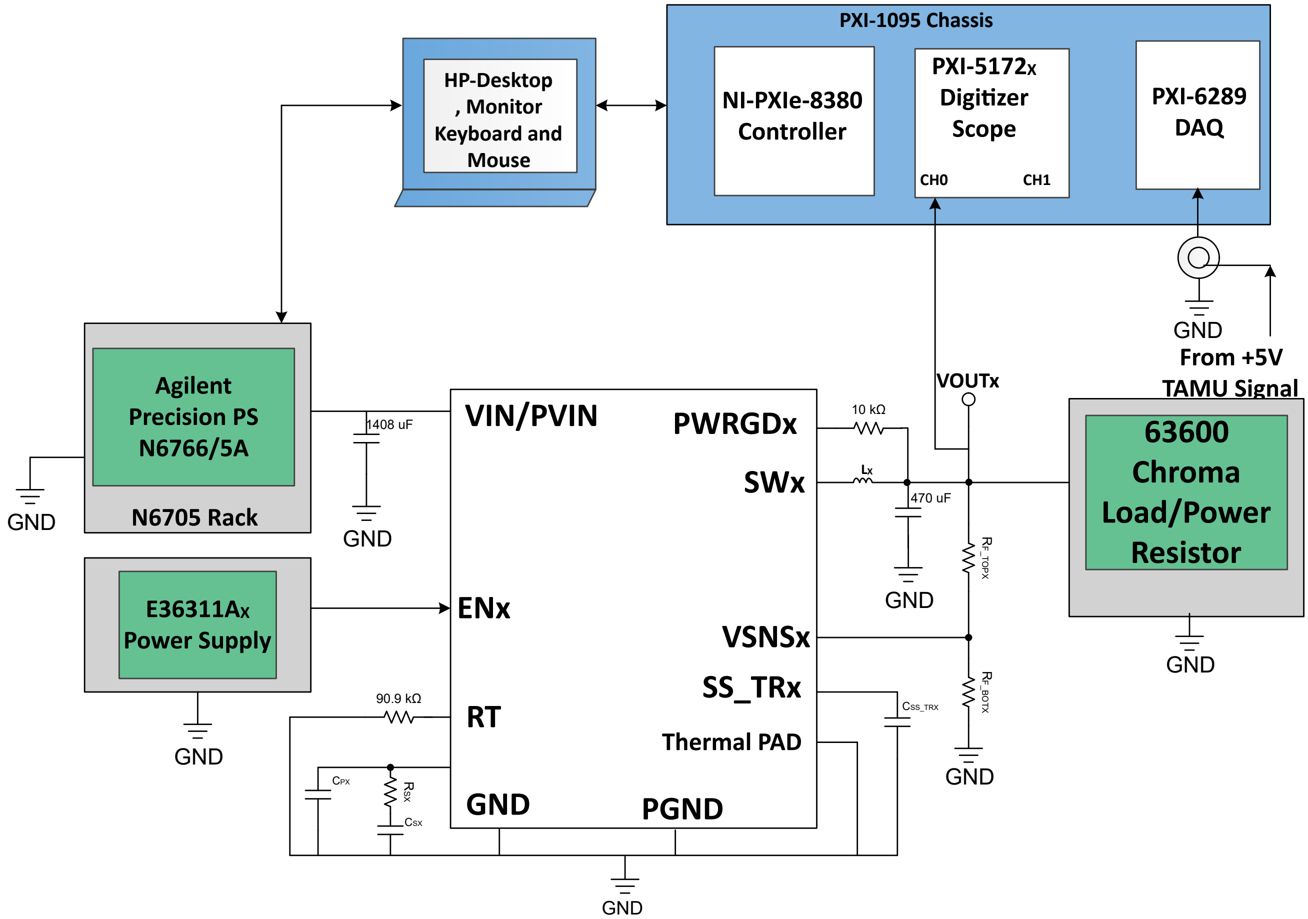

Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H4102-SEP

Table 6-2. Comp Network and Output Component Values

V_{OUT} (V)	L_X (H)	R_{F_TOPX} (Ω)	R_{F_BOTX} (Ω)	C_{PX} (F)	R_{SX} (Ω)	C_{SX} (F)	C_{SS_TRX} (F)
1.2	1.8µ	10k	9.88k	330p	10.5k	18n	1.8n
1.8	2.2µ	10k	4.93k	220p	16.2k	18n	2.7n

7 Destructive Single-Event Effects (DSEE)

7.1 Safe Operating Area (SOA) Results

Many TPS7H410x-SP/SEP devices were characterized across voltage, load current, and LET_{EFF} by sweeping bias conditions up to the maximum recommended operating conditions. The purpose of this design of experiments (DOE) was to determine the bias conditions for the TPS7H410x-SP/SEP that fall within a safe operating area (SOA) where the device no longer experiences any destructive single-event effects (DSEE). The observed DSEE effect was a current latch which caused excess leakage on the input. Over the course of all SOA testing, the current latch ranged from 5mA of leakage up to 150mA of leakage. An example of a DSEE failure is shown in the SOA current plot below. In the case where the current latch occurred, the devices continued to operate normally aside from the incremented leakage current. Because the leakage current remained even after power cycling, this latch is considered a DSEE event. During the testing, only one variable was swept at a time while the other remained constant at the maximum recommended operating value. When collecting data for the DSEE SOA of the TPS7H410x-SP/SEP, it was observed that the probability of damaging a device was independent of temperature and output voltage, so data collection was conducted across both SEL and SEB testing at both VOUT = 1.2V and VOUT = 1.8V. Additionally, it was determined the SOA was similar for the TPS7H410x-SP at 75 MeV·cm^2/mg as the TPS7H410x-SEP at 48 MeV·cm^2/mg; therefore, the SOA results presented below include data from the TPS7H410x-SP and TPS7H410x-SEP.

Note that the DSEE results discussed in Section 7.2 and Section 7.3 were based on the findings of this SOA. The bias conditions these units were tested under were the maximum corners found by sweeping V_{IN} and I_{OUT}. The units tested inSection 7.2 and Section 7.3 were not included in the SOA tables below.

Table 7-1. Maximum Recommended Operating Conditions of the TPS7H4102-SEP

Variable Name	Maximum Value	Units
$P_{VIN} = V_{IN}$	7	V
Load current ($I_{LOAD/Channel}$)	3	A
LET_{EFF}	48	MeV·cm^2/mg

For LET_{EFF} ≤ 75 MeV·cm^2/mg and load current of 3A, the maximum permissible input voltage to avoid DSEE is 6.5V. Maximum input voltage of 7V can be achieved at LET ≤ 75MeV·cm^2/mg when the load current is decremented to ≤ 1.5A. A visual representation of the SOA curve can be observed in Figure 7-2. The green area encompasses the points where the TPS7H410x-SP/SEP can be operated at LET ≤ 75MeV·cm^2/mg, with no damaged units observed. The yellow area represents where the TPS7H410X-SP/SEP is marginal and over the course of all testing only one unit had observable DSEE damage. The red area represents the points where DSEE was observed on multiple units and should be avoided to reliably use TPS7H410X-SP/SEP.

DSEE failures were observed under the red area. The cross-section for these event is extremely small (1.94×10^{-8} to 3.69×10^{-7}).. During the SEE test campaign of the TPS7H410x-SP/SEP, 31 units were damaged from a total of 54 units tested. Table 7-2 shows the SOA results for the case where I_{OUT} was held at 3A and the V_{IN} was swept up. In the cases where V_{IN} was started <7V, V_{IN} was swept up by 100mV each run until either failing due to a DSEE event or because the unit reached the max recommended V_{IN} of 7V. Table 7-3 shows the SOA results for the case where V_{IN} was held at 7V and I_{OUT} was swept up. For each unit, the I_{OUT} was swept up by 500mA per run until the device had a DSEE event. Table 7-4 shows the calculated upper-bound cross section when combining the fluences for all runs with same load, voltage, and LET_{EFF}. The cross section values shown on the table calculated are calculated at 95% confidence interval (refer to SLVK047 for more details in the method used to calculate the upper bound cross section). Table 7-5 shows the passing bias conditions based on the SOA. As seen in Figure 7-2, the corners for the "green" condition are V_{IN} < 6.6V with an $I_{OUT/Channel}$ = 3A and V_{IN} = 7V with an $I_{OUT/Channel}$ < 2A, which is what the DSEE testing and results are based on in the respective SEL and SEB sections.

Table 7-2. SOA results with $I_{OUT/Channel}$ = 3A

Unit #	Test Type	Starting V_{IN} (V)	Max Passing V_{IN} (V)	Failing V_{IN} (V)	V_{OUT} (V)
7	All	7	7	—	1.2
8	SEB	7	—	7	1.8
9	SEB	7	7	—	1.8
10	SEB	7	—	7	1.2
11	SEB	7	7	—	1.2
12	SEL	6.3	6.8	6.9	1.2
14	SEB	6.7	—	7	1.8
15	ALL	6.5	7	—	1.2
16	SEB	7	—	7	1.2
18	All	6.5	6.6	6.7	1.8
19	SEB	7	—	7	1.8
20	All	6.3	7	—	1.8
21	All	6.3	6.8	6.9	1.2
22	All	6.3	6.8	6.9	1.2
26	All	6.3	6.9	7	1.8
27	All	6.3	6.8	6.9	1.2
28	All	6.3	6.9	7	1.2
32	All	7	7	—	1.2
33	All	7	7	—	1.8
34	All	7	7	—	1.8
35	All	7	7	—	1.8
36	All	7	7	—	1.2
37	All	7	7	—	1.8
38	All	7	7	—	1.8
39	All	7	7	—	1.2
40	All	7	7	—	1.8
41	All	7	7	—	1.2
42	All	7	7	—	1.8
43	All	7	7	—	1.2
44	SEB	7	7	—	1.8
45	SEB	7	—	7	1.8
46	SEB	7	—	7	1.2
47	SEB	7	—	7	1.8
48	SEB	7	—	7	1.2
49	SEB	7	—	7	1.8
50	SEB	7	—	7	1.2
51	SEB	7	—	7	1.8
52	SEB	7	—	7	1.2
53	SEB	7	—	7	1.8
54	SEB	6.6	—	6.6	1.8
56	All	6.3	6.6	—	1.2

Table 7-2. SOA results with $I_{OUT/Channel}$ = 3A (continued)

Unit #	Test Type	Starting V_{IN} (V)	Max Passing V_{IN} (V)	Failing V_{IN} (V)	V_{OUT} (V)
58	All	7	7	—	1.8
59	SEB	7	—	7	1.2
60	All	6.5	6.5	—	1.2

Table 7-3. SOA Results with V_{IN} = 7V

Unit #	Test Type	Starting $I_{OUT/Channel}$ (A)	Max Passing $I_{OUT/Channel}$ (A)	Failing $I_{OUT/Channel}$ (A)	VOUT (V)
13	SEL	0.5	2.25	2..5	1.8
17	SEB	2.25	2.25	—	1.8
17	SEL	2.25	—	2.25	1.8
18	All	2.25	2.25	—	1.8
23	All	1.5	2.5	3	1.2
24	All	1.5	2	2.5	1.8
25	All	1.5	2.5	3	1.8
29	All	1.5	2.5	2.75	1.2
30	All	1.5	2.75	3	1.8
31	All	1.5	1.5	2	1.8
55	All	1.5	1.5	—	1.2
57	All	1.5	1.5	—	1.8
60	All	1.5	1.5	—	1.2

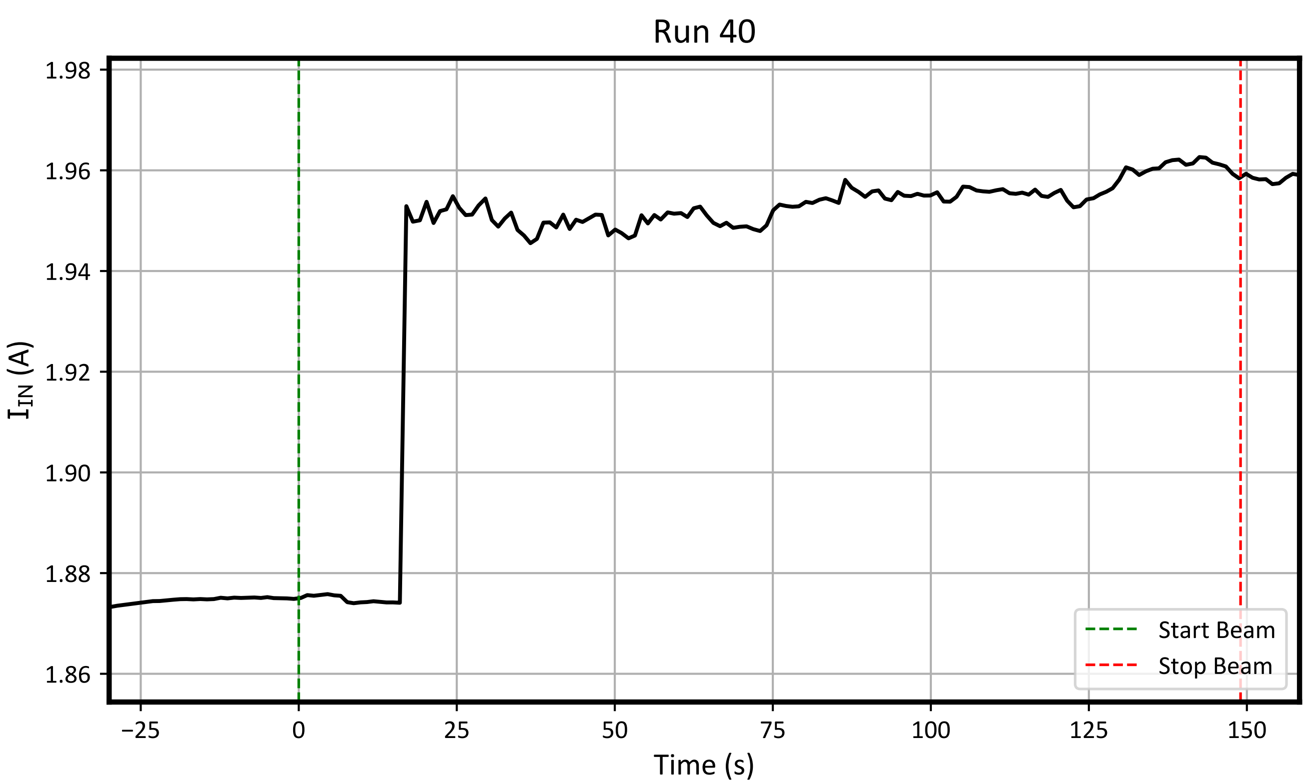

Figure 7-1. Current versus Time for Run #40 of the TPS7H410x SOA Showing DSEE Fail

Table 7-4. DSEE Cross-Section Table

VIN (V)	IOUT/ch (A)	Units Damaged (#)	Total Runs (#)	Upper Bound Cross Section (cm^2/device)
6.3	3	0	15	2.46×10^{-8}
6.4	3	0	7	5.27×10^{-8}
6.5	3	0	15	2.46×10^{-8}
6.6	3	1	13	4.29×10^{-8}
6.7	3	2	11	6.57×10^{-8}
6.8	3	0	9	4.10×10^{-8}
6.9	3	4	9	1.14×10^{-7}
7	3	20	57	5.42×10^{-8}
7	2.75	1	2	2.79×10^{-7}
7	2.5	2	7	1.03×10^{-7}
7	2.25	0	6	6.15×10^{-8}
7	2	1	7	7.96×10^{-8}
7	1.5	0	19	1.94×10^{-8}
7	1	0	1	3.69×10^{-7}
7	0.5	0	1	3.69×10^{-7}

Table 7-5. Passing SOA Bias Conditions

	Passing SOA Bias Conditions	
	IOUT/Channel = 3A	VIN = 7V
Green	VIN < 6.6V	IOUT < 2A
Yellow	6.6V ≤ VIN < 6.7V	2A ≤ IOUT < 2.5A
Red	VIN ≥ 6.7V	IOUT ≥ 2.5A

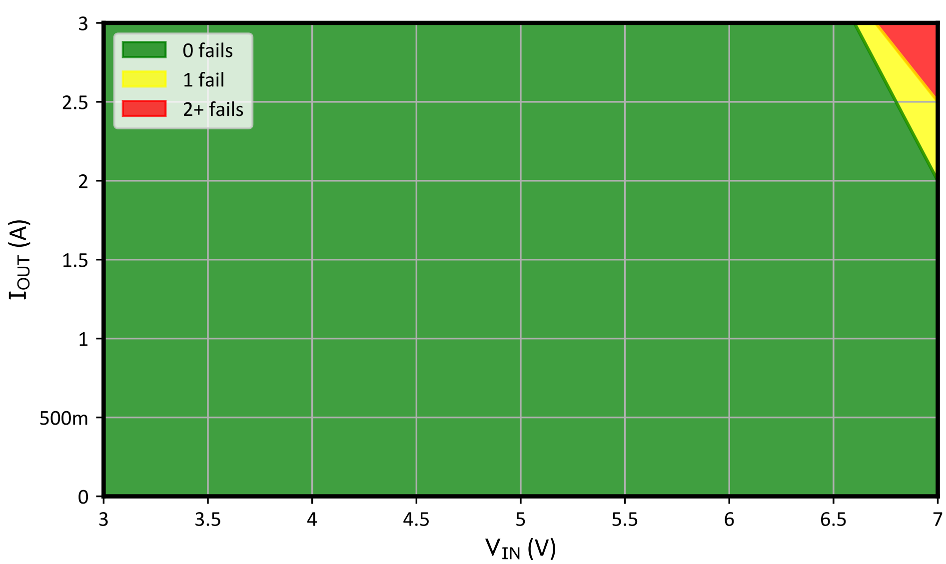

Figure 7-2. SOA Curve for the TPS7H410X-SP/SEP

7.2 Single-Event Latch-up (SEL) Results

During the SEL testing the device was heated to 125°C using a PID controlled heat gun (MISTRAL 6 System (120V, 2400W)). The temperature of the die was constantly monitored during testing at TAMU through an IR camera integrated into the control loop to create closed-loop temperature control. The die temperature was verified using a standalone FLIR thermal camera prior to exposure to heavy ions at KSEE.

The species used for the SEL testing was ^{109}Ag (TAMU) at 15 MeV/nucleon and ^{109}Ag (KSEE) at 19.5 MeV/nucleon. For both ions an angle of incidence of 0° was used to achieve a LET_{EFF} of ≈ 48MeV·cm^2/mg (for more details refer to Table 5-1). The kinetic energy in the vacuum for ^{109}Ag (TAMU) is 1.635 GeV and ^{109}Ag (KSEE) is 2.125GeV. Flux of ≈ 10^5 ions/cm^2/s and a fluence of ≈10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was ≈2 minutes. The 4 devices were powered up for SEL at the maximum recommended operating conditions based on the SOA, which are a V_{IN} of 6.5V and 3A/channel in the "high current case" and a V_{IN} of 7V and 1.5A/channel in the "high voltage case". Output conditions were tested in two different configurations, either with each channel configured to output 1.2V or each channel configured to output 1.8V. During testing of the 4 devices, the TPS7H4102-SEP did not exhibit any SEL with heavy-ions with LET_{EFF} = 48 MeV·cm^2/mg at flux ≈10^5 ions/cm^2/s, fluence of ≈10^7 ions/cm^2, and a die temperature of 125°C, while maintaining operating conditions within the SOA. Table 7-6 shows the SEL test conditions and results. Figure 7-3 shows a plot of the current vs time for run #1.

Table 7-6. Summary of TPS7H4102-SEP SEL Test Condition and Results

Run #	Unit #	Facility	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions/cm^2/s)	Fluence (ions/cm^2)	V_{IN} (V)	V_{OUT} (V)	$I_{OUT/Channel}$ (A)	SEL (# Events)
1	1	TAMU	^{109}Ag	48	1.14×10^5	1.00×10^7	6.5	1.8	3	0
2	2	TAMU	^{109}Ag	48	1.10×10^5	1.00×10^7	6.5	1.2	3	0
3	3	TAMU	^{109}Ag	48	1.17×10^5	1.00×10^7	7	1.8	1.5	0
4	4	TAMU	^{109}Ag	48	1.14×10^5	1.00×10^7	7	1.2	1.5	0

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

$\sigma_{SEL} \leq 9.22 \times 10^{-8}$ cm^2/device for LET_{EFF} = 48 MeV·cm^2/mg and T = 125°C.

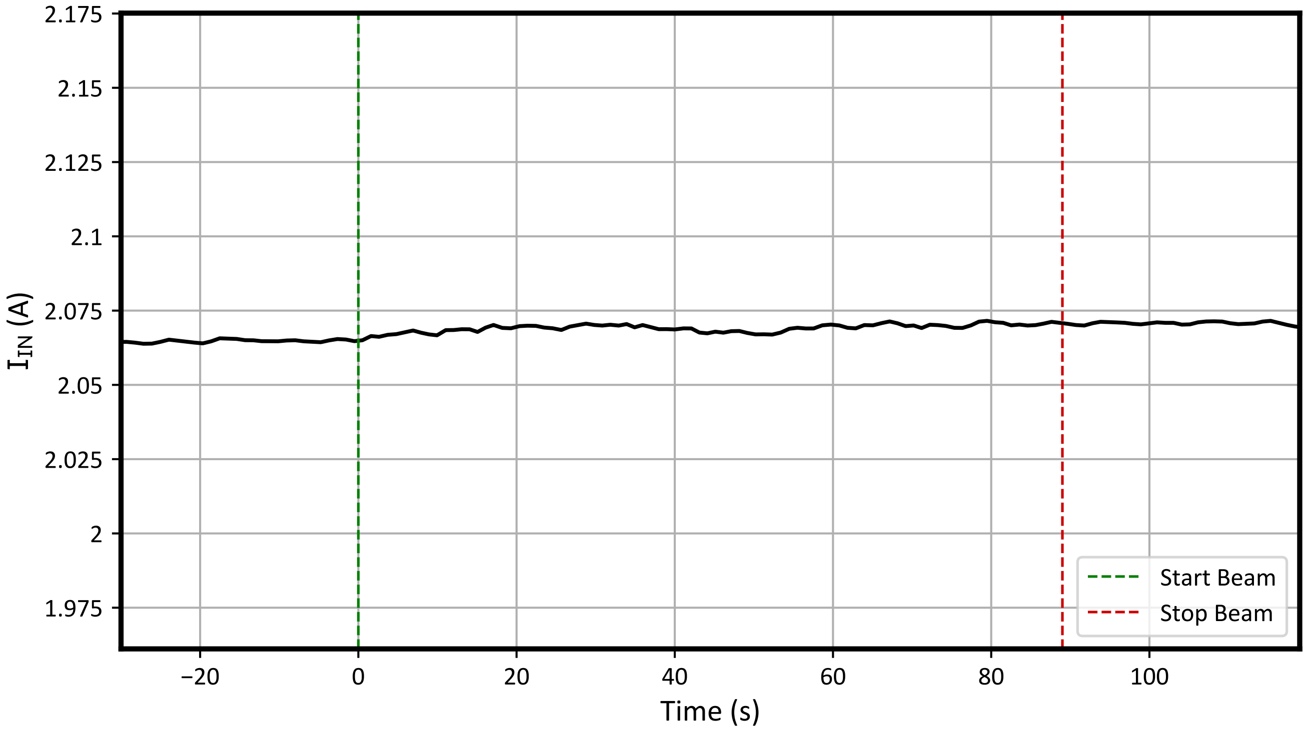

Figure 7-3. Current vs Time for Run #1 of the TPS7H4102-SEP at T = 125°C (V_{IN} = 6.5V, V_{OUT} = 1.8V, I_{OUT} = 3A/ch)

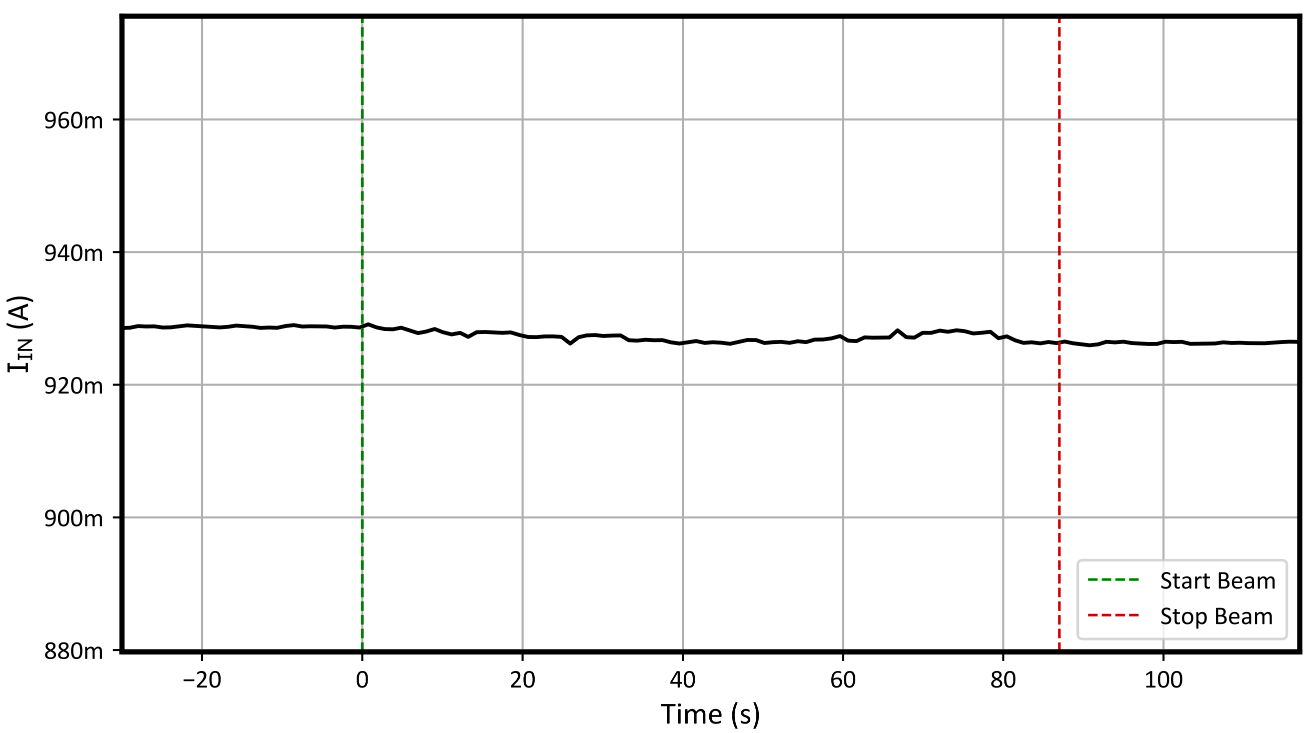

Figure 7-4. Current vs Time for Run #3 of the TPS7H4102-SEP at T = 125°C (V_{IN} = 7V, V_{OUT} = 1.8V, I_{OUT} = 1.5A/ch)

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

During the SEB/SEGR characterization, the device was tested at room temperature of approximately 25°C. The device was tested under both the enabled and disabled mode. For the SEB-OFF mode the device was disabled using each channel's EN-pin by forcing 0V (using CH # 1/3 of a E36311A Keysight PS).

The species used for the SEB testing was ^{109}Ag (TAMU) at 15 MeV/nucleon and ^{109}Ag (KSEE) at 19.5 MeV/nucleon. For both ions an angle of incidence of 0° was used to achieve a LET_{EFF} of ≈ 48MeV·cm^2/mg (for more details refer to Table 5-1). The kinetic energy in the vacuum for ^{109}Ag (TAMU) is 1.635 GeV and ^{109}Ag (KSEE) is 2.125GeV. Flux of ≈10^5 ions/cm^2/s and a fluence of ≈10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was ≈2 minutes. The 4 devices were powered up for SEL at the maximum recommended operating conditions based on the SOA, which are a V_{IN} of 6.5V and 3A/channel in the "high current case" and a V_{IN} of 7V and 1.5A/channel in the "high voltage case". Output conditions were tested in two different configurations, either with each channel configured to output 1.2V or each channel configured to output 1.8V. During testing of the 4 devices, the TPS7H4102-SEP did not exhibit any SEB with heavy-ions with LET_{EFF} = 48 MeV·cm^2/mg at flux ≈10^5 ions/cm^2/s , fluence of ≈10^7 ions/cm^2, and a die temperature of 25°C while maintaining operating conditions within the SOA. Table 7-7shows the SEB/SEGR test conditions and results.

Table 7-7. Summary of TPS7H4102-SEP SEB/SEGR Test Condition and Results

RUN #	UNIT #	Facility	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/cm^2/s)	FLUENCE (ions/cm^2)	ENABLED STATUS	V_{IN} (V)	V_{OUT} (V)	$I_{OUT/Channel}$ (A)	SEB EVENT?
5	1	TAMU	^{109}Ag	48	1.15×10^5	1.00×10^7	EN	6.5	1.8	3	No
6	1	TAMU	^{109}Ag	48	1.17×10^5	1.00×10^7	DIS	7	0	0	No
7	2	TAMU	^{109}Ag	48	1.17×10^5	1.00×10^7	EN	6.5	1.2	3	No
8	2	TAMU	^{109}Ag	48	1.13×10^5	1.00×10^7	DIS	7	0	0	No
9	3	TAMU	^{109}Ag	48	1.19×10^5	1.00×10^7	EN	7	1.8	1.5	No
10	3	TAMU	^{109}Ag	48	1.18×10^5	1.00×10^7	DIS	7	0	0	No
11	4	TAMU	^{109}Ag	48	1.22×10^5	1.00×10^7	EN	7	1.2	1.5	No
12	4	TAMU	^{109}Ag	48	1.16×10^5	1.00×10^7	DIS	7	0	0	No

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

$\sigma_{SEB} \leq 4.61 \times 10^{-8}$ cm^2/device for LET_{EFF} = 48 MeV·cm^2/mg and T = 25°C.

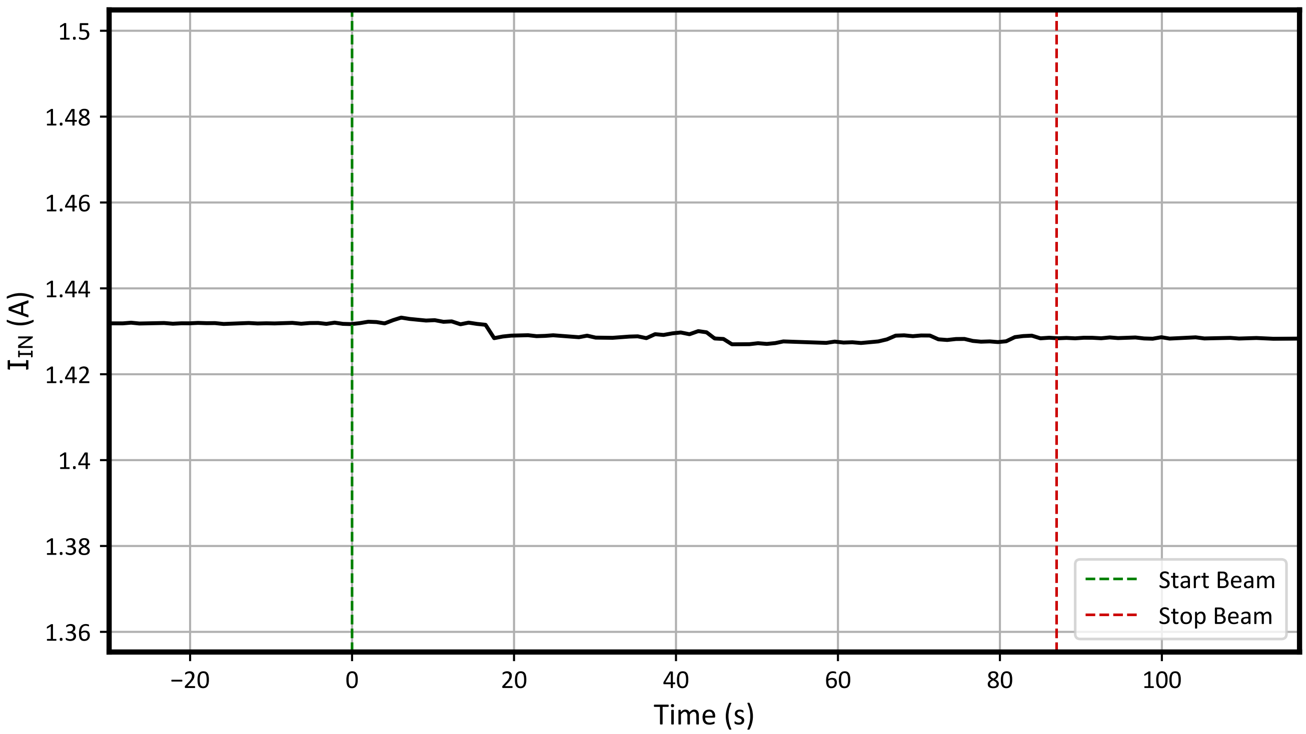

Figure 7-5. SEB On Run #7 (V_{IN} = 6.5V, V_{OUT} = 1.2V, I_{OUT} = 3A/ch)

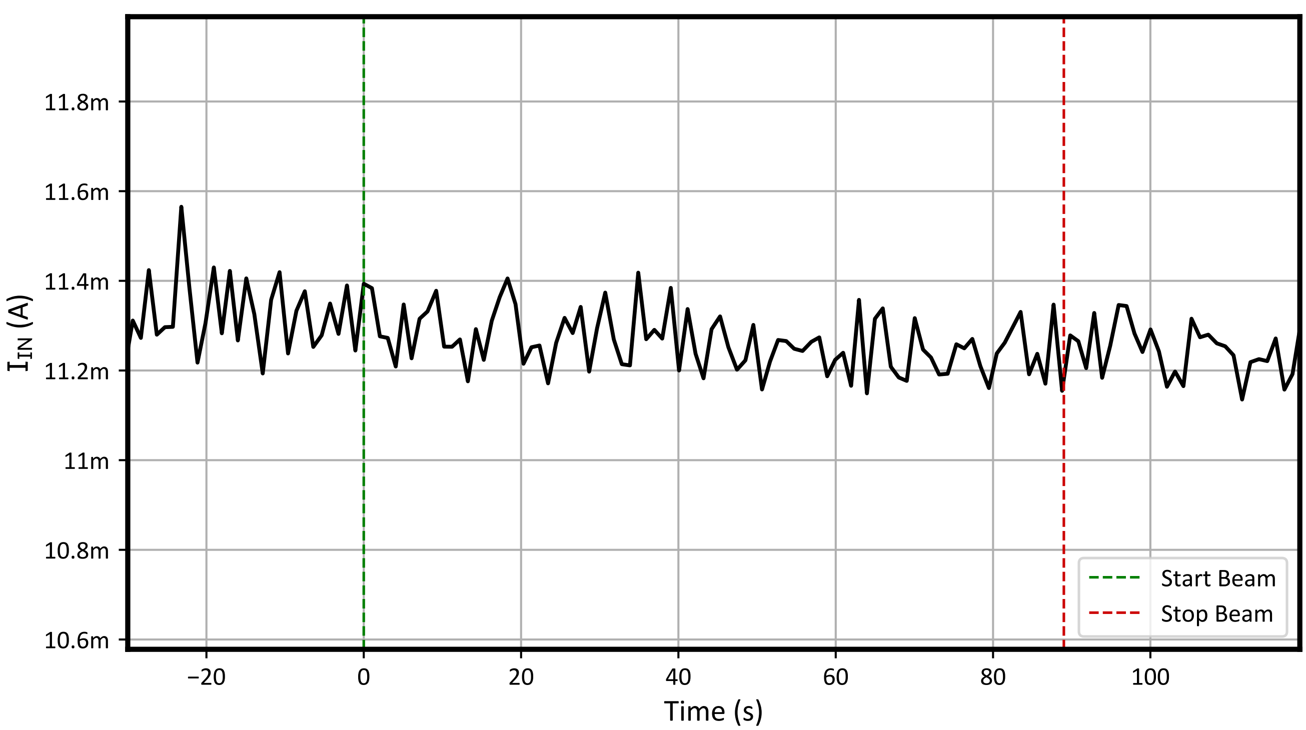

Figure 7-6. SEB Off Run #8 (V_{IN} = 7V)

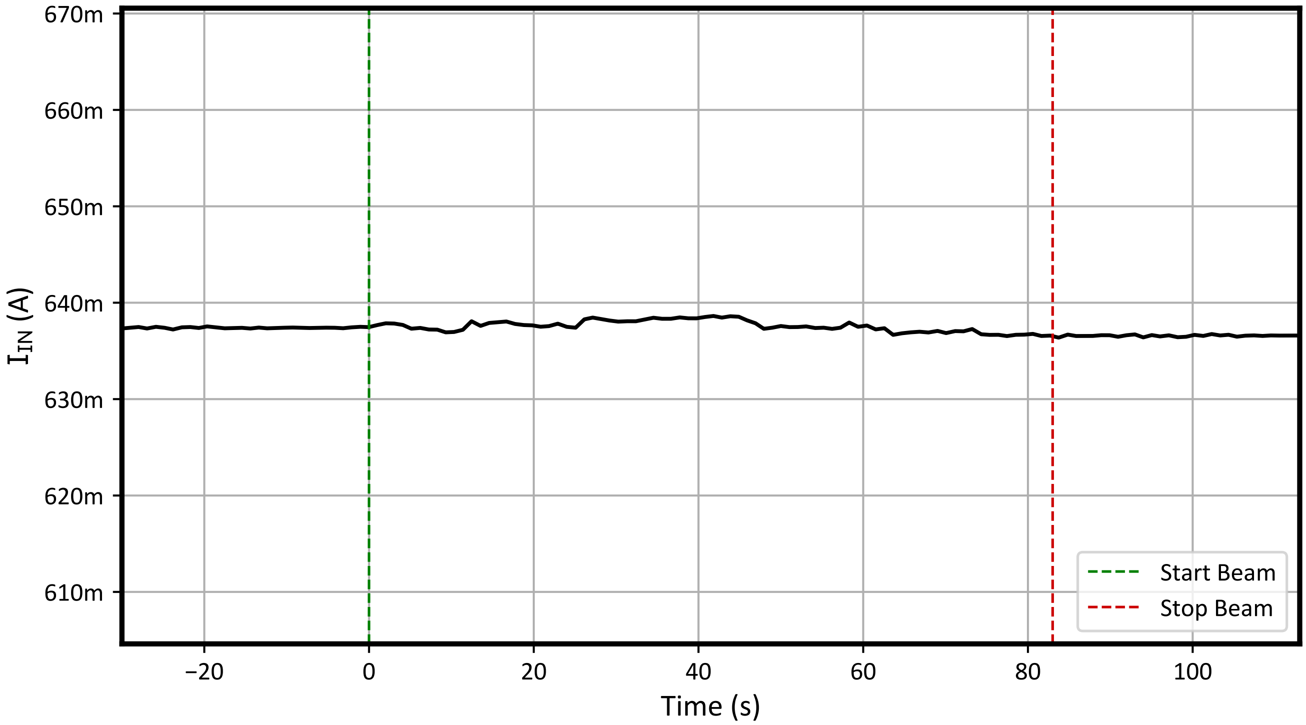

Figure 7-7. SEB On Run #11 (V_{IN} = 7V, V_{OUT} = 1.2V, I_{OUT} = 1.5A/ch)

8 Single-Event Transients (SET)

SET are defined as heavy-ion-induced transients upsets on each channel's VOUT of the TPS7H4102-SEP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for the SET testing were Silver (^{109}Ag) for an LET_{EFF} = 48 MeV·cm^2/mg, for more details refer to Table 5-1. Flux of ≈10^5 ions/cm^2/s and a fluence of ≈10^7 ions/cm^2 per run were used for the SETs characterization discussed on this chapter.

SET testing was conducted in two bias conditions, V_{IN} = 5V with V_{OUT} = 1.8V and V_{IN} = 3.3V with V_{OUT} = 1.2V. One unit was characterized at each bias condition, waveform size, sample rate, trigger type, value, and signal for all scopes used is presented on Table 8-1. Table 8-2 summarizes the results for the two units tested. As the summary of results shows, there were no observed transients on any of the output channels during the SET testing, indicating the TPS7H4102-SEP is SET and SEFI free at 48 MeV·cm^2/mg.

Note: Only one Signal was used as a trigger source at a time, this table 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.

Table 8-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
PXIe-5172 (1)	V_{OUT1}	Window	± 3%	20k	100MS/s
PXIe-5172 (2)	V_{OUT2}	Window	± 3%	20k	100MS/s

Table 8-2. Summary of TPS7H4102-SEP SET Test Condition and Results

RUN #	UNIT #	Facility	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/cm^2/s)	FLUENCE (ions/cm^2)	V_{IN} (V)	V_{OUT} (V)	I_{OUT}/Channel (A)	PXIe-5172 V_{OUT1} (#)	PXIe-5172 V_{OUT2} (#)
13	1	TAMU	^{109}Ag	48	1.14× 10^5	1.00 × 10^7	5	1.8	3	0	0
14	2	TAMU	^{109}Ag	48	1.18× 10^5	1.00 × 10^7	3.3	1.2	3	0	0

9 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations and simplified SEE cross-sections according to methods described in *Heavy Ion Orbital Environment Single-Event Effects Estimations* application report. We assume a minimum shielding configuration of 100 mils (2.54mm) of aluminum, and “worst-week” solar activity (this is similar to a 99% upper bound for the environment). Using the 95% upper-bounds for the SEL and the SEB/SEGR, the event rate calculation for the SEL and the SEB/SEGR is shown on Table 9-1 and Table 9-2, respectively. SET orbit rate for is presented on Table 9-2. **Note that this number is for reference since no SEL, SEB/SEGR, or SET events were observed at the SOA bias conditions discussed in this report.**

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

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	48	4.50×10^{-4}	9.22×10^{-8}	4.15×10^{-11}	1.73×10^{-3}	6.60×10^{7}
GEO		1.48×10^{-3}		1.36×10^{-10}	5.67×10^{-3}	2.01×10^{7}

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

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	48	4.50×10^{-4}	4.61×10^{-8}	2.08×10^{-11}	8.65×10^{-4}	1.32×10^{8}
GEO		1.48×10^{-3}		6.81×10^{-11}	2.84×10^{-3}	4.03×10^{7}

Table 9-3. 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)	48	4.50×10^{-4}	3.69×10^{-7}	1.66×10^{-10}	6.92×10^{-3}	1.65×10^{7}
GEO		1.48×10^{-3}		5.45×10^{-10}	2.27×10^{-2}	5.03×10^{6}

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 TPS7H4102-SEP 7V, 3A per channel, multichannel, peak-current mode, synchronous buck converter. Heavy-ions with LET_{EFF} = 48 MeV·cm^2/mg were used for the SEE characterization campaign. Flux of ≈10^5 ions/cm^2/s and fluences of 10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H4102-SEP is free of destructive SEL and SEB at LET_{EFF} = 48 MeV·cm^2/mg at the SOA bias conditions described in this report. Transients conditions and scope configurations at LET_{EFF} = 48 MeV·cm^2 /mg on V_{OUT} are presented and discussed, showing that the TPS7H4102-SEP is SET and SEFI free. CREME96-based worst week event-rate calculations for LEO(ISS) and GEO orbits for the DSEE and SET are presented for reference.

A References

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