Radiation Report

TPS7H4012-SP and TPS7H4013-SP Single-Event Effects (SEE)

TEXAS INSTRUMENTS

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TPS7H401x-SP. Heavy-ions with LET_{EFF} of 75 MeV×cm^2/mg were used to irradiate eight production 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 TPS7H401x-SP is SEL-free up to 75 MeV×cm^2/ mg at T=125°C and SEB/SEGR free up to 75 MeV×cm^2/mg at T=25°C. Output signals including V_{OUT} (3% window), SS_TR (edge negative trigger at 50% below nominal) and PWRGD (edge negative trigger at 50% below nominal) were monitored to check for transients and SEFIs. The results showed the device is SEFI free up to 75 MeV×cm^2/mg at T = 25°C. SETs are characterized and discussed at LET_{EFF} = 75 MeV×cm^2/mg.

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1 Introduction

The TPS7H401x-SP is a 14V synchronous buck converter optimized for use in a space environment. The peak current mode converter obtains high efficiency with good transient performance and reduced component count. The TPS7H4012-SP supports up to 6A output current while the TPS7H4013-SP supports up to 3A output current.

The wide voltage range of the TPS7H401x-SP enables the device to be used as a point of load regulator to convert directly from a 12V or 5V rail. The output voltage start-up ramp is controlled by the SS_TR pin. Power sequencing is possible with the EN and PWRGD pins.

Additionally, various features are included such as an optimized current limit for each device, a flexible switching frequency, and configurable compensation.

The device is offered in a 44-pin plastic package. General device information and test conditions are listed in Table 1-1. For more detailed technical specifications, user guides, and application notes, see TPS7H4012-SP product page. and TPS7H4013-SP product page.

Table 1-1. Overview Information

Description (1)	Device Information
TI Part Number	TPS7H4012-SP, TPS7H4013-SP
Orderable Number	5962R2122103PYE, 5962R2122104PYE
Device Function	Synchronous Buck Converter
Technology	LBC7 (Linear BiCMOS 7)
Exposure Facility	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 TPS7H401x-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 TPS7H401x-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 TPS7H401x-SP was tested for SEL at the maximum recommended input voltage (V_{IN}) of 14V. The output load was configured to provide a constant resistance value to provide the maximum output current of each respective device. During testing of the eight devices, the TPS7H401x-SP did not exhibit any SEL with heavy-ions with LET_{EFF} = 75 $MeV \times cm^2/mg$ at flux of ≈1×10^5 $ions/cm^2/s$, fluence of ≈10^7 $ions/cm^2$, and a die temperature of ≈125°C.

The TPS7H401x-SP was evaluated for SEB/SEGR at a maximum voltage of 14V in 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 TPS7H401x-SP is SEB/SEGR-free up to LET_{EFF} = 75 $MeV \times cm^2/mg$ at a flux of ≈1×10^5 $ions/cm^2/s$, fluences of ≈10^7 $ions/cm^2$, and a die temperature of ≈25°C.

During SET/SEFI testing, the TPS7H401x-SP was characterized at V_{IN} of 5V and 12V. V_{OUT}, SS_TR, and PWRGD signals were monitored. Throughout this testing, not a single SEFI was observed, demonstrating that the TPS7H401x-SP is SEFI free up to LET_{EFF} = 75$MeV \times cm^2/mg$ at a flux of ≈10^5 $ions/cm^2/s$, fluences of ≈10^7 $ions/cm^2$, and a die temperature of ≈25°C. SETs were characterized with an LET_{EFF} = 75 $MeV \times cm^2/mg$ at a flux of ≈10^5 $ions/cm^2/s$, fluences of ≈10^7 $ions/cm^2$, and a die temperature of ≈25°C. For more details on the SET testing of the TPS7H401x-SP, see Section 8.

3 Device and Test Board Information

The TPS7H401x-SP is packaged in a 44-pin plastic package as shown in Figure 3-1. The TPS7H401x-SP evaluation module (EVM) was used to evaluate the performance and characteristics of the TPS7H401x-SP under heavy ion radiation. The TPS7H4012EVM is shown in Figure 3-2 and its schematic is shown in Figure 3-4. The TPS7H4013EVM is shown in Figure 3-3 and its schematic is shown in Figure 3-5. The TPS7H401xEVM was used for this test campaign with TPS7H410x-SP units populated onto U1.

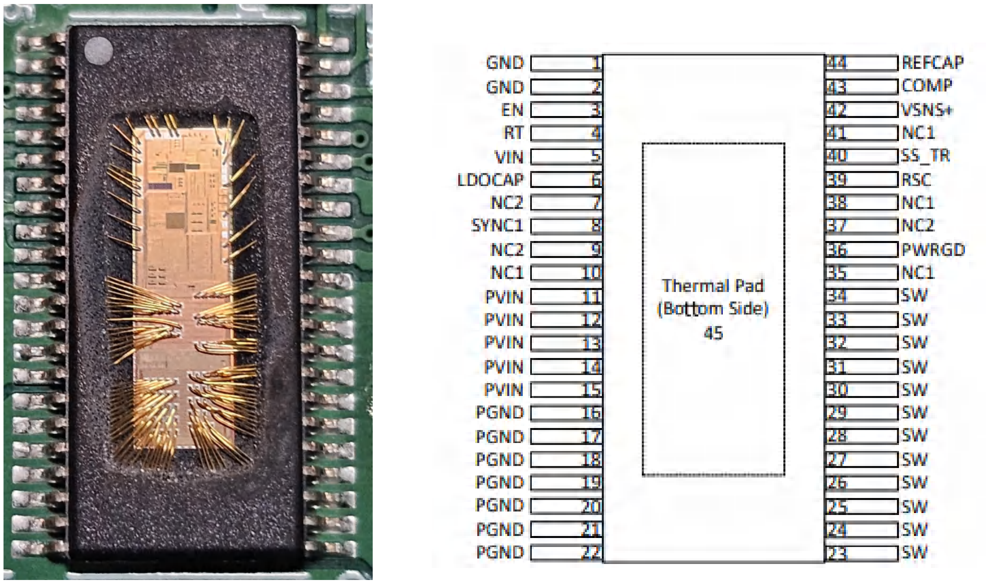


Figure 3-1. Photograph of Delidded TPS7H401x-SP (Left) and Pinout Diagram (Right)

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

Jumper on J6 was configured in the 2-3 position for all testing

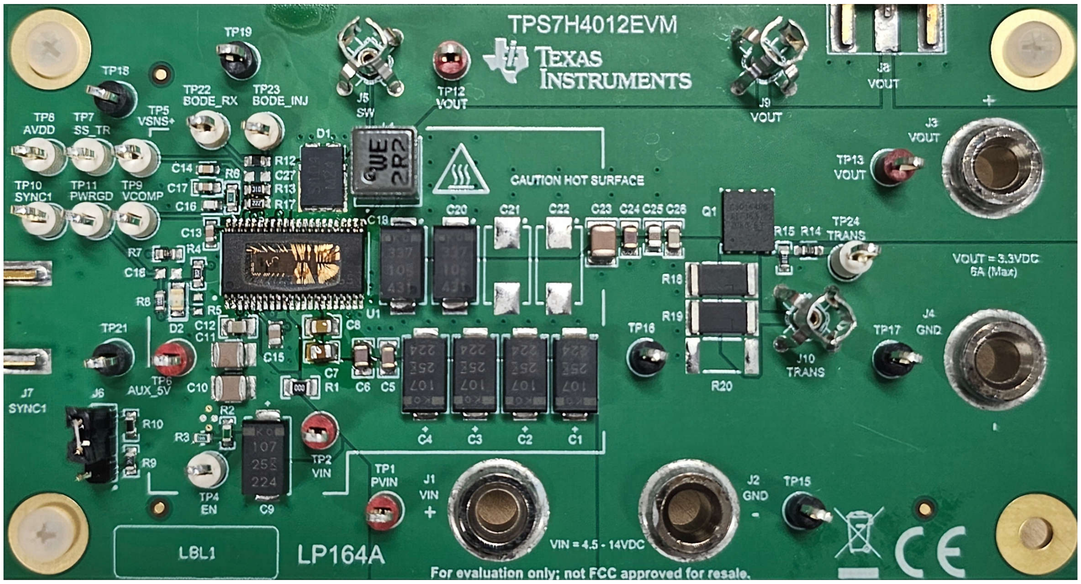


Figure 3-2. TPS7H4012-SP EVM Top View

Jumper on J6 was configured in the 2-3 position for all testing

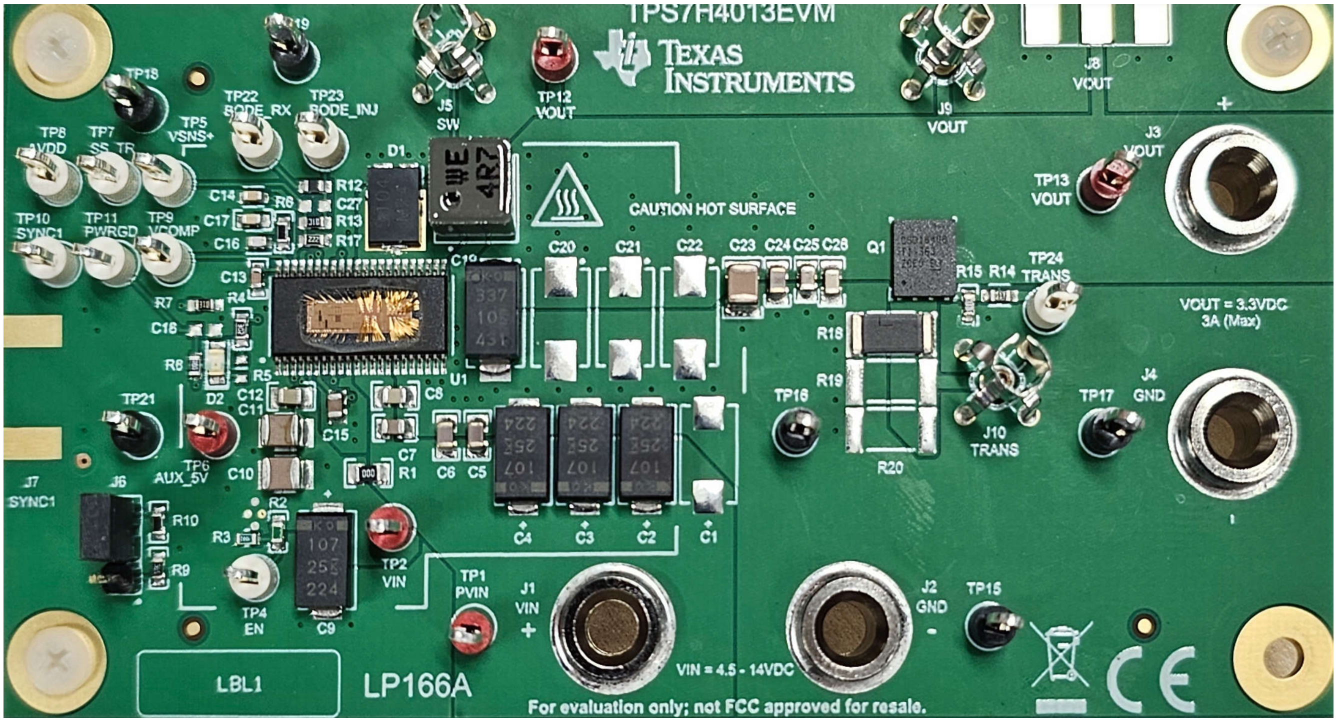


Figure 3-3. TPS7H4013-SP EVM Top View

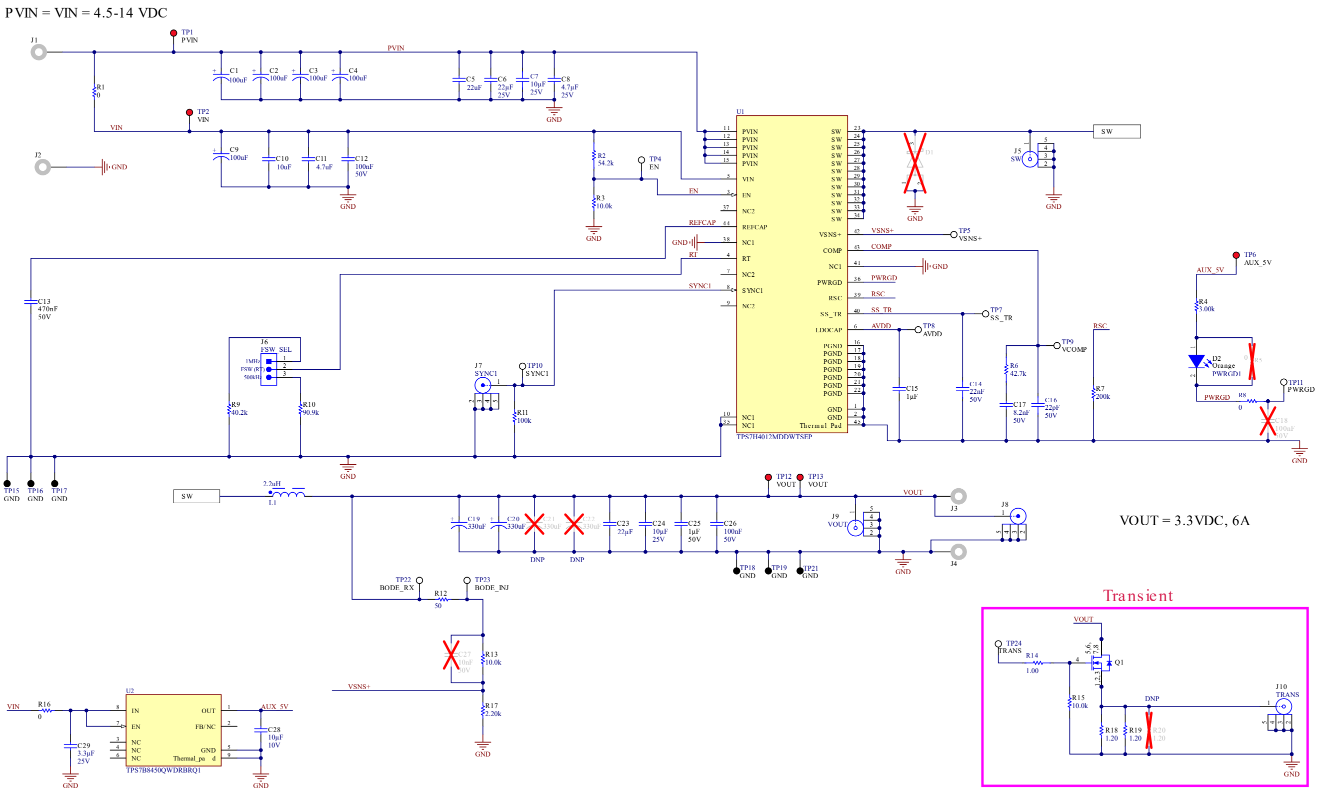


Figure 3-4. TPS7H4012EVM Schematics

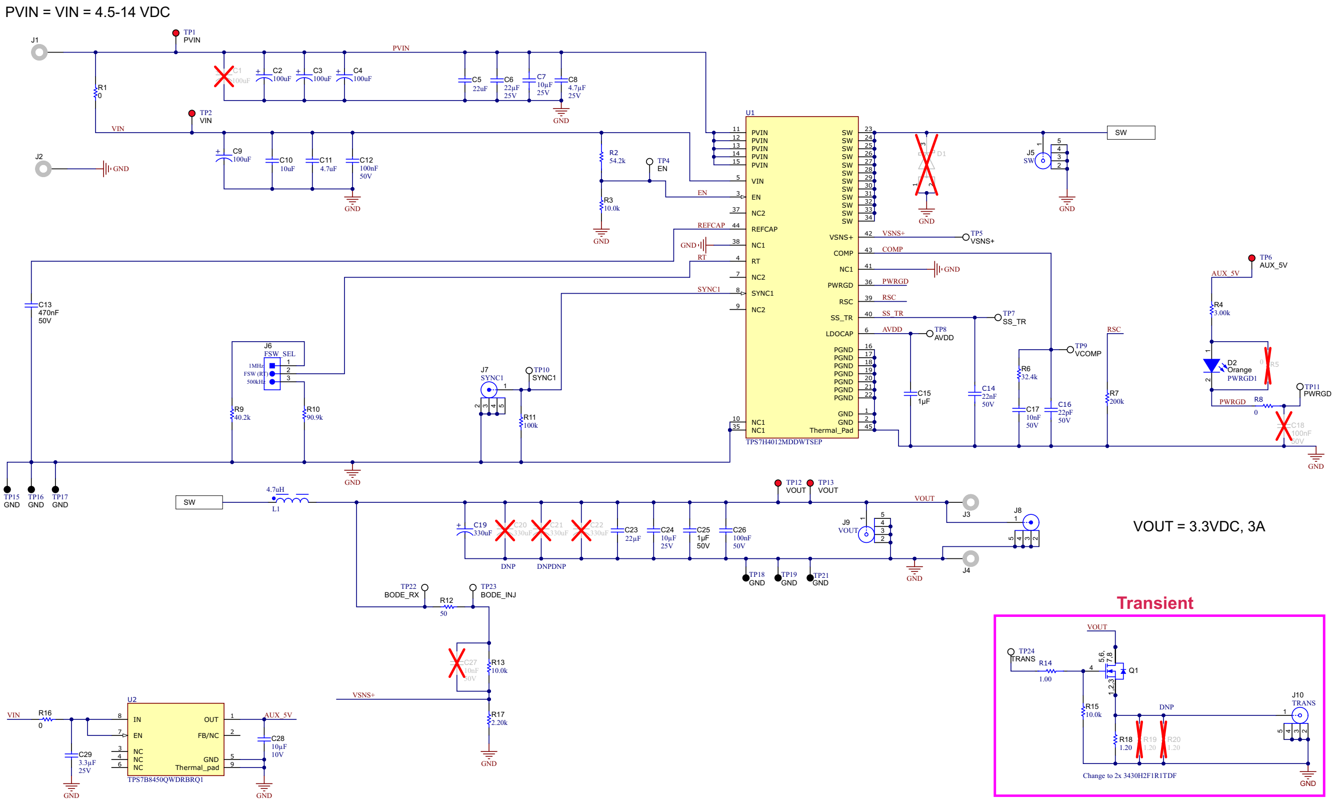


Figure 3-5. TPS7H4013EVM Schematics

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by the TAMU Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 1in 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 8.44×10^4 to 1.33×10^5 ions/cm^2/s were used to provide heavy-ion fluences of 1.00×10^6 to 1.00×10^7 ions/cm^2.

For the experiments conducted on this report, there was one ion used ^{165}Ho. ^{165}Ho was used to obtain LET_{EFF} of 75 MeV×cm^2/mg. The total kinetic energies for the ion was:

- ^{165}Ho = 2.474GeV (15MeV/nucleon)
  - Ion uniformity for these experiments was between 95% and 96%

Figure 4-1 and Figure 4-2 shows the TPS7H401xEVM used for data collection at the TAMU facility. Although not visible in this photo, the beam port has a 1mil 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 40mm for all runs.

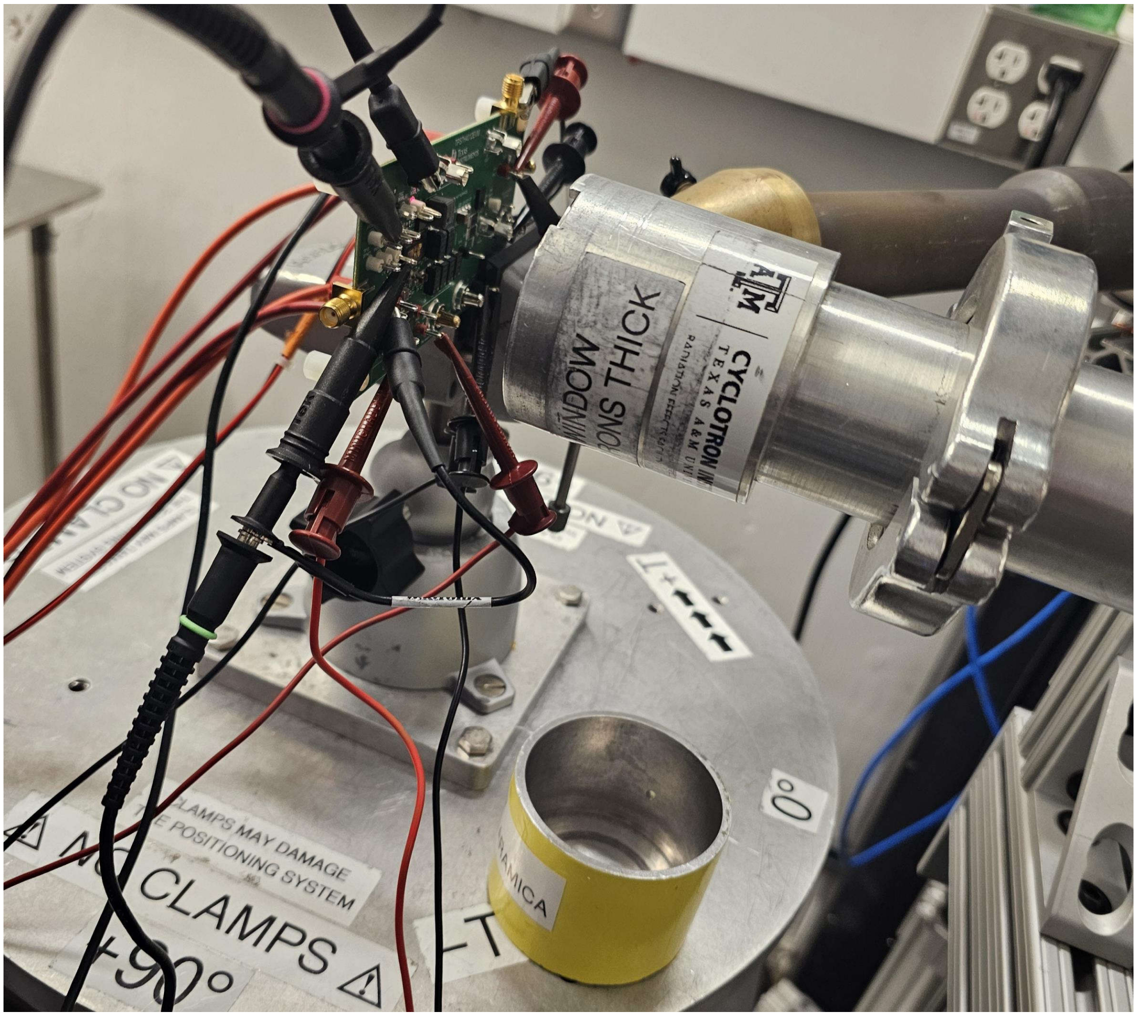


Figure 4-1. Photograph of the TPS7H4012-SP EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

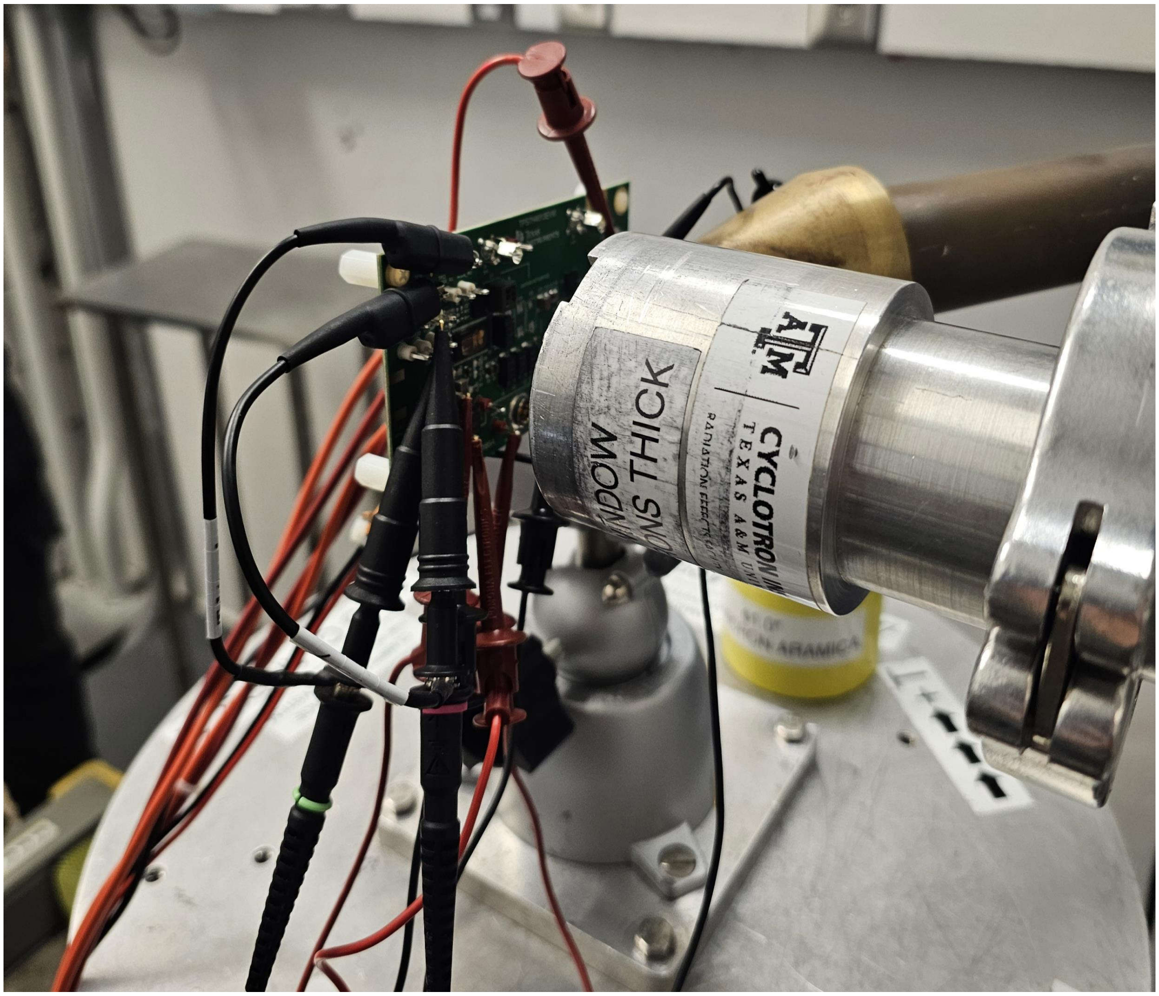
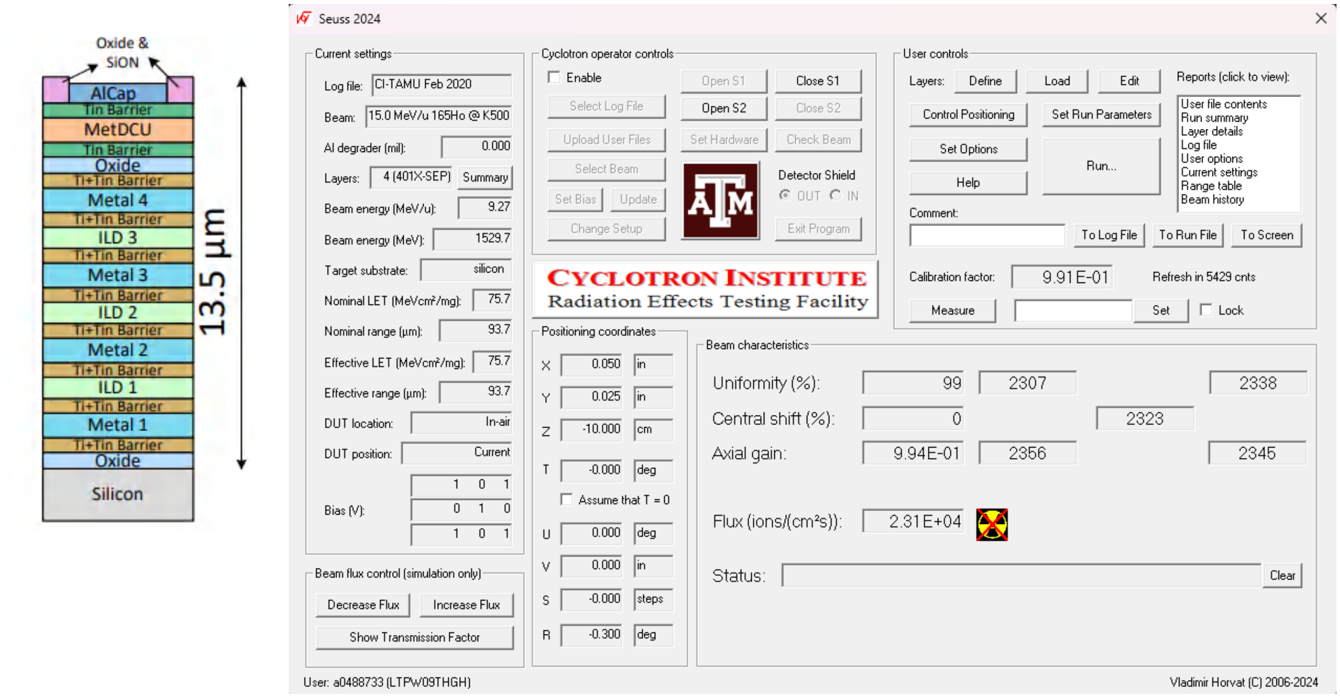


Figure 4-2. Photograph of the TPS7H4013-SP EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

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



Log file: CI-TAMU Feb 2020
Beam: 15.0 MeV/u 165Ho @ K500
Al degrader (mil): 0.000
Layers: 4 (401X-SEP)
Beam energy (MeV/u): 9.27
Beam energy (MeV): 1529.7
Target substrate: silicon
Nominal LET (MeVcm²/mg): 75.7
Nominal range (µm): 93.7
Effective LET (MeVcm²/mg): 75.7
Effective range (µm): 93.7
DUT location: In-air
DUT position: Current
Bias (V): 1 0 1 / 0 1 0 / 1 0 1

X 0.050 in
Y 0.025 in
Z -10.000 cm
T -0.000 deg
U 0.000 deg
V 0.000 in
S -0.000 steps
R -0.300 deg

Calibration factor: 9.91E-01
Refresh in 5429 cnts

Uniformity (%): 99 2307 2338
Central shift (%): 0 2323
Axial gain: 9.94E-01 2356 2345
Flux (ions/(cm²s)): 2.31E+04
Status:

User: a0488733 (LTPW09THGH)
Vladimir Horvat (C) 2006-2024

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H401x-SP (Left) and SEUSS 2020 Application Used to Determine Key Ion Parameters (Right)

The TPS7H401x-SP is fabricated in the TI Linear BiCMOS 250-nm process with a back-end-of-line (BEOL) stack consisting of four levels of standard thickness aluminum and Damascene copper. The total stack height from the surface of the passivation to the silicon surface is 13.5µm 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 40mm air gap, and the BEOL stack over the TPS7H401x-SP, the effective LET (LET$_{EFF}$) at the surface of the silicon substrate and the depth 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.

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)
^{165}Ho	15	0	0	0	97.2	75

6 Test Setup and Procedures

There were two input supplies used to power the TPS7H401x-SP which provided V_{IN} and EN. The V_{IN} for the device was provided through Channel 3 of an N6705C power module and ranged from 5 and 12V for SET to 14V for SEL and SEB/SEGR. EN was powered by Channel 1 of an E36311A power supply and ranged from 0V for SEB Off to 5V for all other testing. AUX_5V was supplied via channel 2 of an E36311A power supply in order to drive PWRGD high to 5V during the SEE testing.

The instrument used to load the TPS7H401x-SP was a Chroma 63600 E-Load that was used in Constant Resistance (CR) mode. For the TPS7H4012-SP, the value of CR was 0.5436Ω and provided a 6A load on the device. For the TPS7H4013-SP, the value of CR was 1.0872Ω and provided a 3A load on the device.

The primary signal monitored on the EVM was V_{OUT} and this was done using a PXIe-5172 scope card with a 3% window trigger based on the nominal measured value of V_{OUT}. All SEL, SEB On, 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. The secondary signals monitored were the PWRGD and SS_TR pins. These signals were monitored on their own PXIe-5172 cards and were configured to have negative edge triggers. Both had a negative edge trigger at 50% below nominal.

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 TPS7H4012-SP and Figure 6-2 shows a block diagram of the setup used for SEE testing of the TPS7H4013-SP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the TPS7H401x-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
AUX_5V	E36311A (CH #2)	25V, 1A	0.1A	5V
V_{OUT}	PXIe-5172 (1)	100MS/s	—	100MS/s
SS_TR	PXIe-5172 (2)	100MS/s	—	100MS/s
PWRGD	PXIe-5172 (3)	100MS/s	—	100MS/s
V_{OUT}	Chroma 63600 E-Load	80A	High	—

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 test facilities. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H401x-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, 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.

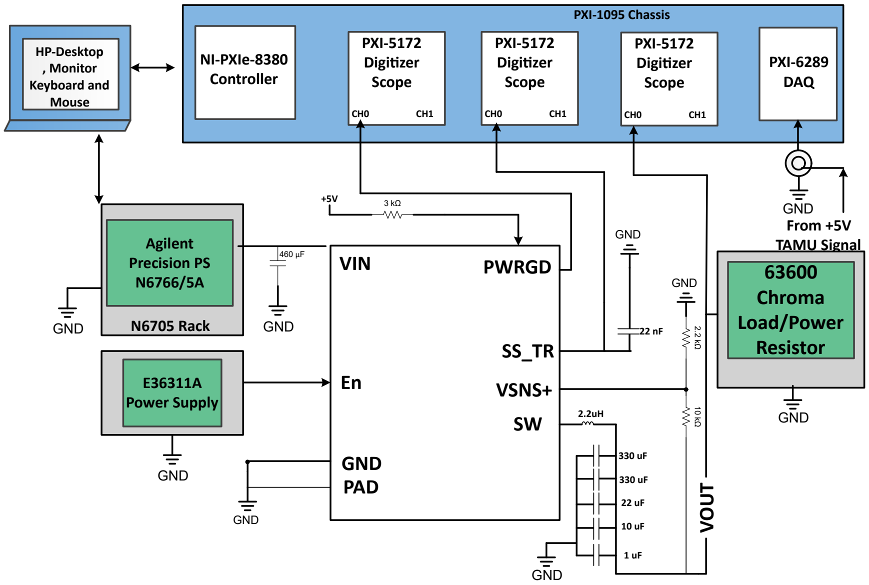


Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H4012-SP

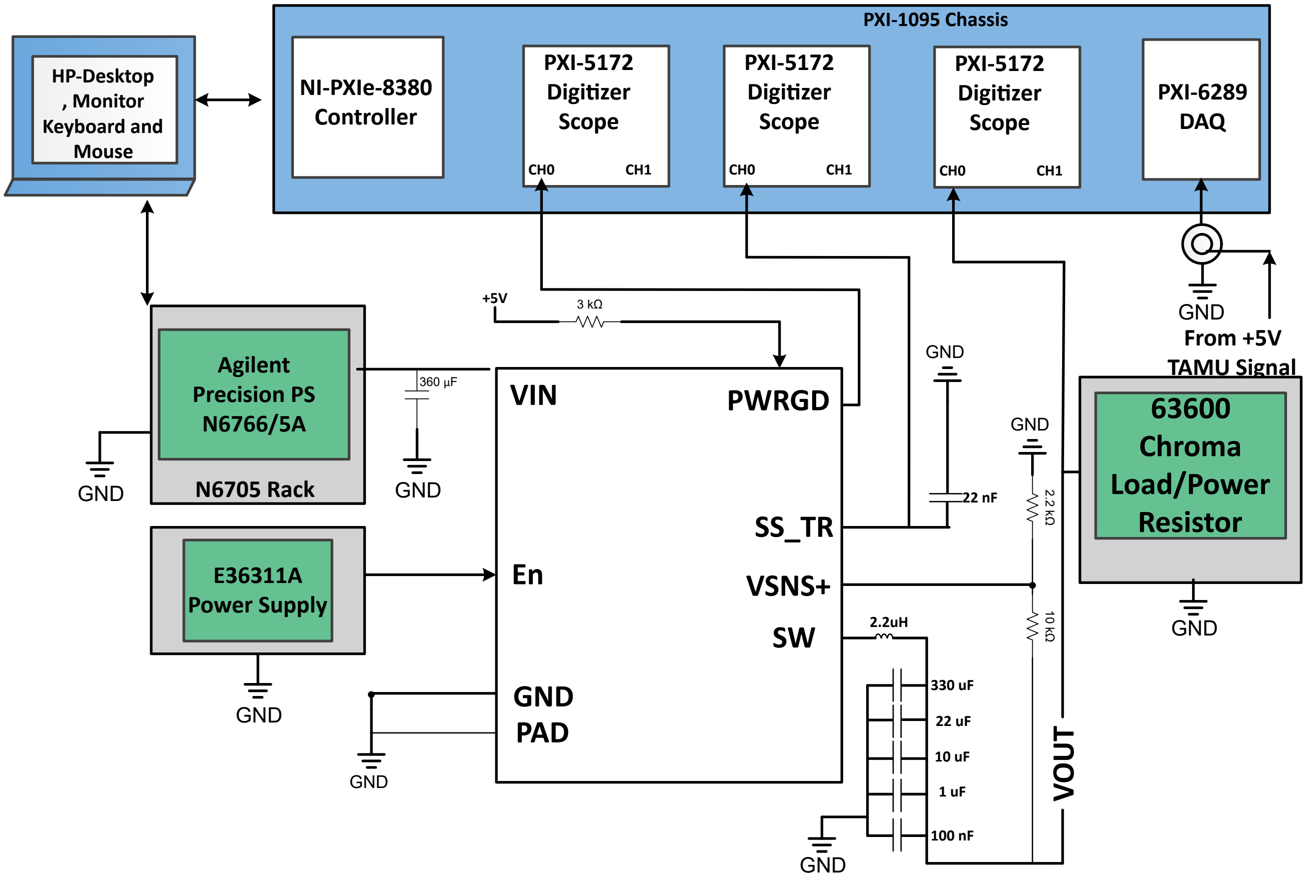


Figure 6-2. Block Diagram of the SEE Test Setup for the TPS7H4013-SP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

During the SEL testing the device was heated to 125°C by using a Closed-Loop 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 species used for the SEL testing was Holmium (^{165}Ho at 15MeV/nucleon). For the ^{165}Ho ion an incidence angle of 0° was used to achieve an LET_{EFF} = 75 MeV×cm^2/mg (For more details, see Table 5-1). The kinetic energy in the vacuum for this ions is 2.474 GeV. Flux of ≈1 × 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 eight devices were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 14V with the maximum recommended load of each respective device. No SEL events were observed during all eight runs, indicating that the TPS7H401x-SP is SEL-free up to 75 MeV×cm^2/mg. Note that due to the performance of the TPS7H4011-SP an experiment was conducted with the TPS7H4012-SP and the TPS7H4013-SP to determine if a SW to GND Schottky diode was required for operation during SEE testing. As shown in the table below it was found that both the TPS7H4012-SP and TPS7H4013-SP pass the full SEL run conditions regardless of whether or not the Schottky is present, indicating the Schottky is not required for SEE performance.Table 7-1 shows the SEL test conditions and results. Figure 7-1 shows a plot of the current versus time for run 3.

Table 7-1. Summary of TPS7H401x-SP SEL Test Condition and Results

Device	Run Number	Unit Number	SW to GND Schottky?	Ion	LET_{EFF} (MeV × cm^2/mg)	Flux (ions/cm^2/s)	Fluence (ions /cm^2)	V_{IN}	I_{OUT} (A)	SEL (# Events)
TPS7H4012-SP	1	1	Yes	^{165}Ho	75	9.76 × 10^4	1 x 10^7	14	6	0
	2	2	Yes	^{165}Ho	75	9.72 × 10^4	1 x 10^7	14	6	0
	3	3	No	^{165}Ho	75	1.08 × 10^5	1 x 10^7	14	6	0
	4	4	No	^{165}Ho	75	1.02 × 10^5	1 × 10^7	14	6	0
TPS7H4013-SP	5	5	Yes	^{165}Ho	75	1.07 × 10^5	1 × 10^7	14	3	0
	6	6	Yes	^{165}Ho	75	1.09 × 10^5	1 × 10^7	14	3	0
	7	7	No	^{165}Ho	75	1.26 × 10^5	1 × 10^7	14	3	0
	8	8	No	^{165}Ho	75	1.28 × 10^5	1 × 10^7	14	3	0

Using the MFTF method shown in *Single-Event Effects (SEE) Confidence Interval Calculations* and combining (or summing) the fluences of the eight runs at 125°C (8 × 10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as: $\sigma_{SEL} \leq 4.61 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75 MeV×cm^2/mg and T = 125°C.

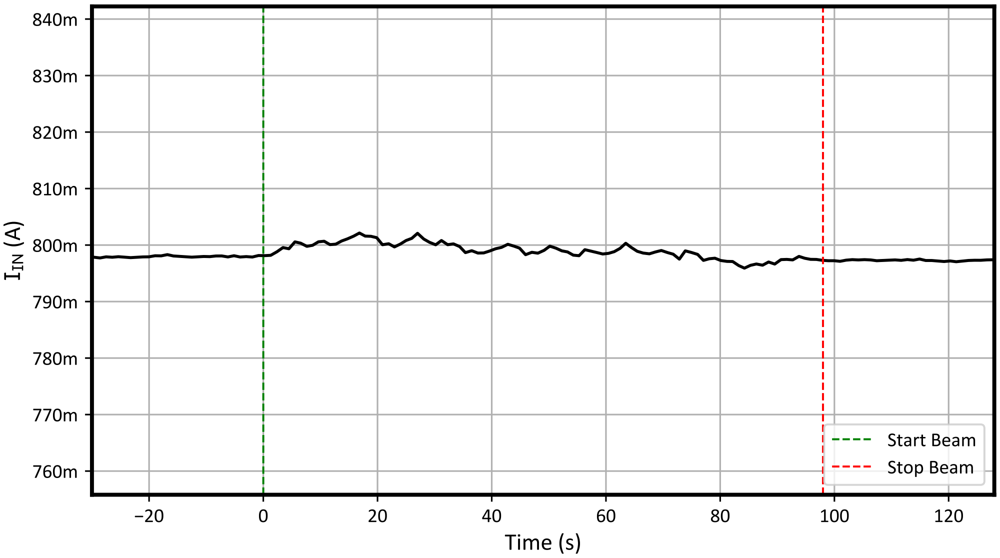


Figure 7-1. SEL Current versus Time for Run 3 of the TPS7H4013-SP at T = 125°C (V_{OUT} = 3.3V)

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 ≈25°C. The device was tested under both the enabled and disabled mode. For the SEB-OFF mode the device was disabled using the EN-pin by forcing 0V (using Channel 1 of a E36311A Keysight PS). During the SEB/SEGR testing with the device enabled/disabled, not a single input current event was observed.

The species used for the SEB testing was Homium (^{165}Ho @ 15MeV/nucleon). For the ^{165}Ho ion an angle of incedence of 0° was used to achieve an LET_{EFF} = 75 MeV×cm^2/mg (for more details refer to Table 5-1). The kinetic energy in the vacuum for this ion is 2.474 GeV (15-MeV/amu line). Flux of ≈1×10^5 ions/cm^2/s and a fluence of ≈10^7 ions/cm^2 was used for the run. Run duration to achieve this fluence was ≈2 minutes. The eight devices (same as used in SEL testing) were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 14V with the max recommended load of each respective device. No SEB/SEGR current events were observed during the eight runs, indicating that the TPS7H401x-SP is SEB/SEGR-free up to LET_{EFF} = 75 MeV×cm^2/mg and across the full electrical specifications. Note that due to the electrical performance of the TPS7H4011-SP (14V, 12A buck) an experiment was conducted with the TPS7H4012-SP and the TPS7H4013-SP to determine if a Schottky diode from SW to GND was required for operation during SEE testing. As shown in the table below it was found that both the TPS7H4012-SP and TPS7H4013-SP pass the full SEB run conditions regardless of whether or not the Schottky is present, indicating the Schottky is not required for SEE performance. Table 7-2 shows the SEB/SEGR test conditions and results.

Table 7-2. Summary of TPS7H401x-SP SEB/SEGR Test Condition and Results

	Run Number	Unit Number	SW to GND Schottky ?	ION	LET_{EFF} (MeV × cm^2/mg)	FLUX (ions/cm^2/s)	FLUENCE (ions/ cm^2)	Enabled Status	V_{IN}	I_{OUT} (A)	SEB EVENT?
TPS7H4012-SP	9	1	Yes	^{165}Ho	75	1.04 x 10^5	9.99 x 10^6	EN	14	6	No
	10		Yes	^{165}Ho	75	9.19×10^4	9.99×10^6	DIS	14	6	No
	11	2	Yes	^{165}Ho	75	9.98×10^4	1.00×10^7	EN	14	6	No
	12		Yes	^{165}Ho	75	9.74×10^4	1.00×10^7	DIS	14	6	No
	13	3	No	^{165}Ho	75	8.44×10^4	1.00×10^7	EN	14	6	No
	14		No	^{165}Ho	75	1.24×10^5	1.00×10^7	DIS	14	6	No
	15	4	No	^{165}Ho	75	1.02×10^5	1.00×10^7	EN	14	6	No
	16		No	^{165}Ho	75	9.82 x 10^4	1.00 x 10^7	DIS	14	6	No
TPS7H4013-SP	17	5	Yes	^{165}Ho	75	1.07×10^5	1.00 x 10^7	EN	14	3	No
	18		Yes	^{165}Ho	75	1.13×10^5	1.00 x 10^7	DIS	14	3	No
	19	6	Yes	^{165}Ho	75	1.06×10^5	1.00 x 10^7	EN	14	3	No
	20		Yes	^{165}Ho	75	1.17×10^5	1.00 x 10^7	DIS	14	3	No
	21	7	No	^{165}Ho	75	1.27×10^5	1.00 x 10^7	EN	14	3	No
	22		No	^{165}Ho	75	1.31×10^5	1.00 x 10^7	DIS	14	3	No
	23	8	No	^{165}Ho	75	1.25×10^5	1.00 x 10^7	EN	14	3	No
	24		No	^{165}Ho	75	1.33×10^5	1.00 x 10^7	DIS	14	3	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:

$\sigma_{SEB} \leq 2.31 \times 10^{-8}$ cm^2/ device for LET_{EFF} = 75 MeV×cm^2/mg and T = 25°C.

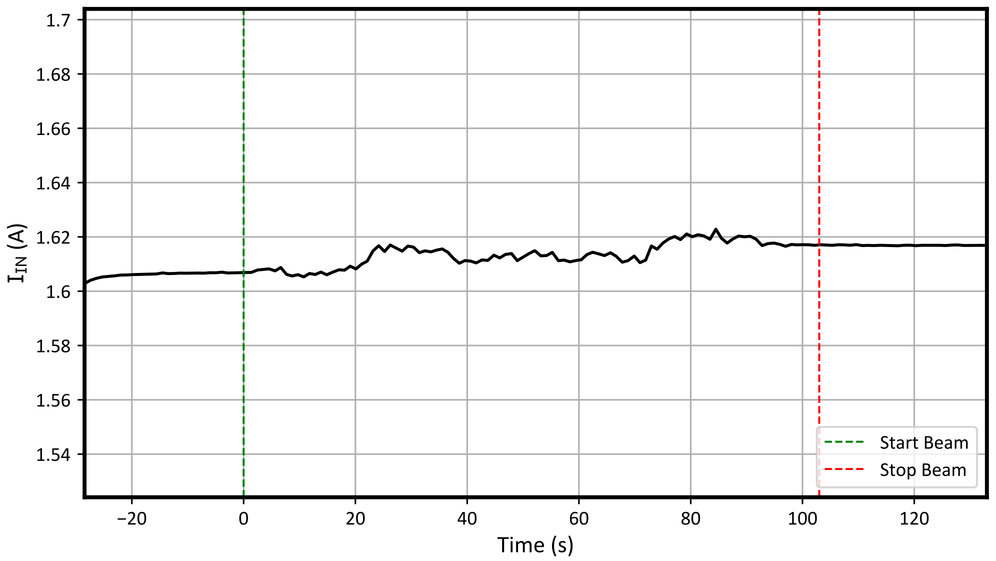


Figure 7-2. SEB On Current vs Time for Run 9 of the TPS7H4012-SP at T = 25°C (V_{OUT} = 3.3V)

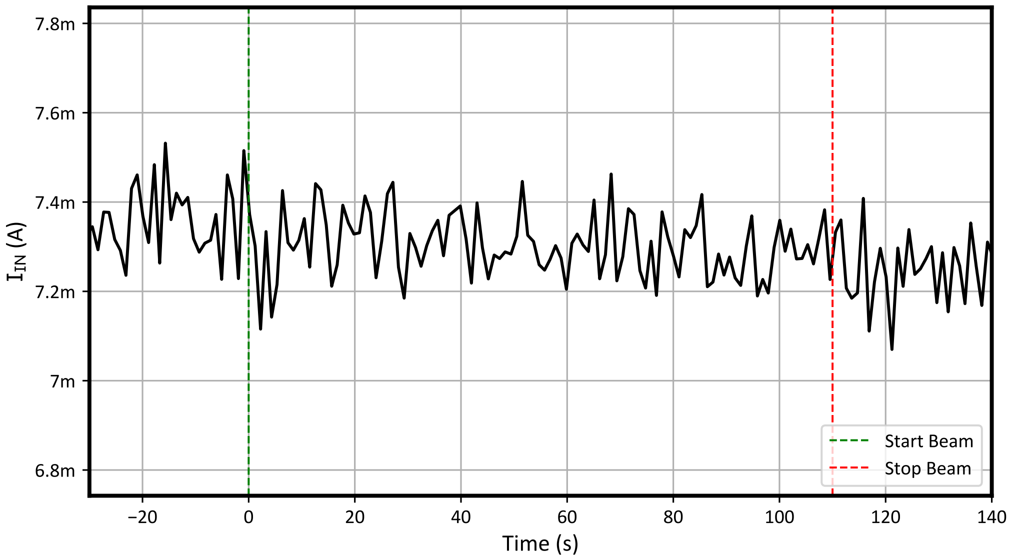


Figure 7-3. SEB Off Current vs Time for Run 10 of the TPS7H4012-SP at T = 25°C (V_{OUT} = 0V)

8 Single-Event Transients (SET)

SETs are defined as heavy-ion-induced transients upsets on the VOUT, SS_TR, or PWRGD of the TPS7H401x-SP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ion species used for the SET testing was Homium (^{165}Ho) for an LET_{EFF} = 75 MeV×cm^2/mg, for more details refer to Table 5-1. Flux of ≈1 × 10^5 ions/cm^2/s and a fluence of 1×10^7 ions/cm^2, per run were used for the SET characterization discussed on this chapter. Over the course of testing eight devices, not a single transient or SEFI was recorded on any of the monitored signals during the V_{IN} = 12V case indicating that the TPS7H401x-SP is SET/SEFI free up to LET_{EFF} = 75 MeV×cm^2/mg at V_{IN} = 12V.

During the V_{IN} = 5V case, two TPS7H4012-SP and two TPS7H4013-SP units that were tested under this condition recorded normal transients greater than 3%. These transients are listed and characterized in tables and figures below. All transients recovered on their own without the need for external intervention and all magnitudes and recovery times are shown in the histogram plots below. Please note that both the TPS7H4012EVM and TPS7H4013EVM have less output capacitance than the original TPS7H4011EVM-CVAL. Please refer to the EVM schematics shown in the Device and Test Board section and the SEE test block diagrams in the Test Setup and Procedures section, as well as the TPS7H4011-SP device page to compare the output capacitances and see the delta in output transient performance under the diferent bias conditions.

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)	VOUT	Window	±3%	50k	100MS/s
PXIe-5172 (2)	SS_TR	Edge/Negative	50%	50k	100MS/s
PXIe-5172 (3)	PWRGD	Edge/Negative	50%	50k	100MS/s

Table 8-2. Summary of TPS7H401x-SP SET Test Condition and Results

Device	Run Number	Unit Number	ION	LET_{EFF} (MeV × cm^2/mg)	V_{IN} (V)	FLUX (ions/cm^2/s)	Fluence (ions/cm^2)	V_{OUT} SET ≥ |3%| (#)	SS_TR SET (#)	PWRGD SET (#)
TPS7H4012-SP	25	1	^{165}Ho	75	12	1.05×10^5	1.00×10^7	0	0	0
	26		^{165}Ho	75	5	1.02×10^5	1.00×10^7	0	0	0
	27	2	^{165}Ho	75	12	1.09×10^5	1.00×10^7	0	0	0
	28		^{165}Ho	75	5	1.06×10^5	1.00×10^7	2	0	0
	29	3	^{165}Ho	75	12	1.05×10^5	1.00×10^7	0	0	0
	30		^{165}Ho	75	5	1.02×10^5	1.00×10^7	109	0	0
	31	4	^{165}Ho	75	12	1.09×10^5	1.00×10^7	0	0	0
	32		^{165}Ho	75	5	1.06×10^5	1.00×10^7	0	0	0
TPS7H4013-SP	33	5	^{165}Ho	75	12	1.08×10^5	1.00×10^7	0	0	0
	34		^{165}Ho	75	5	1.11×10^5	1.00×10^7	159	0	0
	35	6	^{165}Ho	75	12	1.28×10^5	1.00×10^7	0	0	0
	36		^{165}Ho	75	5	1.27×10^5	1.00×10^7	46	0	0
	37	7	^{165}Ho	75	12	1.05×10^5	1.00×10^7	0	0	0
	38		^{165}Ho	75	5	1.02×10^5	1.00×10^7	148	0	0
	39	8	^{165}Ho	75	12	1.09×10^5	1.00×10^7	0	0	0
	40		^{165}Ho	75	5	1.06×10^5	1.00×10^7	195	0	0

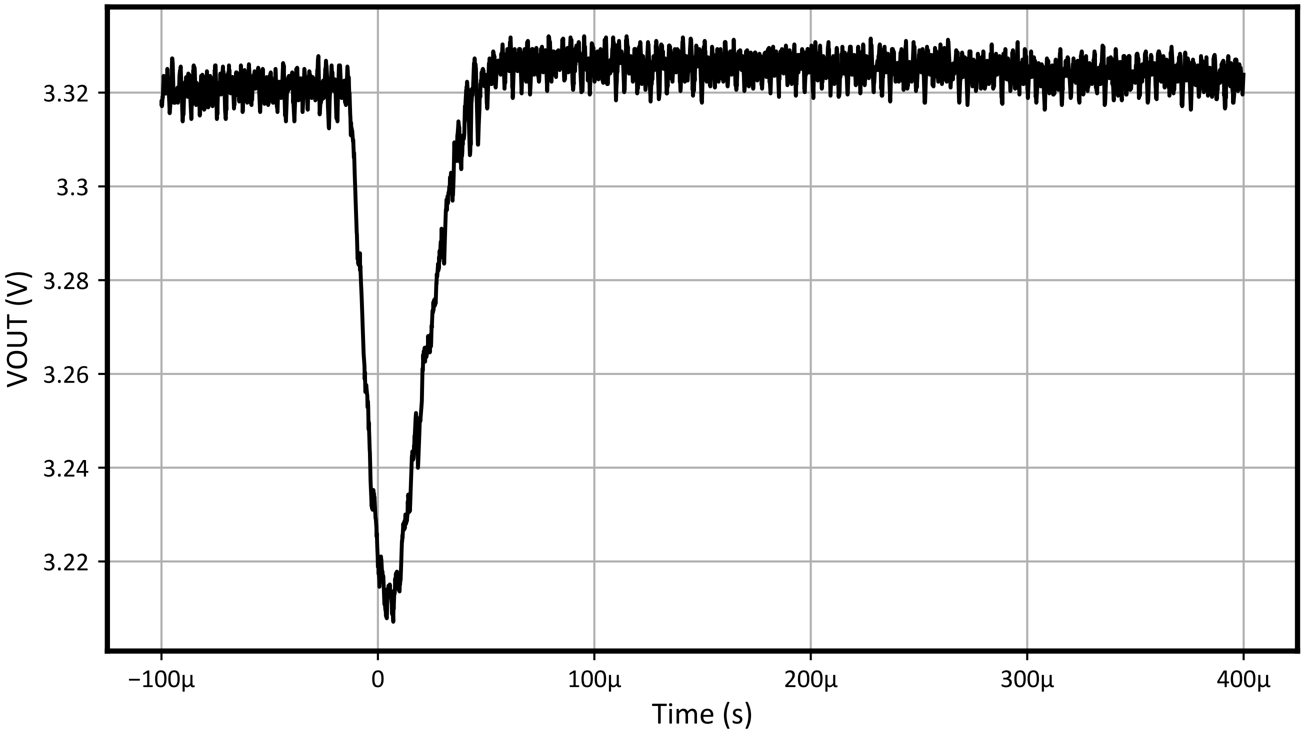


Figure 8-1. TPS7H4012-SP V_{OUT} SET for Run 26 (V_{IN}=5V)

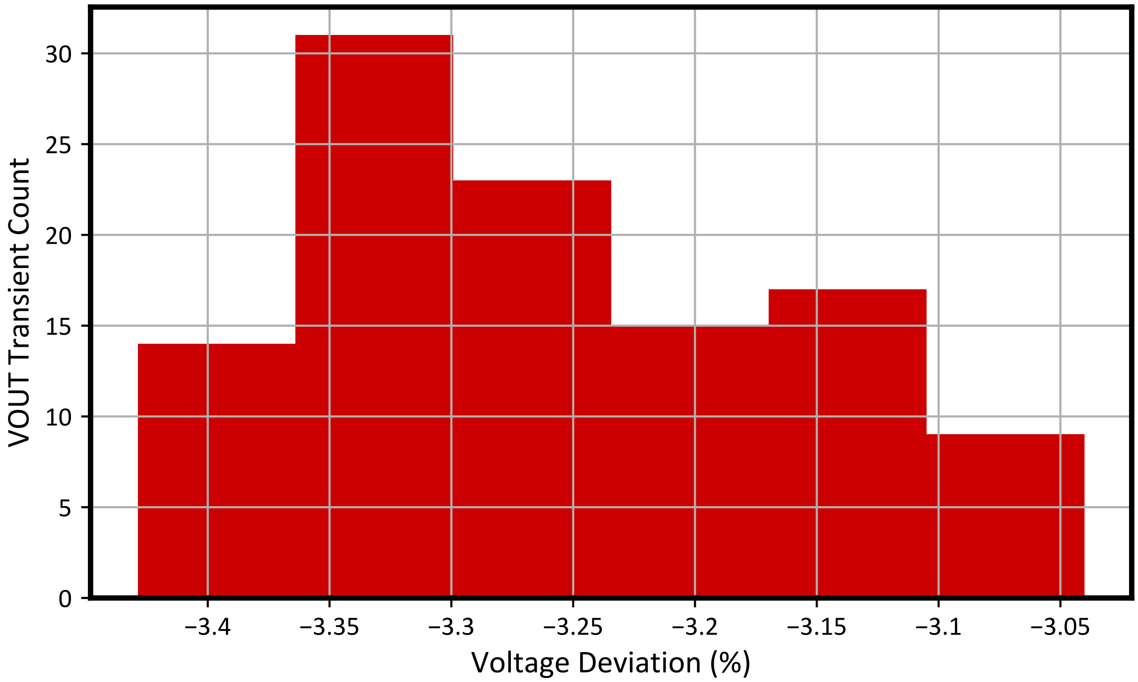


Figure 8-2. TPS7H4012-SP V_{OUT} SET Voltage Deviation (%) Histogram

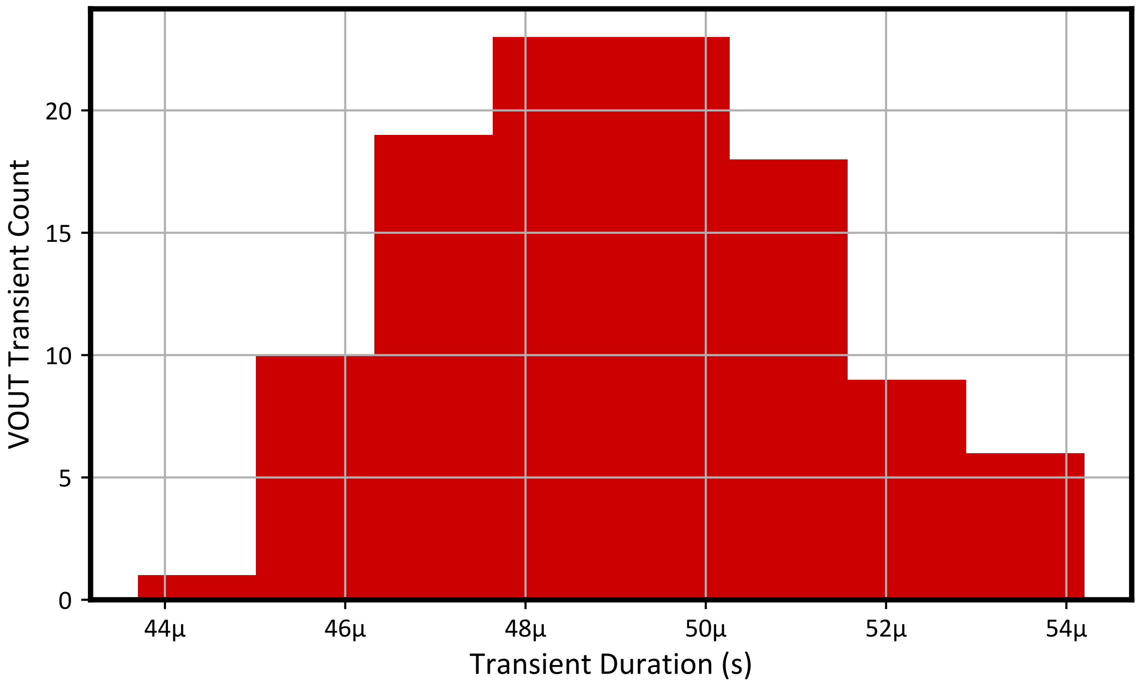


Figure 8-3. TPS7H4012-SP V_{OUT} SET Transient Duration (s) Histogram

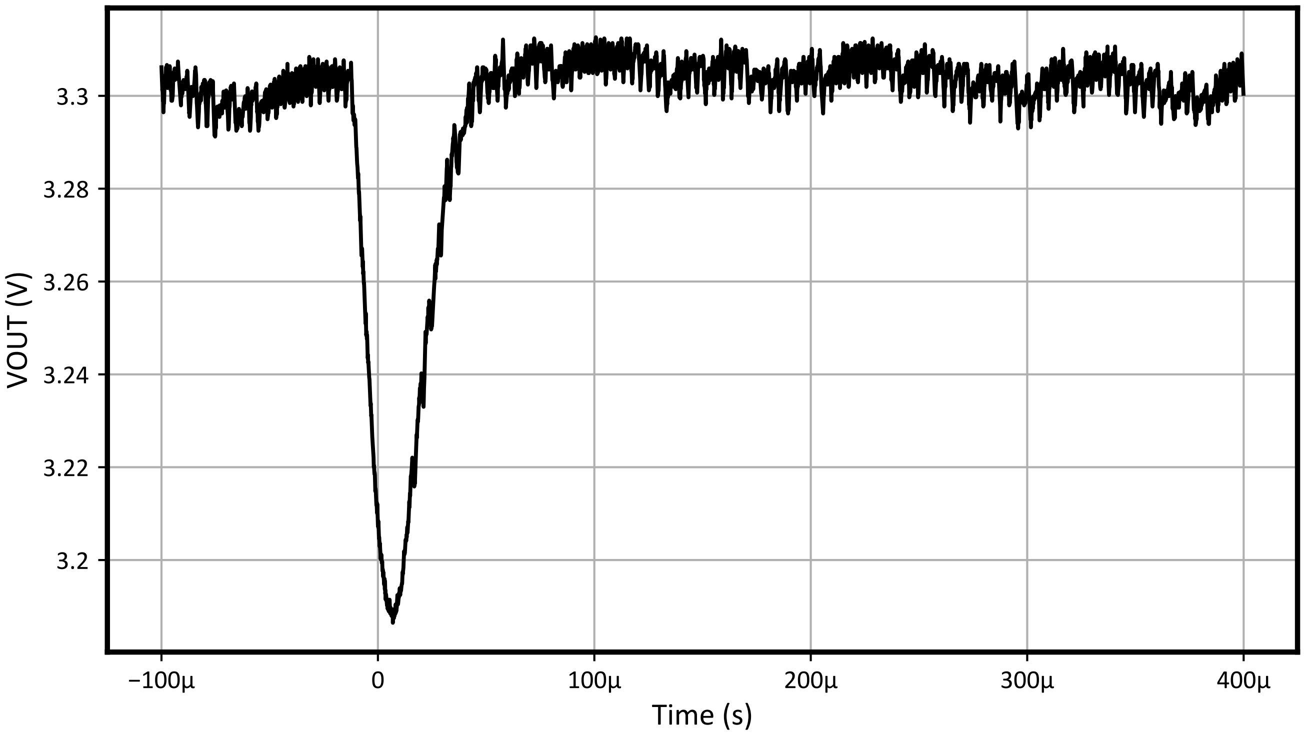


Figure 8-4. TPS7H4013-SP V_{OUT} SET for Run 34 (V_{IN}=5V)

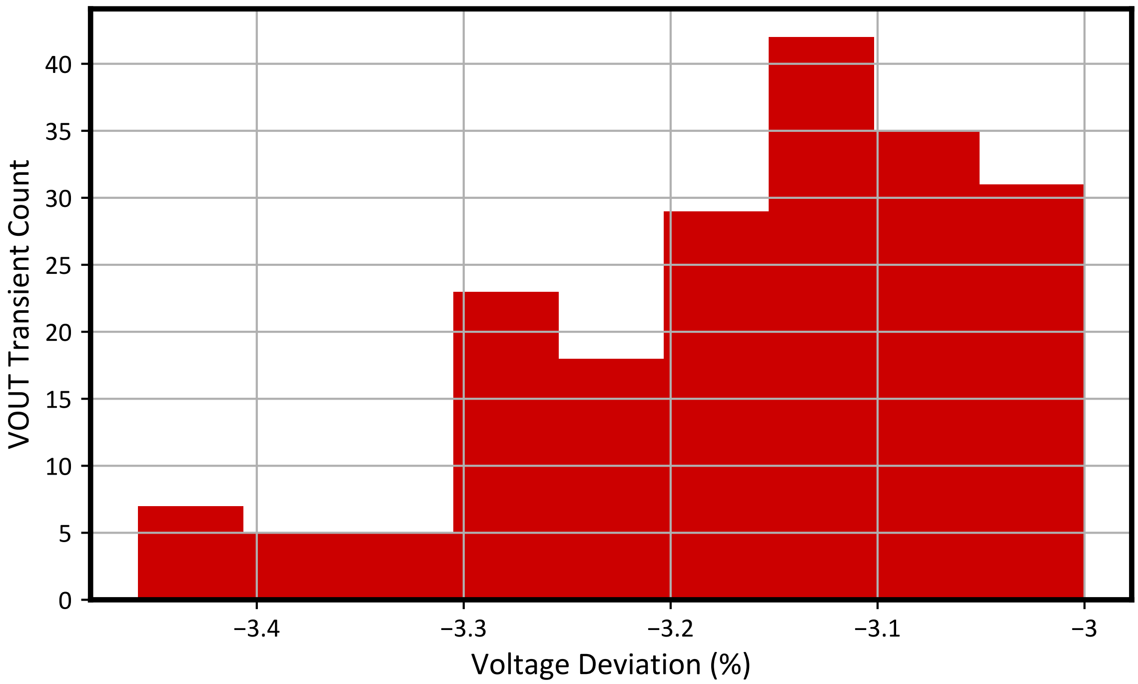


Figure 8-5. TPS7H4013-SP V_{OUT} SET Voltage Deviation (%) Histogram

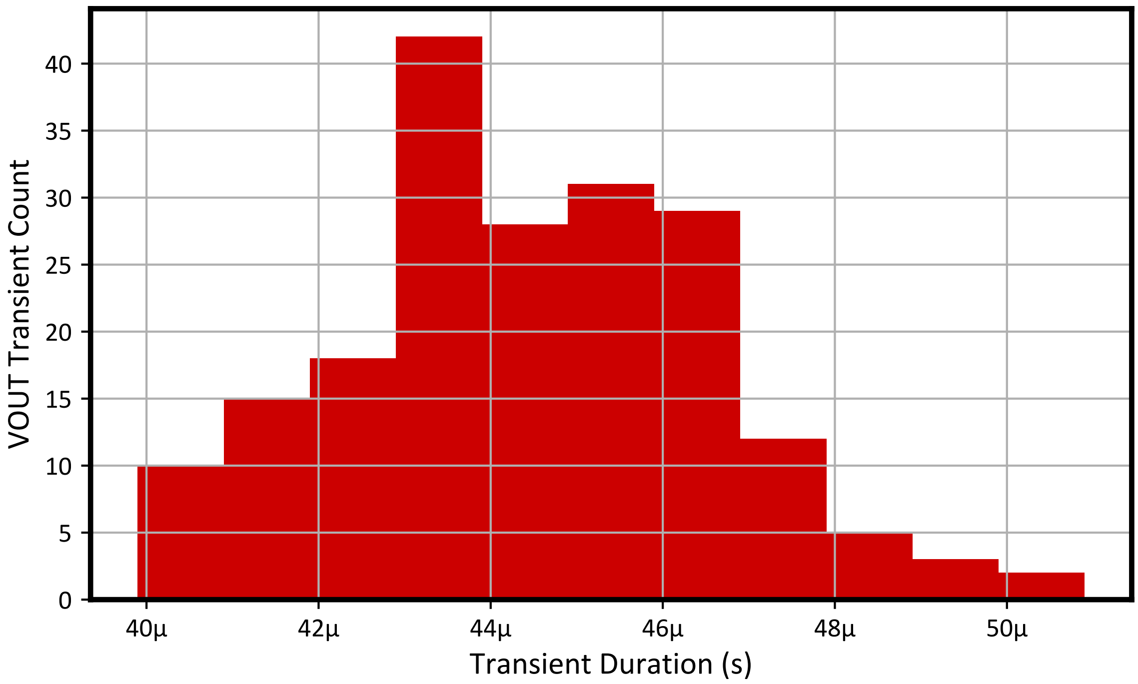


Figure 8-6. TPS7H4013-SP V_{OUT} SET Transient Duration (s) Histogram

Table 8-3. TPS7H401x-SP SET Cross-Sections

Device	VIN (V)	# SETs	Fluence (ions/cm^2)	Upper-Bound Cross-Section (cm^2)
TPS7H4012-SP	5	113	4.00×10^7	3.34×10^{-6}
	12	0	4.00×10^7	9.22×10^{-8}

Table 8-3. TPS7H401x-SP SET Cross-Sections (continued)

Device	VIN (V)	# SETs	Fluence (ions/cm^2)	Upper-Bound Cross-Section (cm^2)
TPS7H4013-SP	5	832	4.00×10^7	1.49×10^{-5}
	12	0	4.00×10^7	9.22×10^{-8}

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*. Assume a minimum shielding configuration of 100mils (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 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 9-2, respectively. Note that this number is for reference since no SEL, SEB/SEGR, or V_{IN}=12V 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}	4.61×10^{-8}	2.89×10^{-12}	1.20×10^{-4}	9.49×10^{8}
GEO		1.77×10^{-4}		8.15×10^{-12}	3.40×10^{-4}	3.36×10^{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}	2.31×10^{-8}	1.44×10^{-12}	6.01×10^{-5}	1.90×10^{9}
GEO		1.77×10^{-4}		4.08×10^{-12}	1.70×10^{-4}	6.72×10^{8}

Table 9-3. V_{IN}=12V 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}	4.61×10^{-8}	2.89×10^{-12}	1.20×10^{-4}	9.49×10^{8}
GEO		1.77×10^{-4}		8.15×10^{-12}	3.40×10^{-4}	3.36×10^{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 TPS7H401x-SP synchronous buck converter. Heavy-ions with LET_{EFF} = 75 MeV×cm^2/mg were used for the SEE characterization campaign. Flux of ≈1×10^5 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 TPS7H401x-SP is free of destructive SEL and SEB and SEFI free up to LET_{EFF} = 75 MeV×cm^2/mg across the full electrical specifications. SETs are characterized and discussed at LET_{EFF} = 75 MeV×cm^2/mg. CREME96-based worst-week event-rate calculations for LEO(ISS) and GEO orbits for the DSEE and V_{IN}=12V SET cases are presented for reference.

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