Radiation Report

TPS7H1121-SP Single-Event Effects (SEE)

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TPS7H1121-SP. Heavy-ions with LET_{EFF} of 75MeV·cm^2/mg were used to irradiate 9 total (6 pre-production and 3 production) devices. Flux of 5.08 x 10^4 to 1.07 x 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 TPS7H1121-SP is SEL-free up to 75MeV·cm^2/mg at T = 125°C and SEB/SEGR free up to 75MeV·cm^2/mg at T = 25°C. Output signals including V_{OUT} (3% window), PG (edge trigger at 500mV below nominal), and SS (edge trigger at 20% below nominal) were monitored to check for transients and or SEFIs. The device showed to be SET and SEFI free up to 75MeV·cm^2/mg at T = 25°C.

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Trademarks

1 Introduction

The TPS7H1121-SP is a radiation-hardened, low-dropout linear regulator (LDO) which operates over a wide input voltage range and is optimized for powering devices in a space environment. The device is capable of sourcing up to 2A over a 2.25V to 14V input. SEE testing on this device was completed with both pre-production and production units. Pre-production units refer to P-type symbolized units that have not completed Texas Instrument's Space Enhanced Product (SEP) qualification flow.

The device offers excellent stability and features a programmable current limit with a wide adjustment range. To support the complex power requirements of FPGAs, DSPs, and micro-controllers, the TPS7H1121-SP provides enable on and off functionality, programmable soft start, and a power good open-drain output.

The device is offered in a 22-pin ceramic 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 TPS7H1121-SP product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H1121-SP
Orderable Number	5962R2320301VXC
Device Function	Low-dropout Regulator
Technology	LBC7 (Linear BiCMOS 7)
Exposure Facility	Facility for Rare Istotope Beams, Michigan State University (20.3 MeV/nucleon) and Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/nucleon)
Heavy Ion Fluence per Run	1.00 × 10^7 ions/cm^2
Irradiation Temperature	25°C (for SEB/SEGR testing), 25°C (for SET testing), and 125°C (for SEL testing)

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2 Single-Event Effects (SEE)

The primary concern for the TPS7H1121-SP 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 TPS7H1121-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 TPS7H1121-SP was tested for SEL at the maximum recommended input voltage (V_{IN}) of 14V. The output of the TPS7H1121-SP was configured to the max (13.3V) and min (0.6V) voltages. The output load was configured depending on the output voltage. During the 13.3V testing a constant resistance value of 6.65Ω was used to create a 2A load on the output. During the 0.6V testing a constant resistance value of 1.685Ω was used to create a 0.35A load, which allowed the device to heat to 125°C. For the 6 devices tested under SEL conditions, the TPS7H1121-SP did not exhibit any SEL with heavy-ions with LET_{EFF} = 75MeV·cm^2/mg at flux 5.90 x 10^4 to 9.99 x 10^4 ions/cm^2 ·s, fluence of ≈10^7 ions/cm^2, and a die temperature of 125°C. To see more details on the SEL testing of the TPS7H1121-SP, please refer to Section 7.1.

The TPS7H1121-SP was evaluated for SEB/SEGR at a maximum input voltage of 14V in the enabled and disabled mode with the output voltage configured to be either 13.3V or 0.6V. For the 0.6V case, the load was set to a CR value of 6Ω for a load of 0.1A to prevent the device from heating ≥25°C. Because the MOSFET has shown to be 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 TPS7H1121-SP is SEB/SEGR-free up to LET_{EFF} = 75 MeV·cm^2/mg at a flux of 5.08 x 10^4 to 1.07 x 10^5 ions/cm^2·s, fluences of ≈10^7 ions/cm^2, and a die temperature of ≈25°C. To see more details on the SEB/SEGR testing of the TPS7H1121-SP, please refer to Section 7.2.

The TPS7H1121-SP was characterized at V_{IN} of 5 and 12V. For SET testing, V_{OUT} was configured to be 3.3V with a CR value of 3.3Ω for a load of 1A. During SET testing the V_{OUT}, SS_TR, and PWRGD signals were monitored. DuringSET testing, not a single transient was observed, demonstrating that the TPS7H1121-SP is SET/SEFI-free up to LET_{EFF} = 75 MeV·cm^2/mg at a flux of 6.34 x 10^4 to 1.05 x 10^5 ions/cm^2·s, fluences of ≈10^7 ions/cm^2, and a die temperature of ≈25°C. To see more details on the SET testing of the TPS7H1121-SP, please refer to Single-Event Transients (SET).

3 Device and Test Board Information

The TPS7H1121-SP is packaged in a 22-pin thermally-enhanced ceramic package as shown in Figure 3-1. The TPS7H1121EVM-CVAL evaluation module was used to evaluate the performance and characteristics of the TPS7H1121-SP under heavy ion radiation. The TPS7H1121EVM-CVAL (Evaluation Module) is shown in Figure 3-2. The EVM schematic is shown in Figure 3-3.

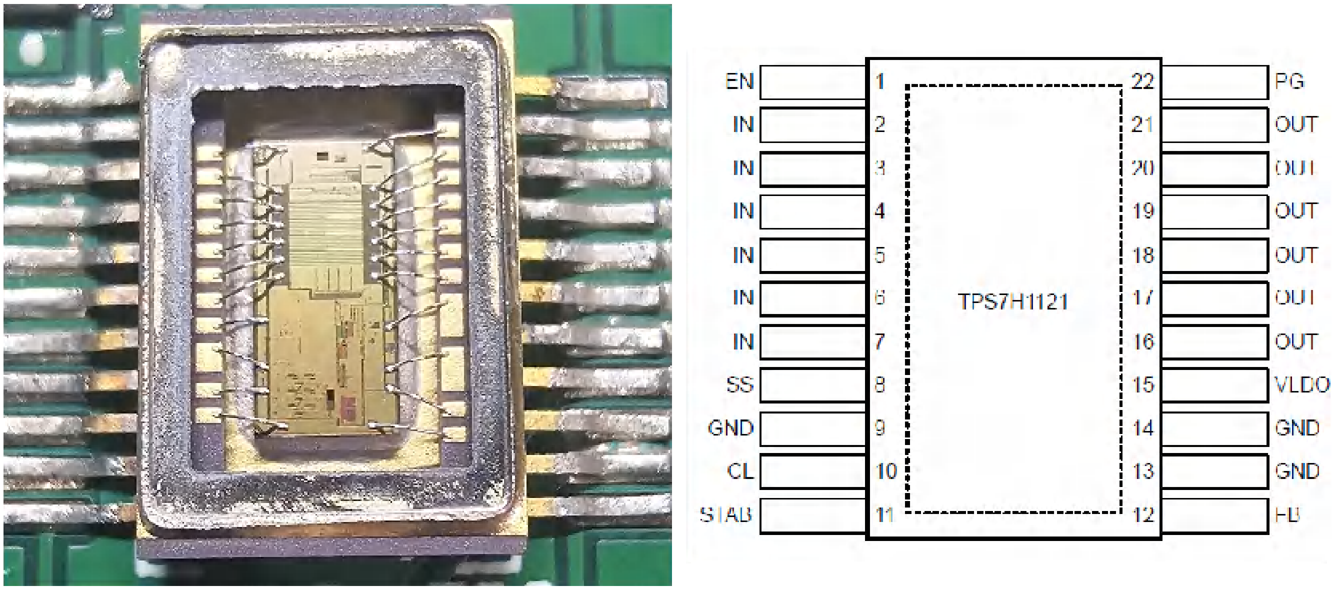


Figure 3-1. Photograph of Delidded TPS7H1121-SP [Left] and Pinout Diagram [Right]

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

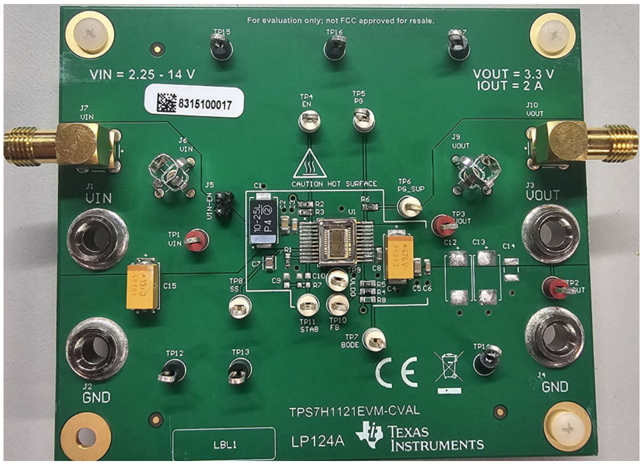


Figure 3-2. TPS7H1121-SP EVM Top View

3.1 Device and Test Board Information Continued

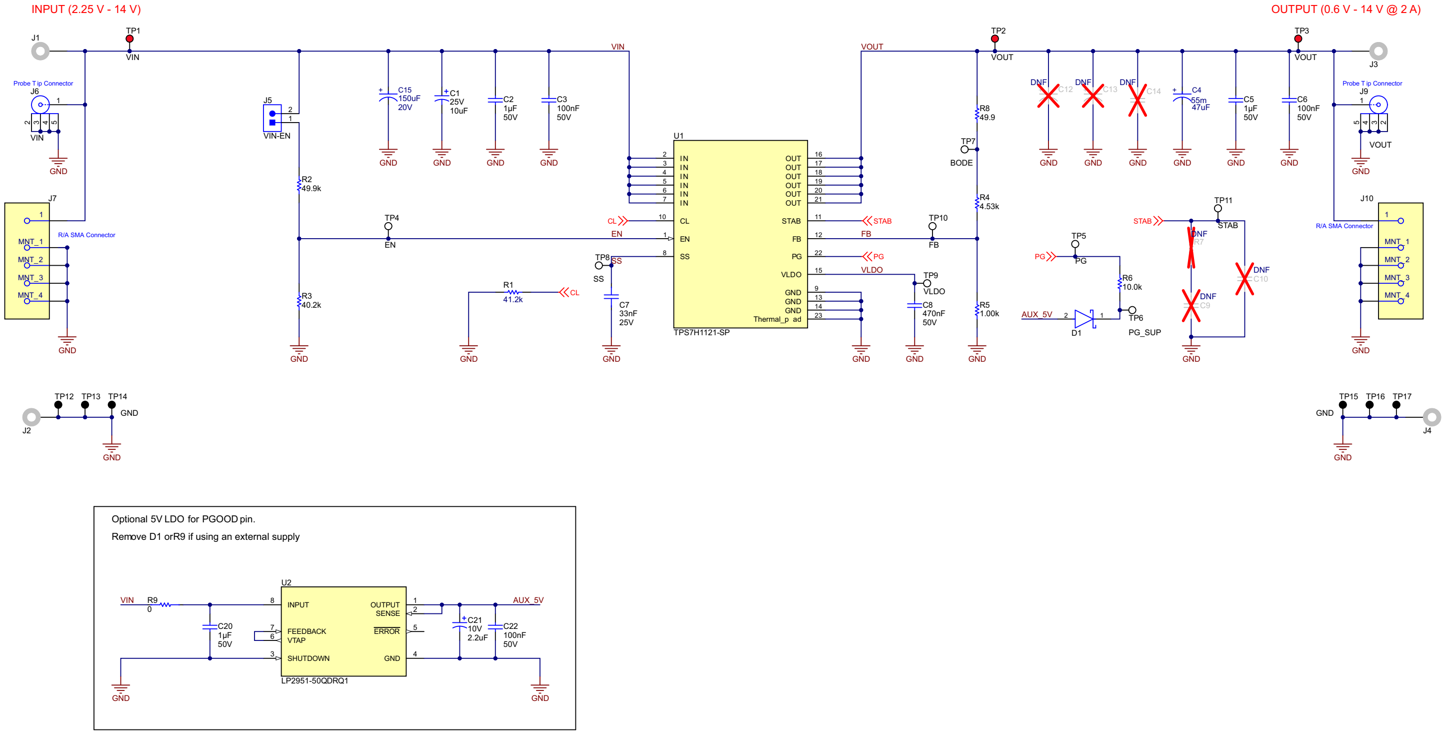


Figure 3-3. TPS7H1121-SP EVM Schematics

4 Irradiation Facility and Setup

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

- Michigan State University (MSU) Facility for Rare Isotope Beams (FRIB) using a linear accelerator 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 20mm x 20mm square cross-sectional area for the in-vacuum scintillator. 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 9.36 x 10^4 to 1.07 x 10^5 ions/cm^2·s was used to provide heavy-ion fluences of 1.00 x 10^7 ions/cm^2.
- 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 5.08 x 10^4 to 6.39 x 10^4 ions/cm^2·s was used to provide heavy-ion fluences of 1.00 x 10^7 ions/cm^2.

For the experiments conducted on this report, there was 2 ions were used, ^{169}Tm and ^{165}Ho. Both were used to obtain LET$_{EFF}$ of 75 MeV·cm^2/mg. The total kinetic energies for the ions were:

- ^{169}Tm = 3.431 GeV (20.3 MeV/nucleon)
  - Ion uniformity for these experiments was between 98% and 98.4%
- ^{165}Ho = 2.474 GeV (15 MeV/nucleon)
  - Ion uniformity for these experiments was between 93% and 96%

Figure 4-1 shows the TPS7H1121EVM-CVAL used for data collection at both facilities. Although not visible in this photo, the beam port has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the accelerator with only minor ion energy loss. The in-air gap between the device and the ion beam port window was maintained at 70-mm for all runs at MSU and 40-mm for all runs at TAMU.

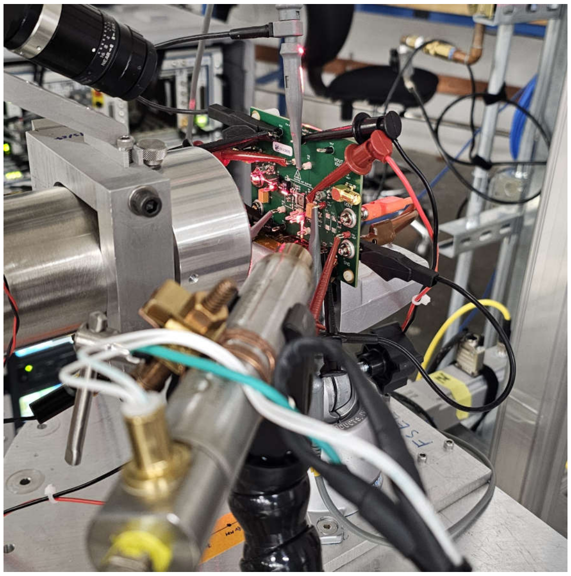
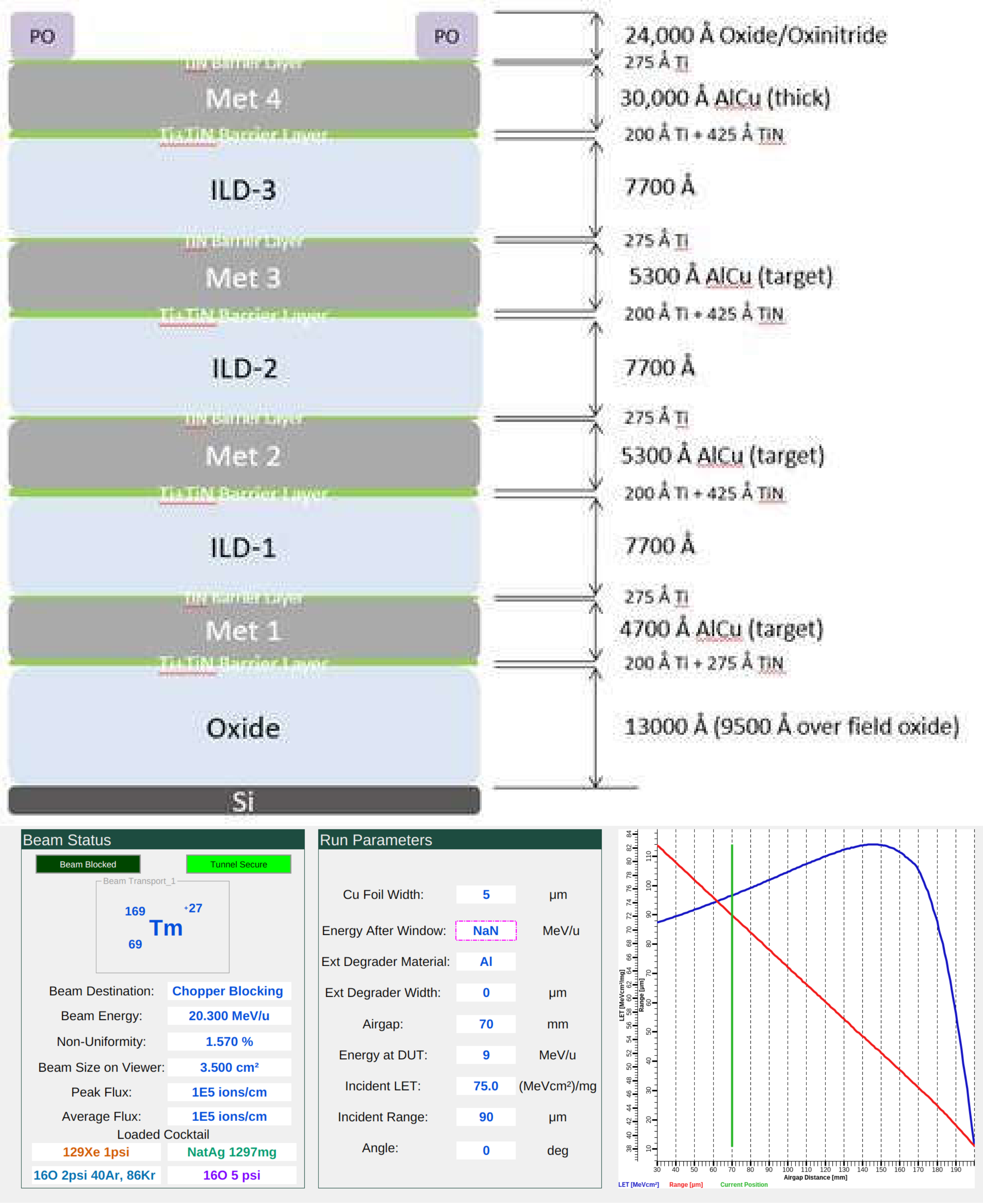


Figure 4-1. Photograph of the TPS7H1121EVM-CVAL in Front of the Heavy-Ion Beam Exit Port at the MSU FRIB

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



Beam Status

Beam Destination: Chopper Blocking
Beam Energy: 20.300 MeV/u
Non-Uniformity: 1.570 %
Beam Size on Viewer: 3.500 cm²
Peak Flux: 1E5 ions/cm
Average Flux: 1E5 ions/cm
Loaded Cocktail
129Xe 1psi | NatAg 1297mg
16O 2psi 40Ar, 86Kr | 16O 5 psi

Run Parameters

Cu Foil Width: 5 µm
Energy After Window: NaN MeV/u
Ext Degrader Material: Al
Ext Degrader Width: 0 µm
Airgap: 70 mm
Energy at DUT: 9 MeV/u
Incident LET: 75.0 (MeVcm²)/mg
Incident Range: 90 µm
Angle: 0 deg

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H1121-SP [Top] and Key Ion Parameters [Bottom]

The TPS7H1121-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. The total stack height from the surface of the passivation to the silicon surface is 10.885-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 70-mm air gap, and the BEOL stack over the TPS7H1121-SP, the effective LET (LET_{EFF}) at the surface of the silicon substrate and the depth was determined with information provided by the MSU FRIB. The results are shown in Ion LET_{EFF}, Depth, and Range in Silicon.

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

ION TYPE	Beam Energy (MeV/nucleon)	ANGLE OF INCIDENCE	DEGRADER STEPS (#)	DEGRADER ANGLE	RANGE IN SILICON (µm)	LET_{EFF} (MeV·cm^2/mg)
^{169}Tm	20.3	0	0	0	90	75
^{165}Ho	15	0	0	0	97.2	75

6 Test Setup and Procedures

There were two input supplies used to power the TPS7H1121-SP which provided V_{IN} and EN. The V_{IN} for the device was provided by Ch. 3 of an N6705C power module and ranged from 5V and 12V for SET to 14V for SEL and SEB/SEGR. EN was powered by Ch. 1 of an E36311A power supply and ranged from 0V for SEB Off to 5V for all other testing.

The instrument used to load the TPS7H1121-SP was a Chroma E36300 E-Load that was used in Constant Resistance (CR) mode. The value of CR was adjusted depending on the type of test. For all DSEE testing with V_{OUT} = 13.3V, the CR value was set to achieve a max load of 2A. For the SEB testing during the V_{OUT} = 0.6V case, the CR value was set to achieve a load of 100mA as the CR value was set such that the load does not heat the device too much to maintain that the test case was valid. For the SEL testing during the V_{OUT} = 0.6V case, the CR value was set to achieve a load of 300mA as this load provided the correct amount of device heating to achieve a die temperature of 125°C. For all SET testing, the CR value was set to achieve a nominal load of 1A.

The primary signal monitored on the EVM was V_{OUT}. This was monitored using a NI PXIe-5172 scope card that was set to trigger on a 3% window based on the nominal measured value of V_{OUT}. Secondary signals monitored include PG and SS. A second NI PXIe-5172 scope card was used to monitor PG on a negative edge trigger, set 500mV below the nominal value of PG. A third NI PXIe-5172 scope card was used to monitor SS on a negative edge trigger, set 20% below the nominal value of SS. During SEE testing, the output signals were monitored to maintain proper device functionality throughout the run. During SEB Off testing, all outputs were monitored on a positive edge trigger at 500mV to detect if the device incorrectly turned on while the device was disabled.

All equipment other 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 through an MXI controller and NI PXIe-8381 remote control module.

Equipment Settings and Parameters Used During the SEE Testing of the TPS7H1121-SP 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 TPS7H1121-SP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the TPS7H1121-SP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{IN}	N6705C (CH #3)	60V, 17A	5A	5 to 14V
EN	E36311A (CH #1)	6V,5A	0.1A	0V, 5V
V_{OUT}	PXIe-5172 (1)	100 MS/s	—	100 MS/s
PG	PXIe-5172 (2)	100 MS/s	—	100 MS/s
SS	PXIe-5172 (3)	100 MS/s	—	100 MS/s
V_{OUT}	Chroma E36300 Load	80A	High	—

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 MSU and TAMU facilities. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H1121-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 monitored the signals. When the output exceeded the pre-defined 3% window trigger or negative edge triggers, 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.

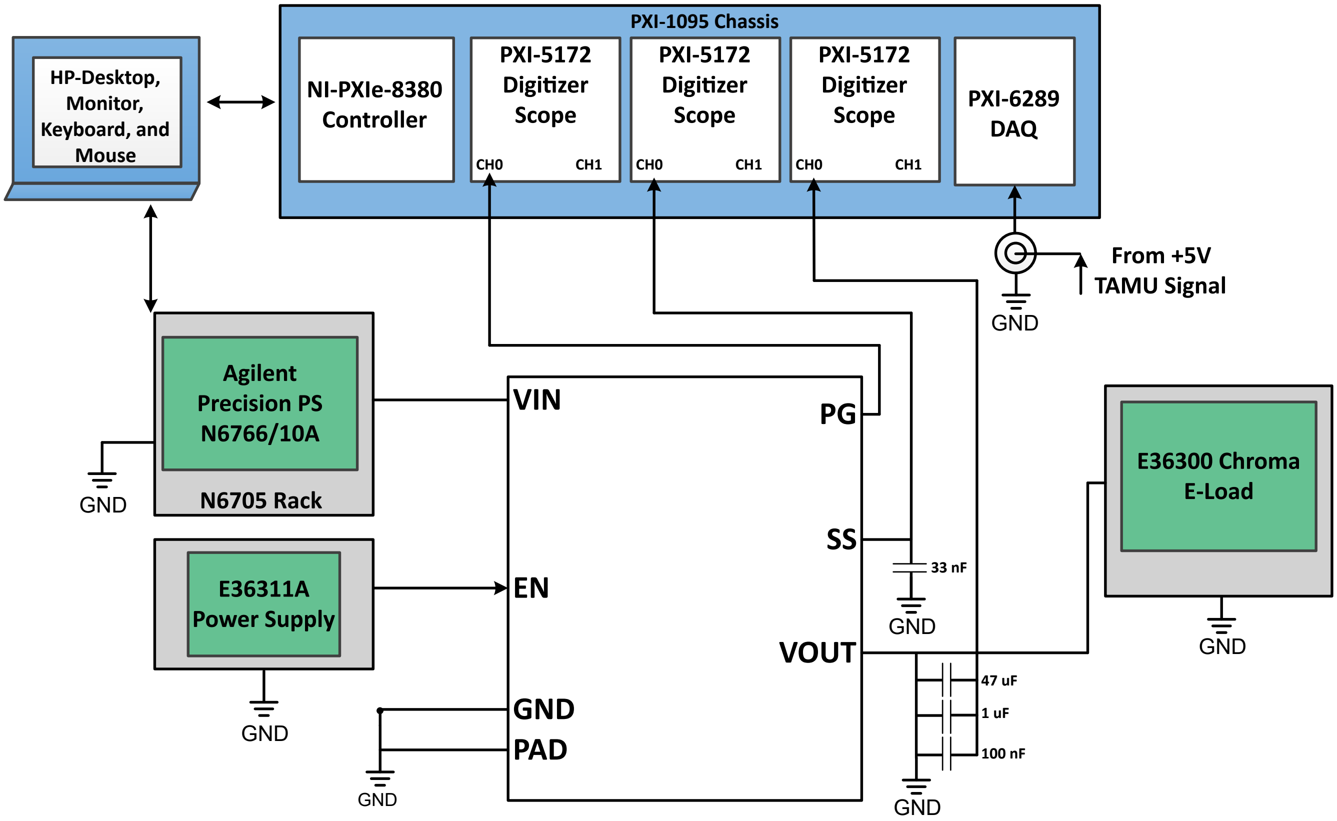


Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H1121-SP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

During the SEL characterization, the device was heated using the load (0.6V case) or with external heat (13.3V case). When using external heat, the device was heated to 125°C by a cool-touch heat gun controlled by a Variac at MSU and a Closed-Loop PID controlled heat gun (MISTRAL 6 System (120V, 2400W) at TAMU. The temperature of the die was verified using FLIR IR camera prior to exposure to heavy ions.

The species used for SEL testing were Thulium (^{169}Tm at 20MeV/nucleon, MSU facility) and Holmium (^{165}Ho at 15 MeV/nucleon, TAMU facility). For both ions an incident angle of 0° was used to achieve an LET_{EFF} = 75 MeV·cm^2/mg (for more details refer to Ion LET_{EFF}, Depth, and Range in Silicon). The kinetic energy in the vacuum for ^{169}Tm is 3.431 GeV and ^{165}Ho is 2.474 GeV. Flux of 5.90 x 10^4 to 9.99 x 10^4 ions/cm^2 ·s and a fluence of approximately 10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was between 2-4 minutes. The six units were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 14V. No SEL events were observed during all six runs, indicating that the TPS7H1121-SP is SEL-free up to 75 MeV·cm^2/mg. Table 7-1 shows the SEL test conditions and results. Figure 7-1 and Figure 7-1 show plots of the current vs time for runs #1 and #3.

Table 7-1. Summary of TPS7H1121-SP SEL Test Condition and Results

Run #	Unit #	Facility	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions·cm^2/mg)	Fluence (# ions)	V_{OUT}	I_{OUT} (A)	SEL (# Events)
1	1	MSU	^{169}Tm	75	9.99 x 10^4	1 x 10^7	13.3	2	0
2	2	MSU	^{169}Tm	75	9.81 x 10^4	1 x 10^7	13.3	2	0
3	3	MSU	^{169}Tm	75	9.99 x 10^4	1 x 10^7	0.6	0.35	0
4	4	MSU	^{169}Tm	75	9.99 x 10^4	1 x 10^7	0.6	0.35	0
5	5	TAMU	^{165}Ho	75	5.92 x 10^4	1 x 10^7	13.3	2	0
6	6	TAMU	^{165}Ho	75	5.90 x 10^4	1 x 10^7	0.6	0.56	0

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 at 125°C (6 × 10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \le 6.15 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75 MeV·cm^2/mg and T = 125°C.

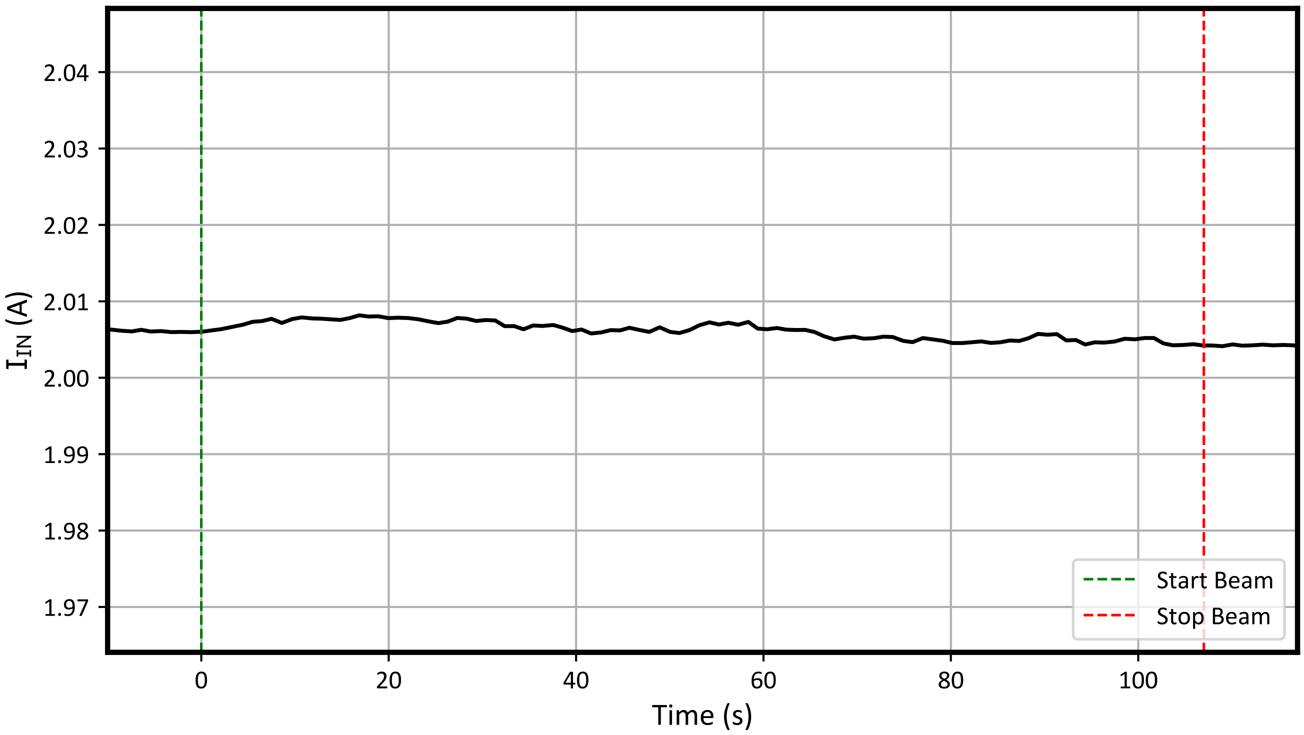


Figure 7-1. SEL Current Versus Time for Run #1 of the TPS7H1121-SP at T = 125°C (V_{OUT} = 13.3V)

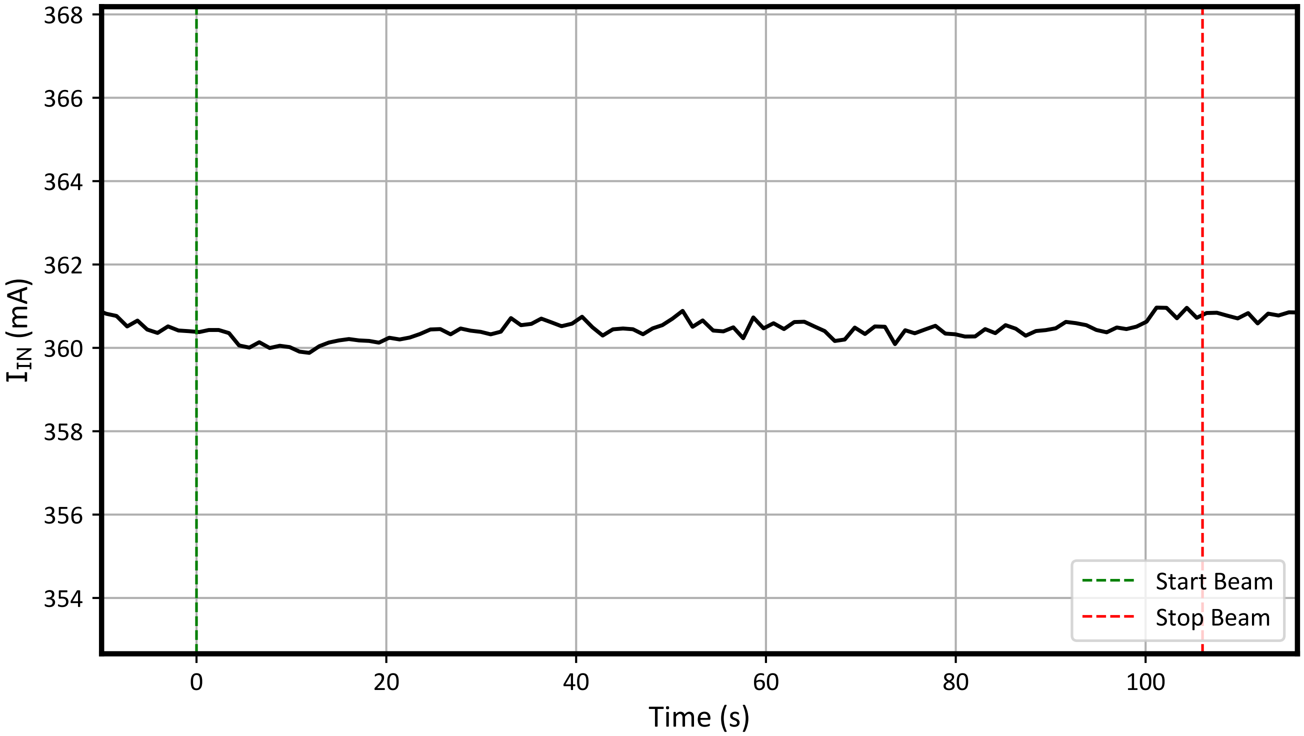


Figure 7-2. SEL Current Versus Time for Run #3 of the TPS7H1121-SP at T = 125°C (V_{OUT} = 0.6V)

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

During the SEB/SEGR characterization, the device was tested at room temperature of approximately 25°C. The device was tested under both the enabled and disabled mode. For the SEB-Off test, the device was disabled using the EN-pin by forcing 0V (using CH #1 of a Keysight E36311A PS). During the all SEB/SEGR testing, not a single input current event was observed.

The species used for SEB/SEGR testing were Thulium (^{169}Tm at 20.3 MeV/nucleon, MSU facility) and Holmium (^{165}Ho at 15 MeV/nucleon, TAMU facility). For both ions an incident angle of 0° was used to achieve an $\mathrm{LET_{EFF}}$ = 75 MeV·cm^2/mg (for more details refer to Ion $\mathrm{LET_{EFF}}$, Depth, and Range in Silicon). The kinetic energy in the vacuum for ^{169}Tm is 3.431 GeV and ^{165}Ho is 2.474 GeV. Flux of 5.08 x 10^4 to 1.07 x 10^5 ions/cm^2·s and a fluence of approximately 10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was between 2-4 minutes. The six units (same as used in SEL testing) were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 14V. No SEB/SEGR current events were observed during the 12 runs, indicating that the TPS7H1121-SP is SEB/SEGR-free up to $\mathrm{LET_{EFF}}$ = 75 MeV·cm^2/mg and across the full electrical specifications. Summary of TPS7H1121-SP SEB/SEGR Test Condition and Results shows the SEB/SEGR test conditions and results. Figure 7-3, Figure 7-4, and Figure 7-3 show plots of the current vs time for runs #7, #8, and #11.

Table 7-2. Summary of TPS7H1121-SP SEB/SEGR Test Condition and Results

Run #	Unit #	Facility	Ion	$\mathrm{LET_{EFF}}$ (MeV·cm^2/mg)	Flux (ions·cm^2/mg)	Fluence (# ions)	Enabled Status	$\mathrm{V_{OUT}}$	$\mathrm{I_{OUT}}$ (A)	SEB (# Events)
7	1	MSU	^{169}Tm	75	1.03 x 10^5	1.00 x 10^7	EN	13.3	2	0
8					1.07 x 10^5	1.00 x 10^7	DIS	0	—	0
9	2	MSU	^{169}Tm	75	9.69 x 10^4	1.00 x 10^7	EN	13.3	2	0
10					9.36 x 10^4	1.00 x 10^7	DIS	0	—	0
11	3	MSU	^{169}Tm	75	1.03 x 10^5	1.00 x 10^7	EN	0.6	0.1	0
12					1.03 x 10^5	1.00 x 10^7	DIS	0	—	0
13	4	MSU	^{169}Tm	75	9.76 x 10^4	1.00 x 10^7	EN	0.6	0.1	0
14					9.85 x 10^4	1.00 x 10^7	DIS	0	—	0
15	5	TAMU	^{165}Ho	75	5.08 x 10^4	1.00 x 10^7	EN	13.3	2	0
16					5.94 x 10^4	1.00 x 10^7	DIS	0	—	0
17	6	TAMU	^{165}Ho	75	5.81 x 10^4	1.00 x 10^7	EN	0.6	0.1	0
18					6.18 x 10^4	1.00 x 10^7	DIS	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 as:

$\sigma_{SEB} \leq 3.07 \times 10^{-8}$ cm^2/device for $\mathrm{LET_{EFF}}$ = 75 MeV·cm^2/mg and T = 25°C.

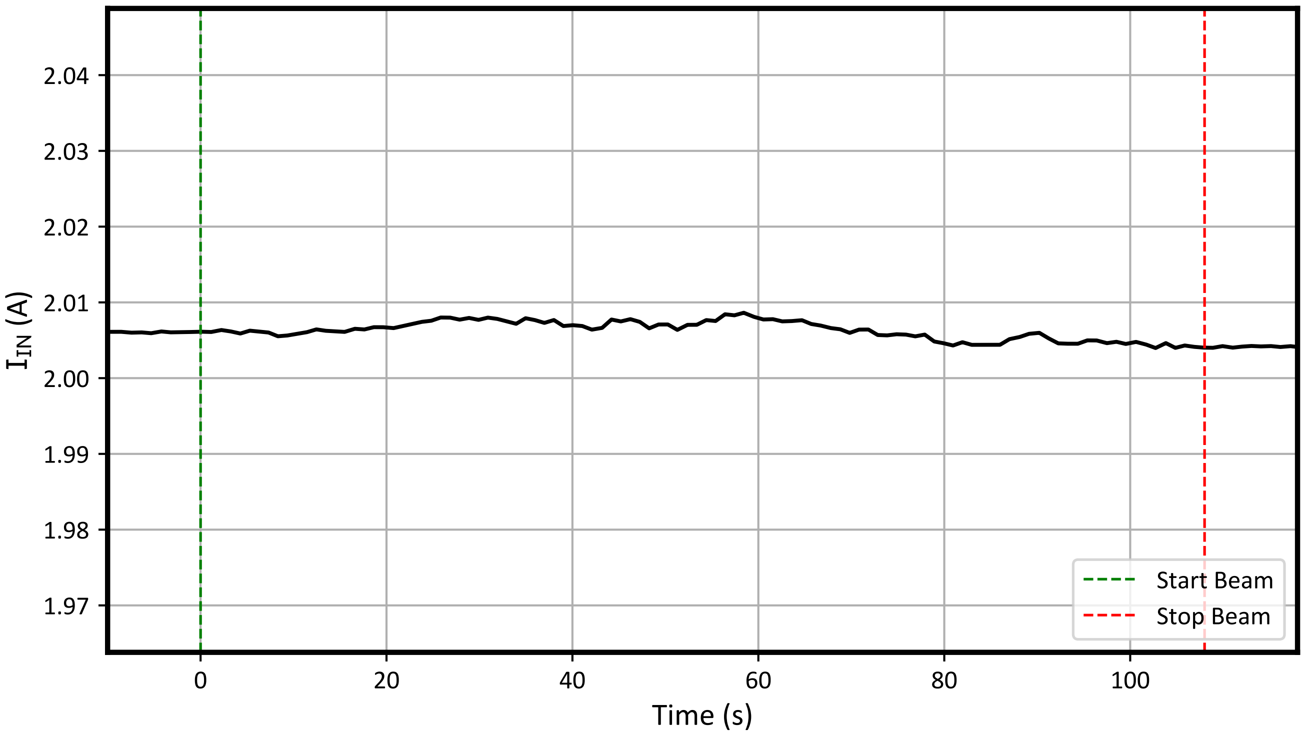


Figure 7-3. SEB On Current Versus Time for Run #7 of the TPS7H1121-SP at T = 25°C (V_{OUT} = 13.3V)

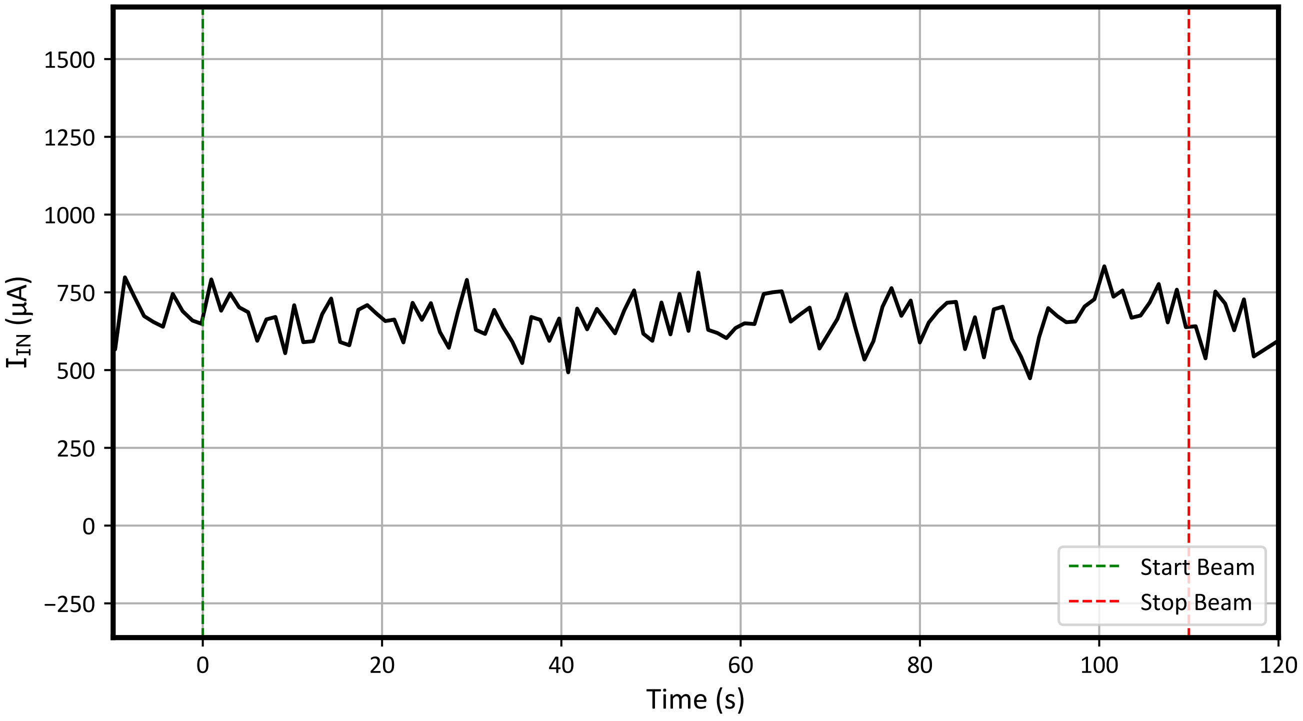


Figure 7-4. SEB Off Current Versus Time for Run #8 of the TPS7H1121-SP at T = 25°C (V_{OUT} = 0V)

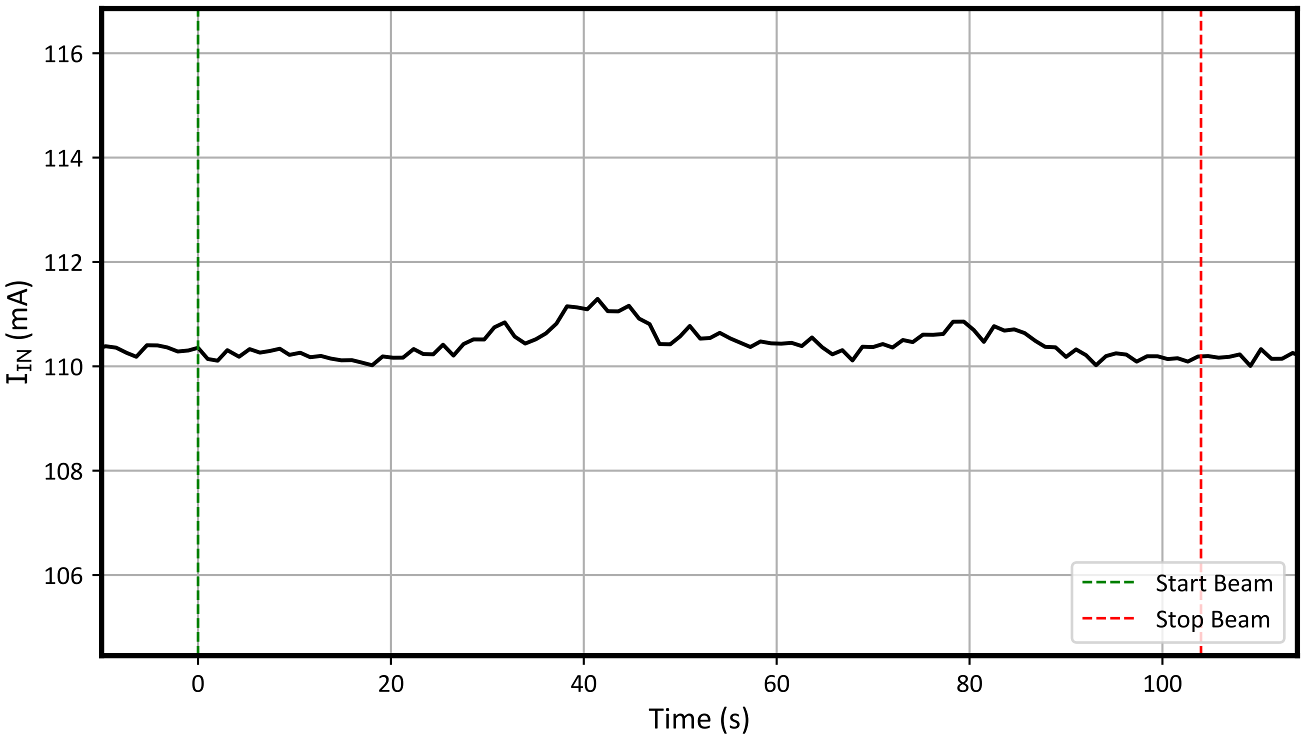


Figure 7-5. SEB On Current vs Time for Run #11 of the TPS7H1121-SP at T = 25°C (V_{OUT} = 0.6V)

8 Single-Event Transients (SET)

SETs are defined as heavy-ion induced transients on V_{OUT}, PG, or SS of the TPS7H1121-SP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ion species used for SET testing were Thulium (^{169}Tm at 20.3 MeV/nucleon, MSU facility) and Holmium (^{165}Ho at 15 MeV/nucleon, TAMU facility). For both ions an incident angle of 0° was used to achieve an LET_{EFF} = 75 MeV·cm^2/mg, for more details refer to Ion LET_{EFF}, Depth, and Range in Silicon. A flux of 6.34 x 10^4 to 1.05 x 10^5 ions/cm^2·s and fluence of 10^7 ions/cm^2 per run were used for the SET characterization discussed in this chapter. Over the course of testing three devices, not a single transient or SEFI was recorded on any of the monitored signals indicating that the TPS7H1121-SP is SET/SEFI free up to LET_{EFF} = 75 MeV·cm^2/mg.

Waveform size, sample rate, trigger type, value, and signal for all scopes used is presented on Table 8-1.

Table 8-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
PXIe-5172 (1)	V_{OUT}	Window	±3%	100k	100MS/s
PXIe-5172 (2)	PG	Edge/Negative	0.5V below nominal	100k	10MS/s
PXIe-5172 (3)	SS	Edge/Negative	20%	100k	10MS/s

Table 8-2. Summary of TPS7H1121-SP SET Test Condition and Results

Run #	Unit #	Facility	Ion	LET_{EFF} (MeV·cm^2/mg)	V_{IN} (V)	Flux (ions·cm^2/mg)	Fluence (# ions)	PXIe-5172 V_{OUT} # ≥ 3%	PXIe-5172 PG#	PXIe-5172 SS #
19	7	MSU	^{169}Tm	75	5	1.04×10^5	1.00×10^7	0	0	0
20					12	9.78×10^4	1.00×10^7	0	0	0
21	8	MSU	^{169}Tm	75	5	9.71×10^4	1.00×10^7	0	0	0
22					12	1.05×10^5	1.00×10^7	0	0	0
23	9	TAMU	^{165}Ho	75	5	6.39×10^4	1.00×10^7	0	0	0
24					12	6.34×10^4	1.00×10^7	0	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 (2.54 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 SEL, SEB/SEGR, and SET the event rate calculations for SEL, SEB/SEGR, and SET are shown on Table 9-1,Table 9-2, and Table 9-1, respectively. **Note that this number is for reference since no SEL, SEB/SEGR, or SET 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)	75	6.26×10^{-5}	6.15×10^{-8}	3.85×10^{-12}	1.60×10^{-4}	7.12×10^{8}
GEO		1.77×10^{-4}		1.09×10^{-11}	4.53×10^{-4}	2.52×10^{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	6.26×10^{-5}	3.07×10^{-8}	1.92×10^{-12}	8.02×10^{-5}	1.42×10^{9}
GEO		1.77×10^{-4}		5.43×10^{-12}	2.26×10^{-4}	5.04×10^{8}

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)	75	6.26×10^{-5}	6.15×10^{-8}	3.85×10^{-12}	1.60×10^{-4}	7.12×10^{8}
GEO		1.77×10^{-4}		1.09×10^{-11}	4.53×10^{-4}	2.52×10^{8}

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 TPS7H1121-SP low-dropout (LDO) linear regulator. Heavy-ions with $\mathrm{LET_{EFF}}$ = 75 MeV·cm^2/mg were used for the SEE characterization campaign. Flux of 5.08 x 10^4 to 1.07 x 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 TPS7H1121-SP is free of destructive SEL and SEB/SEGR and SET/SEFI up to $\mathrm{LET_{EFF}}$ = 75 MeV·cm^2/mg across the full electrical specifications. CREME96-based worstweek event-rate calculations for LEO(ISS) and GEO orbits for the DSEE and SET are presented for reference.

A Total Ionizing Dose from SEE Experiments

The production TPS7H1121-SP is rated to a total ionizing dose (TID) of 100 krad(Si). In the course of the SEE testing, the heavy-ion exposures delivered ≈10 krad(Si) per 10^7 ions/cm^2 run. The cumulative TID exposure was controlled below 100krad (Si) per unit. All nine TPS7H1121-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.

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