Radiation Report

TPS7H5001-SP, TPS7H5002-SP,TPS7H5003-SP and TPS7H5004-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 TPS7H500x-SP. Destructive single-event-effects (DSEE) performance was verified at the maximum recommended voltage of 14 V. SET performance was verified over a variety of different operating conditions including: internal and external clock, F_{SW} = 1 and 2 MHz, error amp (in unity gain), and cross conduction. For the transient characterization, input voltages of 4, 12, and 14 V were used (For TPS7H5002/3/4-SP only a nominal VIN of 12 V was used). Heavy-ions with LET_{EFF} of 30.5 to 75 MeV·cm^2/mg were used during the validation. A total of 11 devices were used for the data collection. Flux of ≈10^5 ions/cm2·s and fluences of ≈10^7 ions/cm^2 per run were used for the characterization. The results demonstrated that the TPS7H500x-SP is SEL and SEB/SEGR free up to 75 MeV·cm^2/mg, at T = 125°C and T = 25°C, respectively, and across the full electrical specifications. SET characterization is presented and discussed for a variety of different operating conditions. This report uses the QMLV TPS7H500X-SP device in a ceramic package. The report is also applicable for the QMLP TPS7H500X-SP device in a plastic package which uses the same die as the QMLV device.

Table of Contents

List of Figures

List of Tables

Trademarks

National Instruments™ and LabVIEW™ are trademarks of National Instruments.
Tektronix™ is a trademark of Tektronix, Inc..
HP-Z4™ is a trademark of HP Inc..
All trademarks are the property of their respective owners.

1 Introduction

The TPS7H500x-SP series (consisting of TPS7H5001-SP, TPS7H5002-SP, TPS7H5003-SP, and TPS7H5004-SP) is a family of high speed radiation-hardness-assured PWM controllers. The TPS7H5001-SP is the parent device with only interconnect differences to support the reduction of features for TPS7H5002/3/4-SP. The controllers provide a number of features that are beneficial for the design of DC-DC converter topologies intended for space applications. The controllers have a 0.613 V ±1 % accurate internal reference and configurable switching frequency up to 2 MHz. Each device offers programmable slope compensation and soft-start. The TPS7H500x-SP series can be driven using an external clock through the SYNC pin or by using the internal oscillator at a frequency programmed by the user. The controller family offers the user various options for switching outputs, synchronous rectification capability, dead time (fixed or configurable), leading edge blank time (fixed or configurable), and duty cycle limit. Each device in the TPS7H500x-SP series has a 22-pin CFP package.

Table 1-1 lists general device information and test conditions For more detailed technical specifications, user guides, and application notes, see the TPS7H500x-SP product page.

Table 1-1. Overview Information

Description(1)	Device Information
TI Part Number	TPS7H500x-SP
Orderable Number	5962R1822201VXC
Device Function	Si and GaN dual output controller
Technology	LBC7
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (25 and 15 MeV/nucleon)
Heavy Ion Fluence per Run	9.96×10^5 – 1.01×10^7 ions/cm^2
Irradiation Temperature	25°C (for SEB/SEGR testing), 25°C (for SET testing), and 125°C (for SEL testing)

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

Each TPS7H500x-SP device has a special set of outputs, configurations, and settings. From device to device, the number of outputs, dead-time and leading edge blank time configurability, and duty cycle limit options can vary. The table below gives a breakdown of each device in the TPS500x-SP series.

Table 1-2. TPS7H500x-SP Device Comparison Table

Device	Primary Outputs	Synchronous Rectifier Outputs	Dead-Time Setting	Leading Edge Blank Time Setting	Duty Cycle Limit Options
TPS7H5001-SP	2	2	Resistor Programmable	Resistor Programmable	50%, 75%, 100%
TPS7H5002-SP	1	1	Resistor Programmable	Resistor Programmable	75%, 100%
TPS7H5003-SP	1	1	Fixed (50-ns typical)	Fixed (50-ns typical)	75%, 100%
TPS7H5004-SP	2	0	Not Applicable	Resistor Programmable	50%

2 Single-Event Effects (SEE)

The primary concern for the TPS7H500x-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 TPS7H500x-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 TPS7H500x-SP was tested for SEL at the maximum recommended voltage of 14 V. The device exhibited no SEL when 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.

The TPS7H500x-SP was evaluated for SEB/SEGR at a maximum voltage of 14 V in the enabled and disabled mode. The device was tested at room temperature with no external thermal control device. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H500x-SP is SEB/SEGR-free up to LET_{EFF} = 75 MeV·cm^2/mg at a flux of ≈10^5 ions/cm^2·s, fluence of ≈10^7 ions/cm^2, and a die temperature of ≈25°C.

The TPS7H500x-SP was characterized for SET at flux of ≈1 × 10^5 ions/cm^2·s, fluence of approximately 1 × 10^7 ions/cm^2, and at room temperature. The TPS7H5001-SP device was characterized at V_{IN} of 4, 12, and 14 V. SET performance was verified over a variety of different operating conditions including: internal and external clock, F_{SW} = 1 and 2 MHz, error amp (in unity gain), and Cross Conduction. For the TPS7H5002/3/4-SP devices, only the 12 V SET performance was tested since the only difference between those devices and the TPS7H5001-SP device is the specific device options. Heavy-ions with LET_{EFF} of 30 to 75 MeV·cm^2/mg were used to characterize the transient performance. A total of 10 devices were used for the SET characterization. To see the SET results of the TPS7H500x-SP, see Section 8.

3 Device and Test Board Information

The TPS7H500x-SP is packaged in a 22-pin thermally-enhanced ceramic flatpack package as shown in Figure 3-1. To see specific pinout differences between TPS7H5001/2/3/4-SP, see the TPS7H5001-SP product page. A special test board designed specifically for radiation testing was used to evaluate the performance of the TPS7H500x-SP under heavy-ions. The test board is shown in Figure 3-2. Figure 3-3 shows the board schematics.

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

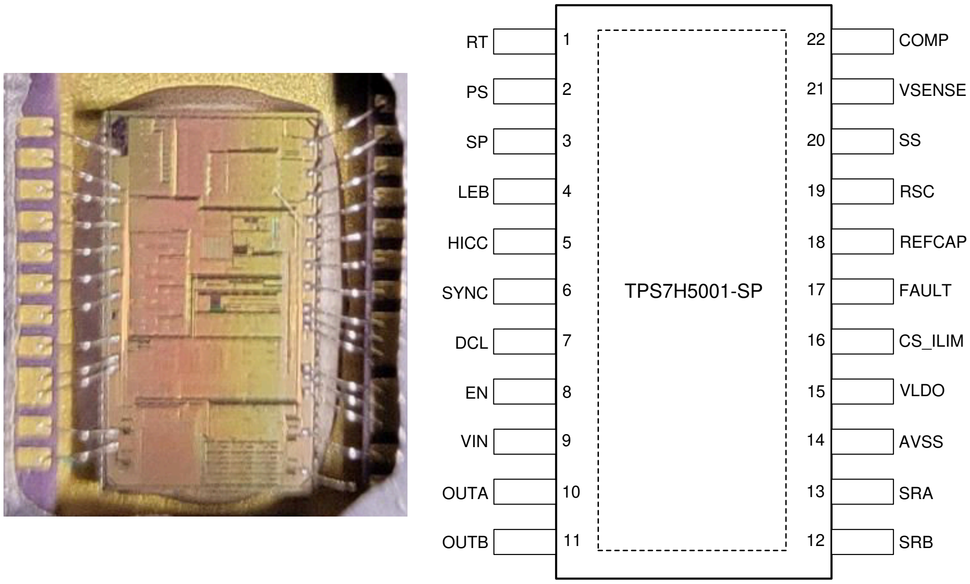


Figure 3-1. Photograph of Delidded TPS7H500x-SP (Left) and Pinout Diagram (Right)

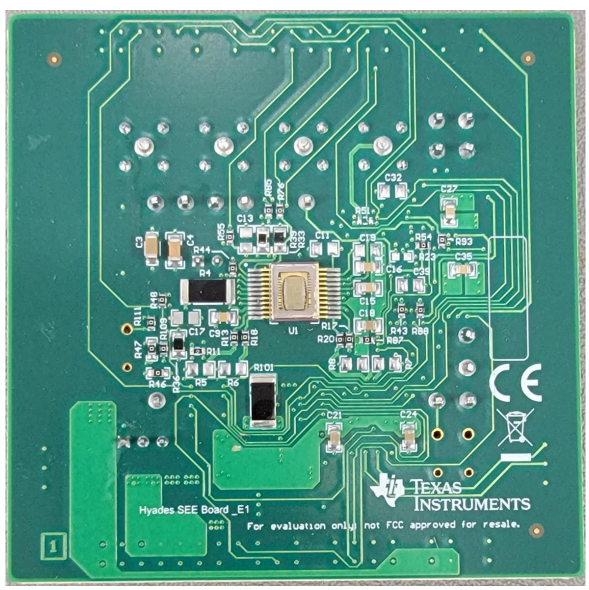


Figure 3-2. TPS7H500x-SP SEE Test Board Top View

For 2 MHz: PS = SP = LEB = 20 kΩ and R_{SC} = 15 kΩ.

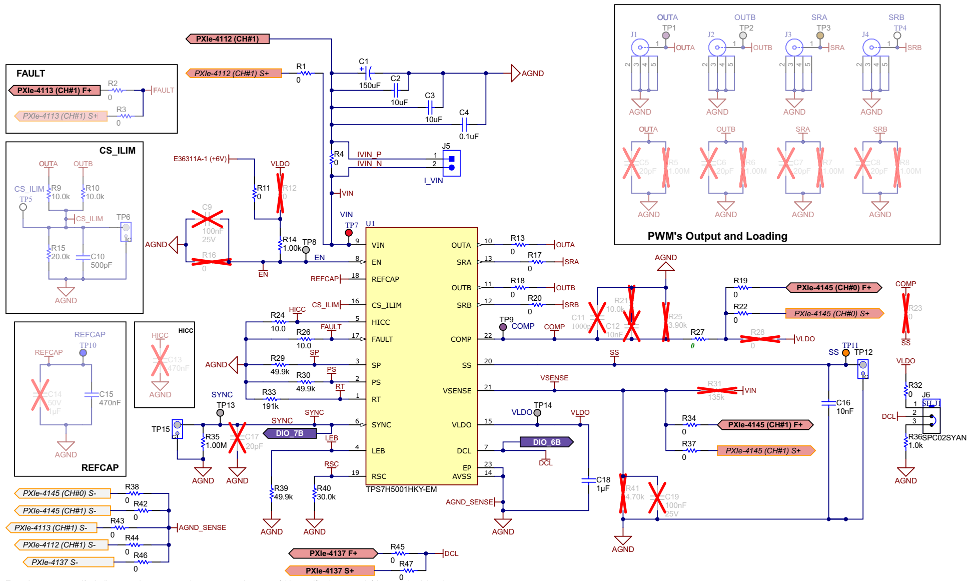


Figure 3-3. TPS7H500x-SP SEE Test Board Schematics

This EVM was used with non-production parts to validate the closed-loop performance. For further discussion, see Section 8.1.

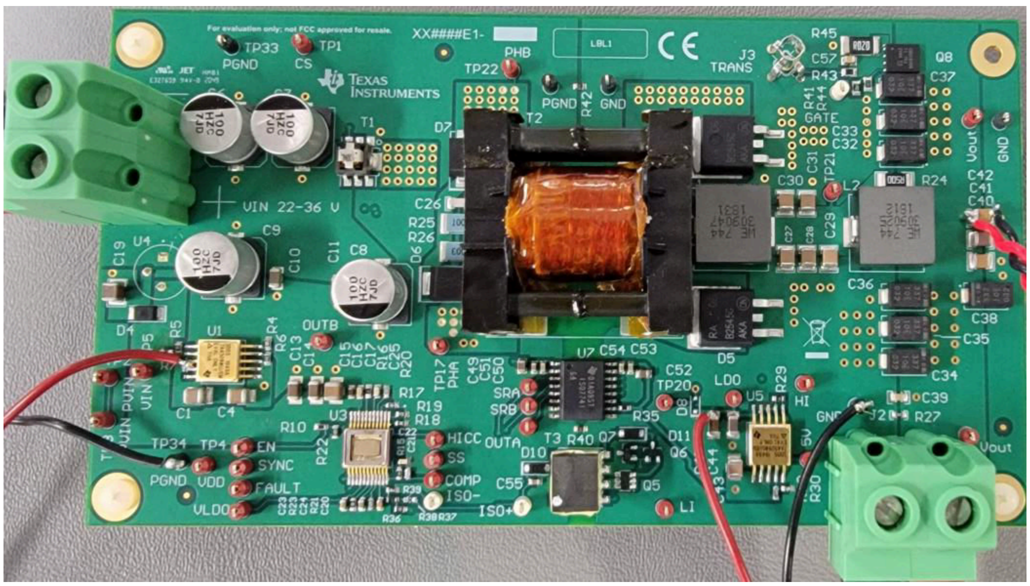


Figure 3-4. TPS7H5001-SP Push-Pull Closed-Loop EVM

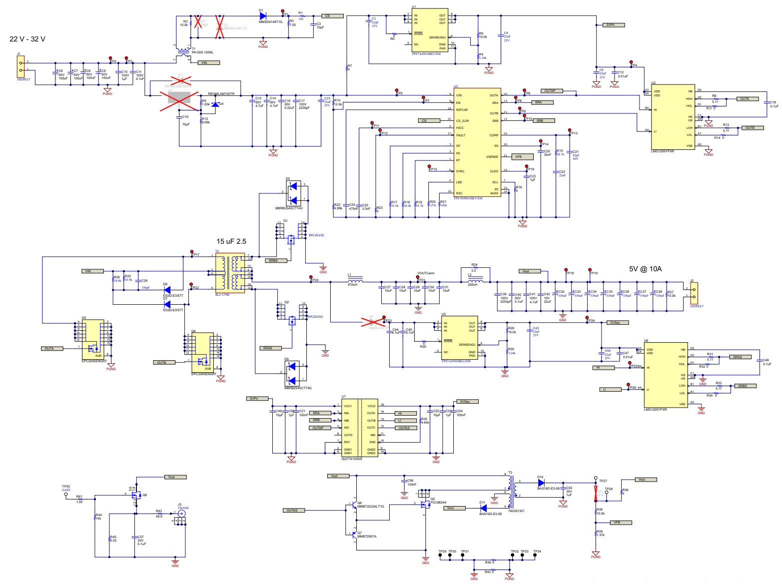


Figure 3-5. Push-Pull EVM Schematics

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 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 7.26×10^{4} to 1.65×10^{5} ions/cm^{2}·s was used to provide heavy-ion fluence of 9.96×10^{6} to 1.01×10^{7} ions/cm^{2}.

For the experiments conducted on this report, there were 4 ions used: Krypton (Kr), Silver (Ag), Praseodymium (Pr), and Holmium (Ho). Kr was used to obtain LET_{EFF} of 30.5, 37.3, and 40.6 MeV·cm^{2}/mg. Ag was used to obtain LET_{EFF} of 47.8 MeV·cm^{2}/mg. Pr was used to obtain LET_{EFF} of 65 and 75 MeV·cm^{2}/mg. Lastly, Ho was used to obtain LET_{EFF} of 75 MeV·cm^{2}/mg. The total kinetic energy for each of the ions are shown in Table 4-1.

Table 4-1. Total Kinetic Energy for Ions Used

Ion Used	Ion Uniformity Range
^{84}Kr = 2.081 GeV (15 MeV/nucleon)	94% to 95%
^{109}Ag = 1.634 GeV (15 MeV/nucleon)	95% to 97%
^{141}Pr = 2.114 GeV (15 MeV/nucleon)	90% to 96%
^{165}Ho = 2.47 GeV (15 MeV/nucleon)	91% to 95%

Figure 4-1 shows the TPS7H500x-SP SEE Test Board used for the data collection 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. The in-air gap between the device and the ion beam port window was maintained at 40 mm for all runs.

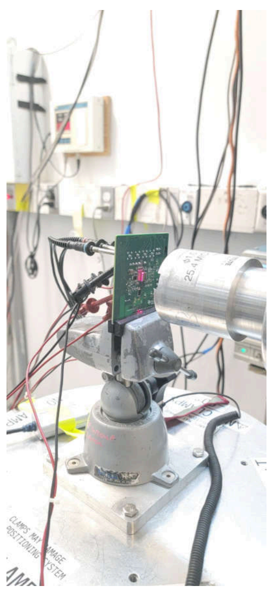


Figure 4-1. Photograph of the TPS7H500x-SP SEE Test Board in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 Depth, Range, and LET_{EFF} Calculation

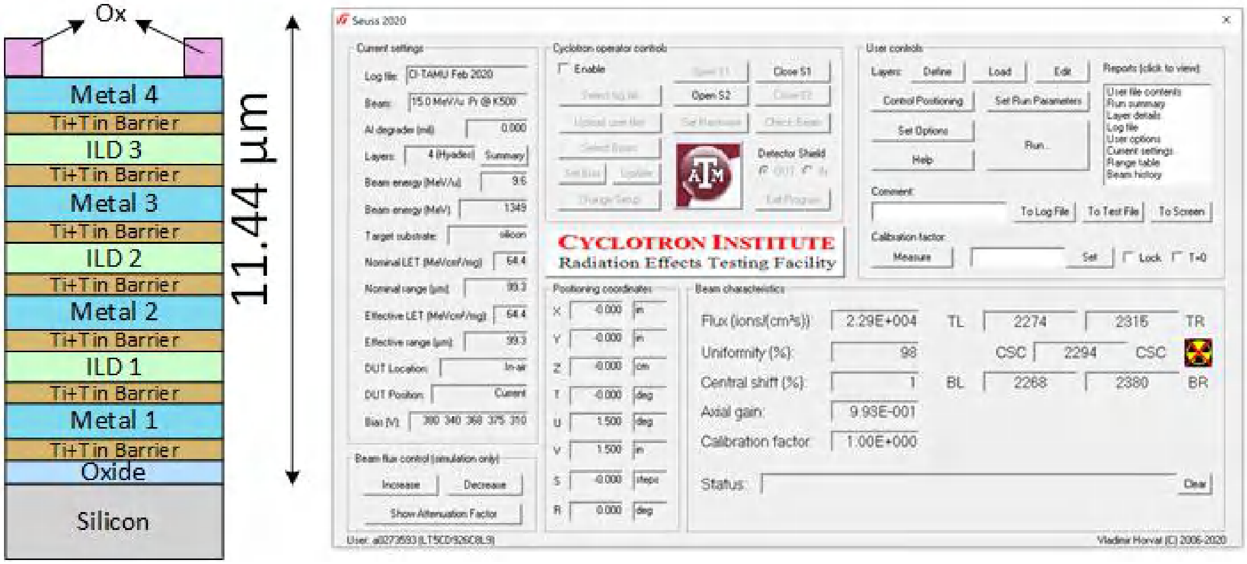


Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H500x-SP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right]

The TPS7H500x-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 11.44 µm based on nominal layer thickness as shown in Figure 5-1. Accounting for energy loss through the 1-mil thick Aramica beam port window, the 40-mm air gap, and the BEOL stack over the TPS7H500x-SP, the effective LET (LET_{EFF}) at the surface of the silicon substrate, the depth, and the ion range was determined with the SEUSS 2020 Software (provided by the Texas A&M Cyclotron Institute and based on the latest SRIM-2013 models [7]). Table 5-1 shows the results . The LET_{EFF} vs range for the used heavy-ion are shown inFigure 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. Ion LET_{EFF}, Depth, and Range in Silicon

Ion Type	Beam Energy (MeV/nucleon)	Angle of Incidence	Range in Silicon (µm)	LET_{EFF} (MeV·cm²/mg)
^{84}Kr	15	0	111	30.5
	15	32	85.1	37.3
	15	37.5	76	40.6
^{109}Ag	15	0	92	48.1
^{141}Pr	15	0	97.6	65
	15	28.5	79	75
^{165}Ho	15	0	94	75

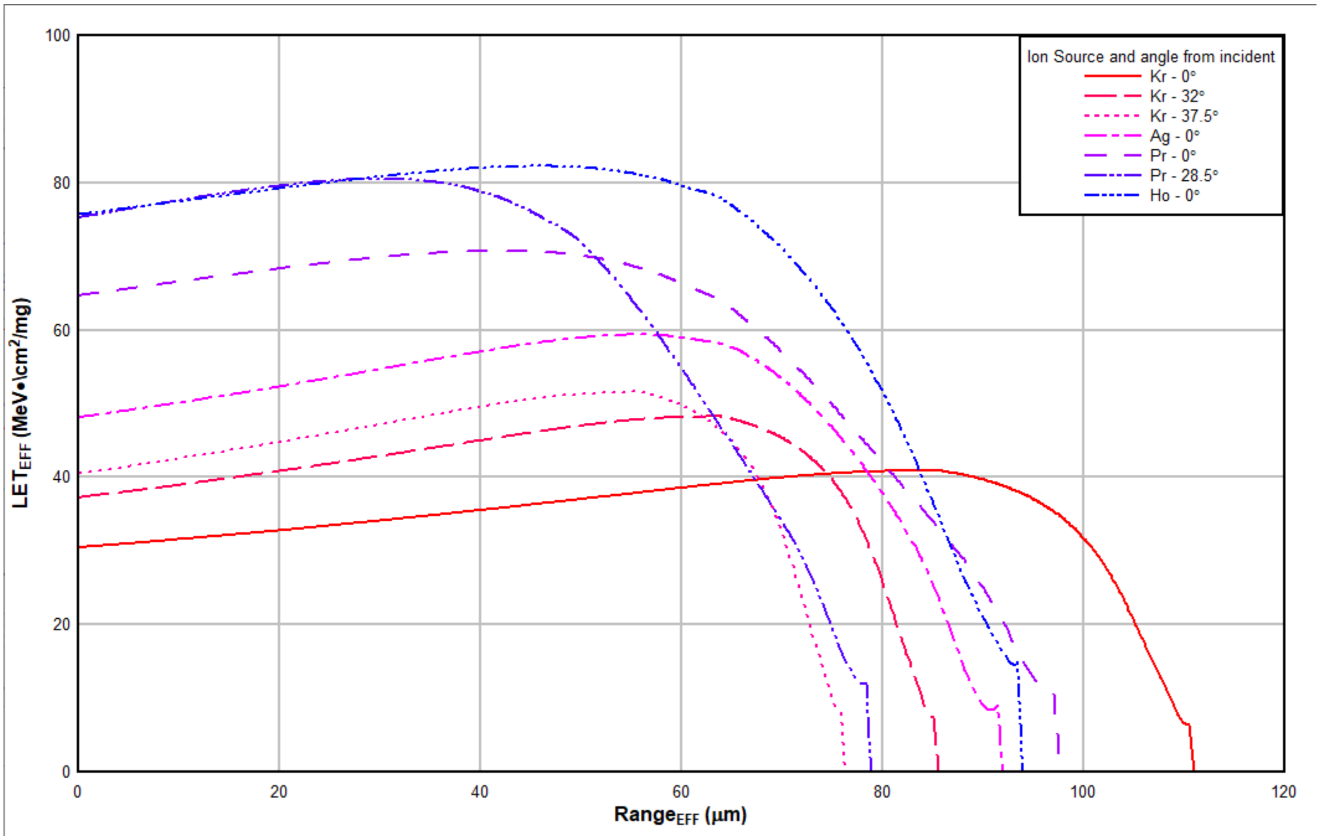


Figure 5-2. LET_{EFF} vs Range for Used Heavy Ions During the SEE Test Campaign

6 Test Setup and Procedures

The device power $(V)_{IN}$ was provided using the Agilent N6705C Power supply in a four-wire configuration. For the validation the device was tested using an "open-loop" configuration, under this configuration the V_{SENSE} and V_{COMP} voltages were forced externally using Channel 0 (CH 0) of two PXIe-4139 SMU (mounted on a PXI-1085 Chassis). For most of the testing, V_{SENSE} was set to 500 mV while V_{COMP} was set to 2 V. However, for F_{SW} = 1 MHz, V_{COMP} was programmed to 1.7 V. For F_{SW} = 2 MHz, V_{COMP} was programmed to 1.4 V, PS = SP = LEB = 20 kΩ and R_{SC} = 15 kΩ. To minimize transient filtering on the OUTX and SRX signals, the only loading on the signals was due to the probes used to monitored these signals (approximately 11 pF). DCL pin was connected to GND through a 1-kΩ pull-down for all testing.

For SEL, SEB, and SEGR testing, the device was powered up to the maximum recommended operating voltage of 14 V. During the SEL testing the device was heated to 125°C by using a TDH35P10R0JE discrete power resistor soldered under the thermal vias on the bottom layer of the coupon card. Using a PXIe-4139 SMU, a current of 1.2 A was forced into the power resistor elevating the die temperature to 125°C. The temperature of the die was verified using thermal camera. During the SEL testing not a single current event was observed.

For the SEB/SEGR characterization, the device was tested under the Enabled and Disabled modes. For the SEB-OFF mode the device was disabled using the EN pin by forcing 100 mV (using CH 0 of a E36311A Keysight PS). When device was on, 5 V was forced to the EN pin. During the SEB and SEGR testing with the device in both the Enabled and Disabled mode, not a single OUTA (only trigger signal used) transient or input current event was observed.

For the SET characterization, the device was powered up to V_{IN} of 4, 12, and 14 V (TPS7H5002/3/4-SP were characterized at 12 V only). Internal and external clocks were used for the validation. For the external clock, a PXIe-5433 AWG was used to provide a 1-MHz pulse clock with 50% duty cycle and 0-V (low level) to 5-V (high level) logic levels into the SYNC pin of the TPS7H5001-SP. During the external clock testing, the RT pin was left floating. Internal switching frequency of 1 MHz was used for the data collection. To characterize the transient performance of the error amp, the SENSE and COMP pins of the device were tied together to operate the amplifier on unity gain. As with the DSEE in which the device can be permanently damaged, the complementary operation of OUTX to SRX is mandatory in synchronous rectifier applications. Cross conduction was tested to check if a transient in critical logic of the TPS7H5001-SP resulting in a momentary non-complementary operation of outputs can occur by using an AND gate tied to OUTA and SRA. Not a single cross conduction upset was recorded during this testing. In addition to the OUTX and SRX, the SS and the VLDO were also characterized for SET.

The SET events were monitored using two National Instruments™ scopes and setup as described in the following:

- PXIe-5110 used to trigger from SRA or SRB using a outside pulse-width trigger at ±30%.
- PXIe-5162 used to trigger from SS using a negative-edge trigger at 600 mV.

In addition an Tektronix™ DPO7104C was used to trigger from OUTA, COMP, or the AND gate used for cross-conduction. Only one signal at a time was used as the trigger. For OUTA, an outside pulse-width trigger at ±30% was used. For the COMP signal, a window trigger at ±10% from the nominal (0.6 V) was used. For the AND gate, a positive-edge trigger at 2.5 V was used (AND gate was powered up at 5 V). For details on SET testing, see Section 8.

All equipment other than the DPO7104C 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. The DPO7104C manufacturer interface was used. The DPO was set to fast-frame for all SET data collection.

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 TPS7H5001-SP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the TPS7H5001-SP

Pin Name	Equipment Used	Capability	Compliance	Range of Values Used
V_{IN}	NI-PXIe 4112 (CH 0)	60 V, 1 A	0.1 A	4, 5, 7, 12, and 14 V
V_{COMP}	NI-PXIe 4139-1 (CH 0)	±6 V, 0.5 A	0.1 A	1.4, 1.7, and 2 V
V_{SENSE}	NI-PXIe 4139-2 (CH 1)			0.5 V
EN	E36311A (CH 0)	5 V, 5 A	0.1 A	100 mV, 5 V
Heater	NI-PXIe-4113	60 V, 3 A	3	1.2 A
SRX	NI-PXIe-5110	1 GS/s	—	100 MS/s
OUTX	DPO7104C	40 GS/s	—	2.5 and 5 GS/s
SS	PXIe-5162	1.5 GS/s	—	2.5 MS/s

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to make sure 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 TPS7H5001-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 pulse-width (OUTX and SRX) exceeded the pre-defined 30% pulse width trigger, a data capture was initiated. In addition to monitoring the time duration of the two scopes (OUTX and SRX), V_{IN} current and the 5-V signal from TAMU were monitored at all times. No sudden increases in current were observed (outside of normal fluctuations) on any of the test runs and indicated that no SEL or SEB/SEGR events occurred during any of the tests.

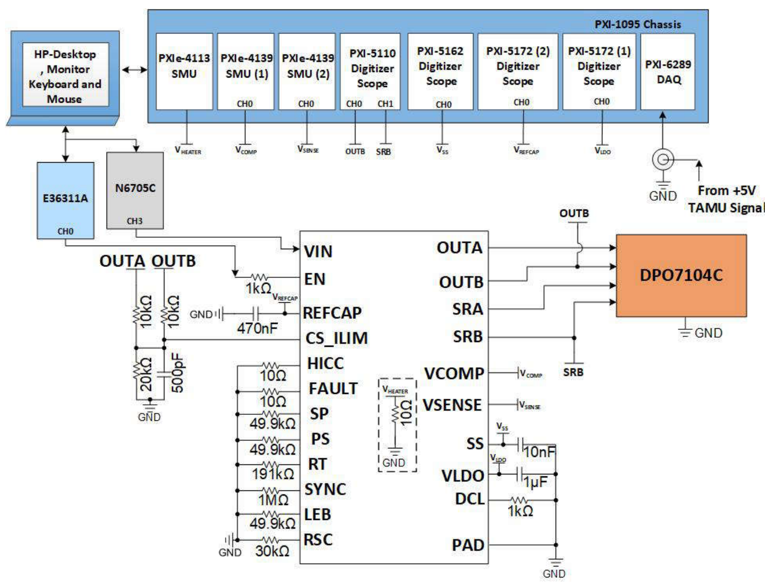


Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H5001-SP

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 TDH35P10R0JE discrete power resistor soldered right under the thermal vias on the bottom layer on the coupon card board. Using a PXIe-4113 SMU, a current of 1.2 A was forced into the power resistor elevating the die temperature to 125°C. The temperature of the die was verified using thermal camera.

The ion species used for the SEL testing was Holmium (^{165}Ho at 15 MeV/nucleon). For ^{165}Ho ion, only the incident angle was used for an LET_{EFF} = 75 MeV·cm^2/mg (for more details, see Section 5). Flux of approximately 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 approximately 2 minutes. The six devices (three for TPS7H5001-SP and one each for TPS7H5002/3/4-SP) were powered up and exposed to the heavy-ions using the maximum recommended voltage of 14 V. No SEL events were observed during all three runs, indicating that the TPS7H500X-SP is SEL-free up to 75 MeV·cm^2/mg. 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 TPS7H500X-SP SEL Test Condition and Results

Run #	Device	Unit #	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions·cm^2/mg)	Fluence (ions·cm^2/mg)	SEL Events
1	TPS7H5001	1	Ho	75	1.19×10^5	1×10^7	0
2	TPS7H5001	2	Ho	75	7.26×10^4	1×10^7	0
3	TPS7H5001	3	Ho	75	1.41×10^5	9.97×10^6	0
73	TPS7H5002	9	Ho	75	1.12×10^5	9.97×10^6	0
74	TPS7H5003	10	Ho	75	1.06×10^5	9.95×10^6	0
75	TPS7H5004	11	Ho	75	1.09×10^5	1×10^7	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* and combining (or summing) the fluences of the three runs (TPS7H5001-SP) at 125°C (3×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 1.23 \times 10^{-7}$ cm^2/ device for LET_{EFF} = 75 MeV·cm^2/mg and T = 125°C.

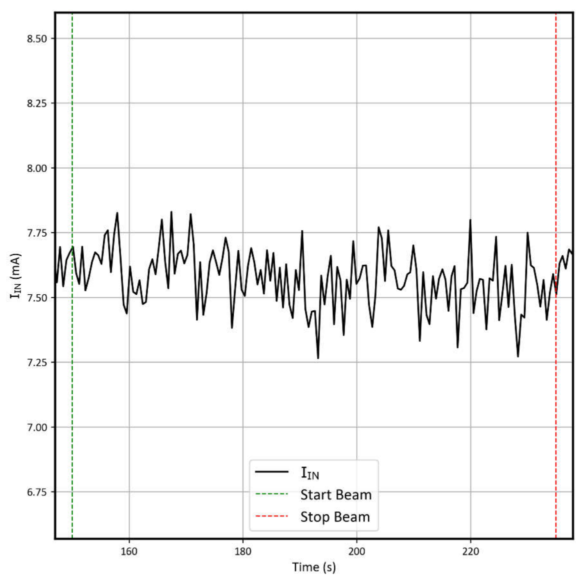


Figure 7-1. Current vs Time for Run #1 of the TPS7H5001-SP at T = 125°C

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

During the SEB and SEGR characterization, the device was tested at room temperature or approximately 25°C. The device was tested under the enabled and disabled mode. For the SEB-OFF mode the device was disabled using the EN pin by forcing 100 mV (using CH 0 of a E36311A Keysight PS). During the SEB and SEGR testing with the device in disabled mode, not a single OUTA (only trigger signal used) transient or input current event was observed.

The ion species used for the SEB and SEGR testing was Holmium (^{165}Ho) at incident angle for an LET_{EFF} = 75 MeV·cm^2/mg. Flux of approximately 10^5 ions/cm^2·s and a fluence of approximately 10^7 ions/cm^2 was used for the run. Run duration to achieve this fluence was approximately 2 minutes. The six devices (three for TPS7H5001-SP and one each for TPS7H5002/3/4-SP) were powered up using the recommended maximum voltage of 14 V. No SEB and SEGR current events were observed during the seven runs, indicating that the TPS7H500X-SP is SEB and SEGR-free up to LET_{EFF} = 75 MeV·cm^2/mg and across the full electrical specifications. Table 7-2 shows the SEB and SEGR test conditions and results. Figure 7-2 shows the current versus time for run #4 (Disabled) and Figure 7-3 shows the current versus time for run #6 (enabled).

Table 7-2. Summary of TPS7H5001-SP SEB/SEGR Test Condition and Results

Run #	Device	Unit #	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions·cm^2/mg)	Fluence (# ions)	Enabled Status
4	TPS7H5001	1	Ho	75	1.24×10^5	1.01×10^7	Disabled
5	TPS7H5001	1	Ho	75	1.26×10^5	9.96×10^6	Disabled
6	TPS7H5001	1	Ho	75	1.31×10^5	9.98×10^6	Enabled
7	TPS7H5001	2	Ho	75	9.73×10^4	1×10^7	Disabled
8	TPS7H5001	2	Ho	75	1.01×10^5	1×10^7	Enabled
9	TPS7H5001	3	Ho	75	1.17×10^5	9.96×10^6	Disabled
10	TPS7H5001	3	Ho	75	1.13×10^5	1×10^7	Enabled
76	TPS7H5002	9	Ho	75	1.06×10^5	9.96×10^6	Disabled
77	TPS7H5002	9	Ho	75	8.12×10^4	9.98×10^6	Enabled
78	TPS7H5003	10	Ho	75	1.14×10^5	9.96×10^6	Disabled
79	TPS7H5003	10	Ho	75	1.15×10^5	9.95×10^6	Enabled
80	TPS7H5004	11	Ho	75	1.13×10^5	1×10^7	Disabled
81	TPS7H5004	11	Ho	75	1.14×10^5	1×10^7	Enabled

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

$\sigma_{SEB} \leq 5.27 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75 MeV·cm^2/mg and T = 25°C.

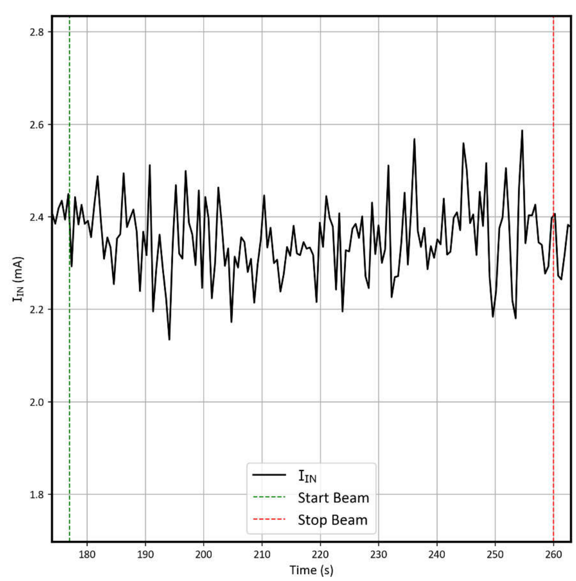


Figure 7-2. Current vs Time for Run #4 (Disabled) for the TPS7H5001-SP at T = 25°C

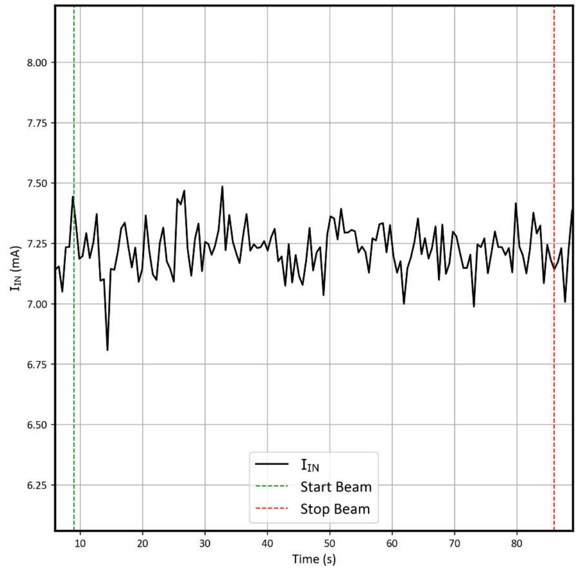


Figure 7-3. Current vs Time for Run #6 (Enabled) for the TPS7H5001-SP at T = 25°C

8 Single-Event Transients (SET)

SET are defined as heavy-ion-induced transients upsets on the OUTX, SRX, SS, and Error Amp (while in unity gain) of the TPS7H500x-SP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for the SET testing were Krypton (^{84}Kr), Silver (^{109}Ag), Praseodymium (^{141}Pr), and Holmium (^{165} Ho) for an LET_{EFF} = 30 to 75 MeV·cm^2/mg. For more details, see Ion LET_{EFF}, Depth, and Range in Silicon. Flux of 7.75 × 10^4 to 1.65 × 10^5 ions/cm^2·s and a fluence of 9.97 × 10^6 to 1 × 10^7 ions/cm^2, per run were used for the SET characterization.

SET testing was categorized as:

1. V_{IN} = 12 V (nominal) at $F_{\mathbf{SW}}$ = 500 kHz

   (All TPS7H500X-SP devices)

   .
2. V_{IN} = 14 V (max) at F_{SW} = 500 kHz.
3. V_{IN} = 4 V at F_{SW} = 500 kHz.
4. Error amplifier.
5. Cross conduction at F_{SW} = 500 kHz.
6. V_{IN} = 4 V (min) at F_{SW} = 500 kHz using an external clock with R_T = open.
7. V_{IN} = 14 V (max) at F_{SW} = 500 kHz using an external clock with R_T = open.
8. V_{IN} = 4 V (min) 12 V (nominal) and 14 V (max) at F_{SW} = 1 MHz using the internal clock with R_T = 90.9 kΩ.
9. V_{IN} = 4 V (min) 12 V (nominal) and 14 V (max) at F_{SW}= 2 MHz using the internal clock with R_T = 38.3 kΩ.

As the list shows, the only SET case that was repeated for the TPS7H5002/3/4-SP devices was the 12-V nominal at F_{SW} = 500 kHz case. All other SET cases were conducted with the TPS7H5001-SP. This was done due to how closely the TPS7H5002/3/4 devices correlated SET wise to the original TPS7H5001-SP device, specifically having similar number of OUTA and SRB transients and the same found onset.

Cross conduction is a concern in synchronous converter applications due to the possibility of a short circuit during an SET upset. In addition to the hardware X-conduction testing, all recorded upsets during all runs discussed on this report (SEL, SEB, and SET) were verified for such conditions when possible. Using software, cross conduction was verified for:

1. OUTA to SRA.
2. OUTB to SRB.
3. OUTA to OUTB.

The PWM signals were converted to digital levels by comparing the voltage levels of the recorded upset to an V_{IH} = 1.89 V (V_{IH} from the LMG1205 GaN driver was used). If the signals were greater than this voltage, a digital one was returned. Otherwise, a logical 0 was recorded. After the signals were converted into a digital value array, a BITAND was implemented using the desired waveforms. If any logical 1 was present on the resulting response, a cross conduction was said to occur. Not a single upset of this kind was recorded across all upsets and all runs including SEL, SEB, and SET.

Table 8-1 shows waveform size, sample rate, trigger type, value, and signal for all scopes used. For SS, not a single capture was recorded under the conditions used for the data collection. For this reason, the data is not presented in the table.

Table 8-1. Scope Settings

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

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
DPO7104C	OUTA	Pulse-Width (Outside)	±30%	500 ns/div or 2 μs/div	2.5 or 5 GS/s
	COMP	Window (Outside)	±10%		
	AND Gate (X-Conduction)	Edge-Positive	2.5 V		
PXIe-5110	SRB	Pulse-Width (Outside)	±30%	4 kS	100 MS/s
PXIe-5162	SS	Edge/Negative	0.6	100 kS	2.5 MS/s

V_{IN} = 12 V (Nominal) at F_{SW} = 500 kHz

For V_{IN} = 12 V and switching frequency of 500 kHz, the results are presented in Table 8-2. The outside-pulse width trigger was set to 30% from the nominal pulse width for both the DPO7104C and the PXIe-5110. Upper-bound cross section at 95% confidence interval and based on SLVK047 are presented in Table 8-3 and Table 8-4. The cross-section plot for this case and Weibull parameter are shown in Figure 8-1 and Table 8-5, respectively. A typical time domain plot for OUTA is shown in Figure 8-2. Since the main concern for a DC-DC converter is the OUTX, (OUTA and OUTB have similar if not equal performance), the OUTA signal was used to characterize the Onset. Due to SRX performing worse behavior than OUTX, the onset was not found during testing. To accurately determine the onset for SRX, a Weibull fit plot was created. Conditions and the Weibull fit plot for SRB are shown below with the remaining 12-V 500-kHz results.

Table 8-2. Summary of TPS7H500x-SP SET Test Condition and Results V_{IN} = 12 V

There is a greater focus on OUTX transients than on SRX transients because OUTX transients have more implication at a system level. This is discussed more in the "System Level Implications" section, please refer to this section for more details.

For the TPS7H5002/3-SP SRA instead of SRB was monitored.

Run Number	Device	Unit Number	Ion	LET_{EFF} (MeV·cm²/mg)	Flux (ions·cm²/mg)	Fluence (Number of Ions)	Number of DPO7104C ≥ 30% (OUTA	Number of PXIe-5110 ≥ 30% (SRB)
11	TPS7H5001	3	^{165}Ho	75	1.20×10^5	1×10^7	114	N/A
12	TPS7H5001	4	^{141}Pr	75	1.07×10^5	1×10^7	96	464
13	TPS7H5001	4	^{141}Pr	65	1.06×10^5	9.99×10^6	91	409
14	TPS7H5001	2	^{141}Pr	75	9.51×10^4	1×10^7	108	532
15	TPS7H5001	2	^{141}Pr	65	1.03×10^5	1×10^7	79	414
16	TPS7H5001	3	^{109}Ag	48	1.22×10^5	9.98×10^6	30	N/A
17	TPS7H5001	3	^{109}Ag	48	1.39×10^5	9.96×10^6	9	N/A
18	TPS7H5001	3	^{109}Ag	48	1.29×10^5	9.98×10^6	N/A	300
19	TPS7H5001	4	^{109}Ag	48	8.27×10^4	1×10^7	12	286
20	TPS7H5001	7	^{84}Kr	40	1.36×10^5	9.95×10^6	3	273
21	TPS7H5001	7	^{84}Kr	37	1.24×10^5	9.99×10^6	0	249
22	TPS7H5001	7	^{84}Kr	30	1.37×10^5	9.96×10^6	0	245
82	TPS7H5002	9	^{165}Ho	74	1.13×10^5	1×10^7	84	577
83	TPS7H5003	10	^{165}Ho	75	1.19×10^5	1×10^7	96	546
84	TPS7H5004	11	^{165}Ho	75	1.14×10^5	9.99×10^6	104	N/A
85	TPS7H5002	9	^{84}Kr	30	1.12×10^5	9.96×10^6	0	212
86	TPS7H5003	10	^{84}Kr	30	1.06×10^5	9.95×10^6	0	216
87	TPS7H5004	11	^{84}Kr	30	1.05×10^5	1×10^7	0	N/A

Table 8-3. Upper Bound Cross Section for OUTA for V_{IN}= 12 V and F_{SW} = 500 kHz Based on TPS7H5001-SP

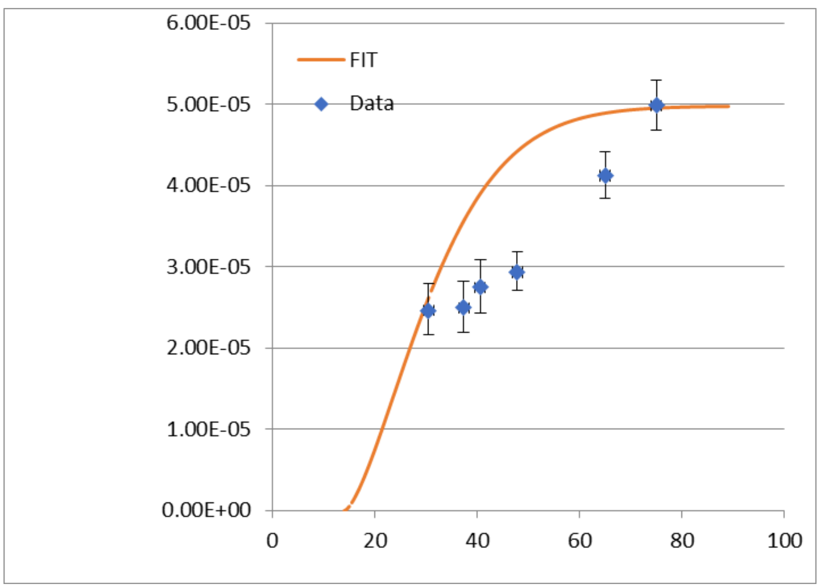
Upper Bound Cross Section was at 95% confidence interval and based on SLVK047.

LET_{EFF} (MeV·cm²/mg)	Number of Upsets	Upper Bound X-Section (cm²)
30	0	3.70×10^{-7}
37	0	3.69×10^{-7}
40	3	8.81×10^{-7}
48	51	2.24×10^{-6}
65	170	9.88×10^{-6}
75	318	1.18×10^{-5}

Table 8-4. Upper Bound Cross Section for SRB for V_{IN}= 12 V and F_{SW} = 500 kHz Based on TPS7H5001-SP

Upper Bound Cross Section was calculated at 95% confidence interval and based on SLVK047.

LET_{EFF} (MeV·cm²/mg)	Number of Upsets	Upper Bound X-Section (cm²)
30	245	2.79×10^{-5}
37	249	2.82×10^{-5}
40	273	3.09×10^{-5}
48	586	3.18×10^{-5}
65	823	4.41×10^{-5}
75	996	5.30×10^{-5}



Upper and lower bound were calculated to 95% confidence. Weibull fit was done for the mean value.

Figure 8-1. Cross Section and Weibull Fit for SRB at V_{IN} = 12 V and F_{SW}= 500 kHz

Table 8-5. Weibull Parameter for SRB at V_{IN}= 12 V and F_{SW}= 500 KHz

Parameter	Value
Upper Bound X-Section	5.30×10^{-5}
X-Sat	4.98×10^{-5}
Onset	14
W	20
s	1.5

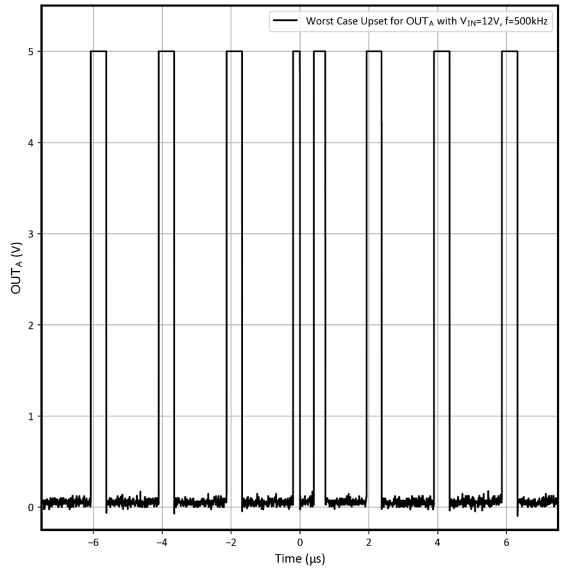


Figure 8-2. Worst Case OUTA Time Domain Upset (Run Number 14)

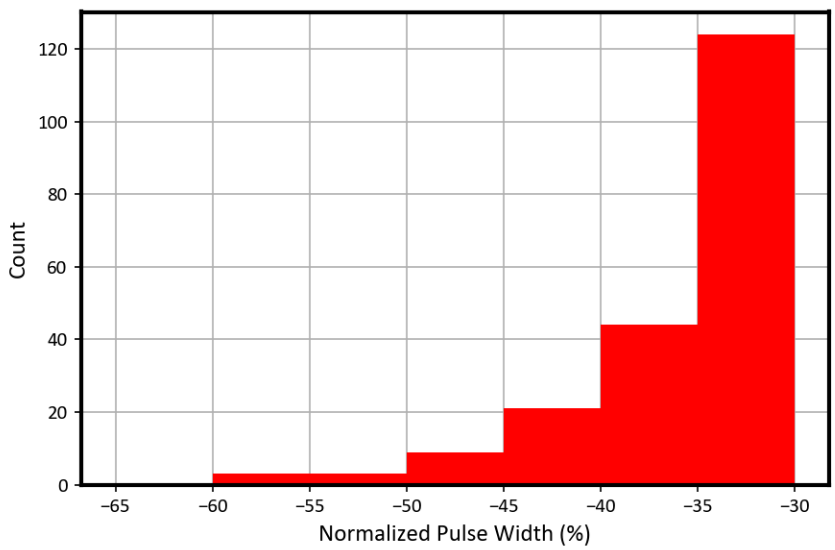


Figure 8-3. OUTA Normalized Percentage Pulse Width Deviation During Trigger

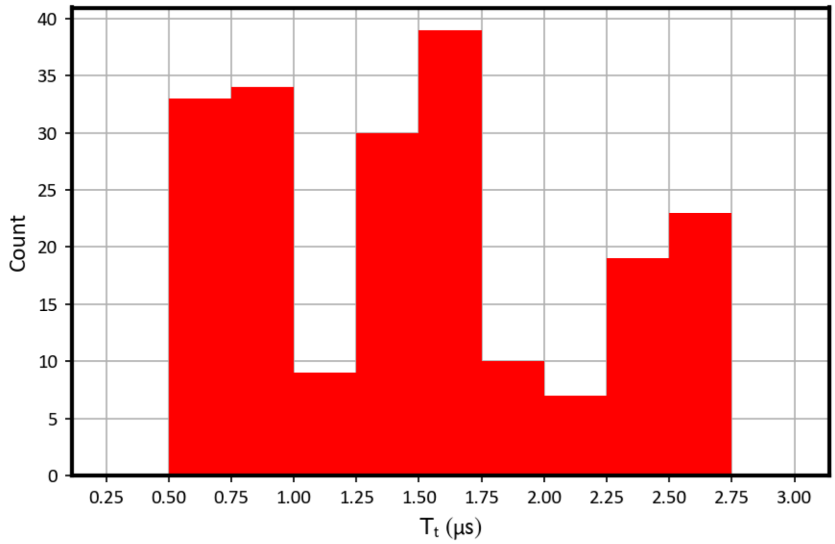


Figure 8-4. OUTA Duration of Triggers (µs)

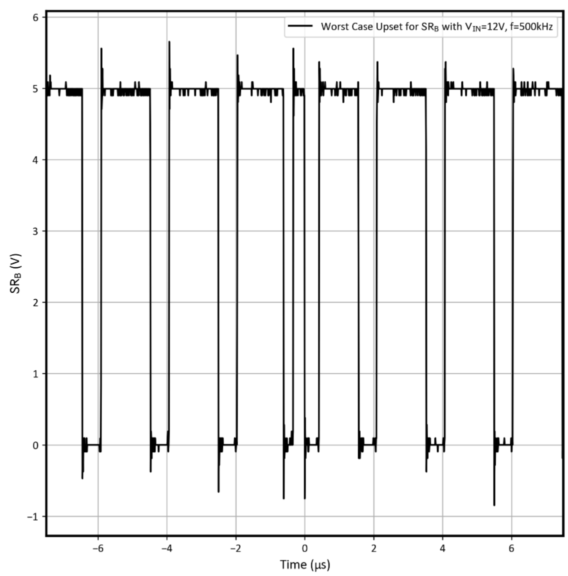


Figure 8-5. Worst Case SRB Time Domain Upset (Run Number 14)

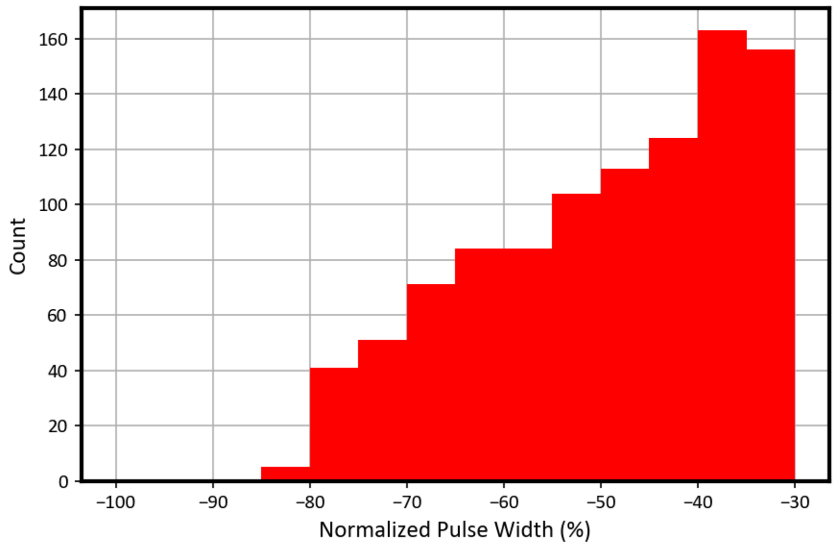


Figure 8-6. SRB Normalized Percentage Pulse Width Deviation During Trigger

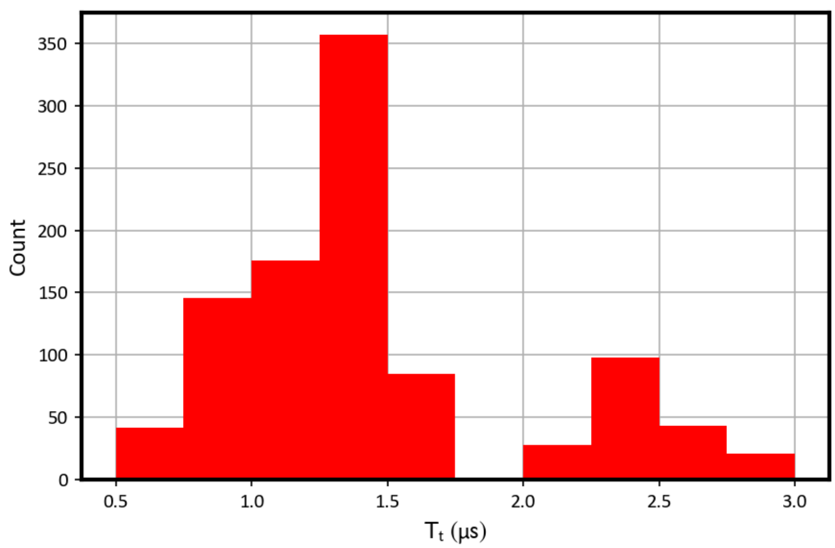


Figure 8-7. SRB Duration of Triggers (µs)

V_{IN}= 14 V (Maximum) at F_{SW}= 500 kHz

Table 8-6. Summary of TPS7H5001-SP SET Test Condition and Results VIN = 14 V

Run Number	Unit Number	Ion	LET_{EFF} ($MeV·cm^2/mg$)	FLUX ($ions·cm^2/mg$)	Fluence (Number of Ions)	Number DPO7104C ≥ 30% (OUTA)	Number PXIe-5110 ≥ 30% (SRB)
23	4	^{141}Pr	75	8.85×10^4	9.97×10^6	100	496
24	4	^{141}Pr	75	1.03×10^5	9.99×10^6	93	494
25	4	^{141}Pr	65	1.11×10^5	9.97×10^6	61	400
26	2	^{141}Pr	75	1.09×10^5	1.00×10^7	120	488
27	2	^{141}Pr	65	1.04×10^5	1.00×10^7	80	372
28	4	^{109}Ag	48	8.19×10^4	1.00×10^7	13	290
29	7	^{84}Kr	37	1.17×10^5	1.00×10^7	1	232

V_{IN}=4-V (Min) at F_{SW} = 500 kHz

Table 8-7. Summary of TPS7H5001-SP SET Test Condition and Results VIN = 4-V

Run Number	Unit Number	Ion	LET_{EFF} ($MeV·cm^2/mg$)	Flux ($ions·cm^2/mg$)	Fluence (Number of Ions)	Number of DPO7104C ≥ 30% (OUTA)	Number of PXIe-5110 ≥ 30% (SRB)
30	4	^{141}Pr	75	1.09×10^5	1.00×10^7	111	617
31	4	^{141}Pr	65	1.19×10^5	1.00×10^7	25	424
32	4	^{141}Pr	65	1.09×10^5	1.00×10^7	112	479
33	4	^{141}Pr	65	1.15×10^5	9.98×10^6	76	451
34	2	^{141}Pr	75	7.66×10^4	1.00×10^7	109	577
35	2	^{141}Pr	65	1.00×10^5	1.00×10^7	79	474
36	4	^{109}Ag	48	9.38×10^4	1.00×10^7	22	306
37	7	^{84}Kr	37	1.35×10^5	9.98×10^6	0	210

Error Amp in Unity Gain

Time Domain Plots for the COMP voltage and Normalized max Value for each upset is shown on Nominal Trigger on COMP Run Number 43 V_{IN} = 12 V

Table 8-8. Summary of TPS7H5001-SP SET Test Condition and Results for the Error Amplifier in Unity Gain.

Run Number	Unit Number	V_{IN} (V)	Ion	LET_{EFF} ($MeV·cm^2/mg$)	Flux ($ions·cm^2/mg$)	Fluence (Number of Ions)	Number of Upsets COMP ≥ |10|%
38	8	14	^{141}Pr	75	1.53×10^5	1.00×10^7	11
39	8	12	^{141}Pr	75	1.65×10^5	1.00×10^7	0
40	8	4	^{141}Pr	75	1.51×10^5	1.00×10^7	0
41	8	4	^{141}Pr	65	1.30×10^5	1.00×10^7	0
42	8	12	^{141}Pr	65	1.41×10^5	1.00×10^7	0
43	8	14	^{141}Pr	65	1.32×10^5	1.00×10^7	32

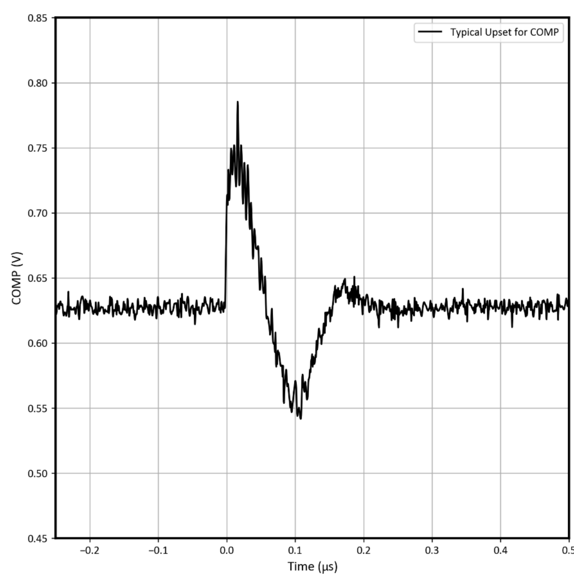


Figure 8-8. Nominal Trigger on COMP Run Number 43 V_{IN} = 12 V

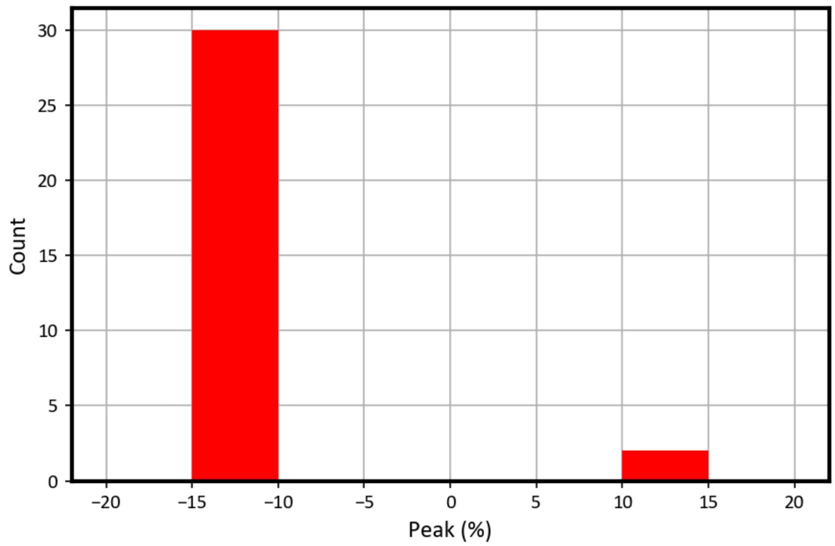


Figure 8-9. Comp Peak Percentage Deviation from Nominal of Triggers

Cross-Conduction (Using Hardware) at F_{SW} = 500 kHz

For cross conduction using hardware an AND Gate (model: SN74AHCT1G08DCKR) was used. IN1 was set as OUTA and IN2 was used as SRA. The output of the AND gate was connected to the CH number 1 of the DPO7104C with an edge trigger at 2.5 V. Not a single trigger was capture indicating that the TPS7H500x-SP is cross-conduction free at the conditions tested and presented here. As mention in the SET introduction, all recorded upset were also verified for the cross conduction in software and not a single cross conduction upset was recorded.

Table 8-9. Summary of TPS7H5001-SP SET Test Condition and Results Cross-Conduction

Run Number	Unit Number	V_{IN} (V)	Ion	LET_{EFF} (MeV·cm²/mg)	Flux (ions·cm²/mg)	Fluence (Number of Ions)	DPO7104C Number Of Upsets
44	3	4	^{141}Pr	75	1.20×10^5	9.97×10^6	0
45	3	12	^{141}Pr	75	1.24×10^5	9.98×10^6	0
46	3	14	^{141}Pr	75	1.23×10^5	1.00×10^7	0

F_{SW} = 500 kHz using an External Clock with R_T = Open

Table 8-10. Summary of TPS7H5001-SP SET Test Condition and Results With External Clock

Run Number	Unit Number	V_{IN} (V)	Ion	LET_{EFF} (MeV·cm²/mg)	Flux (ions·cm²/mg)	Fluence (Number of Ions)	Number DPO7104C ≥ 30% (OUTA)	Number PXIe-5110 ≥ 30% (SRB)
47	2	4	^{141}Pr	75	1.17×10^5	1.00×10^7	23	51
48	2	12	^{141}Pr	75	1.25×10^5	1.00×10^7	22	28
49	2	14	^{141}Pr	75	1.19×10^5	1.00×10^7	1	8
50	2	4	^{141}Pr	65	1.07×10^5	1.00×10^7	1	1
51	2	12	^{141}Pr	65	1.21×10^5	1.00×10^7	1	2
52	2	14	^{141}Pr	65	1.18×10^5	1.00×10^7	1	3
53	2	4	^{109}Ag	48	1.00×10^5	9.98×10^6	0	0
54	2	12	^{109}Ag	48	8.96×10^4	1.00×10^7	0	0
55	2	14	^{109}Ag	48	9.30×10^4	1.00×10^7	0	0

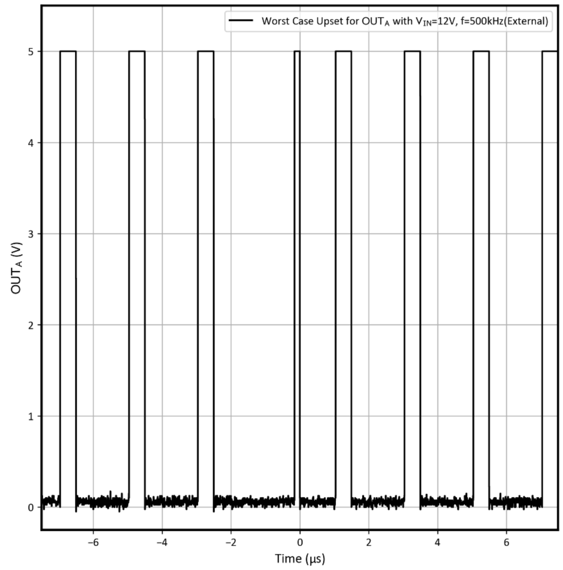


Figure 8-10. Worst Case OUTA Time Domain Upset (Run Number 48)

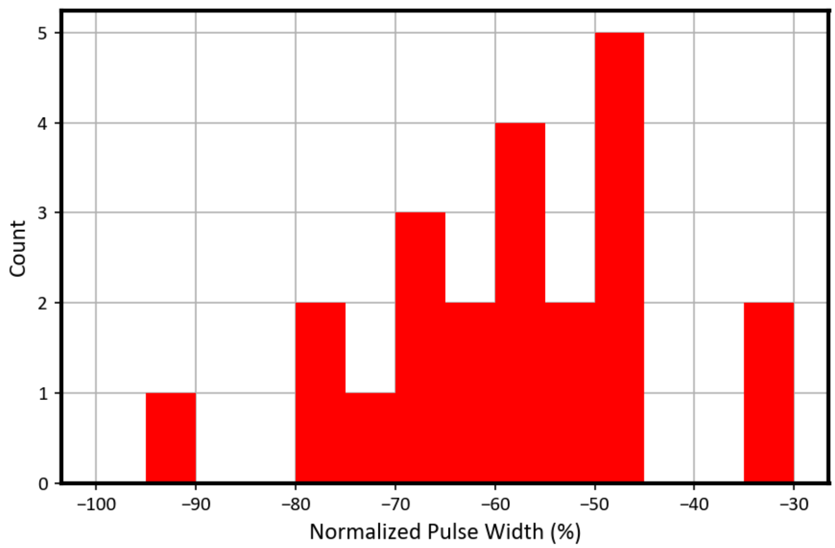


Figure 8-11. OUTA Normalized Percentage Pulse Width Deviation During Trigger With External Clock

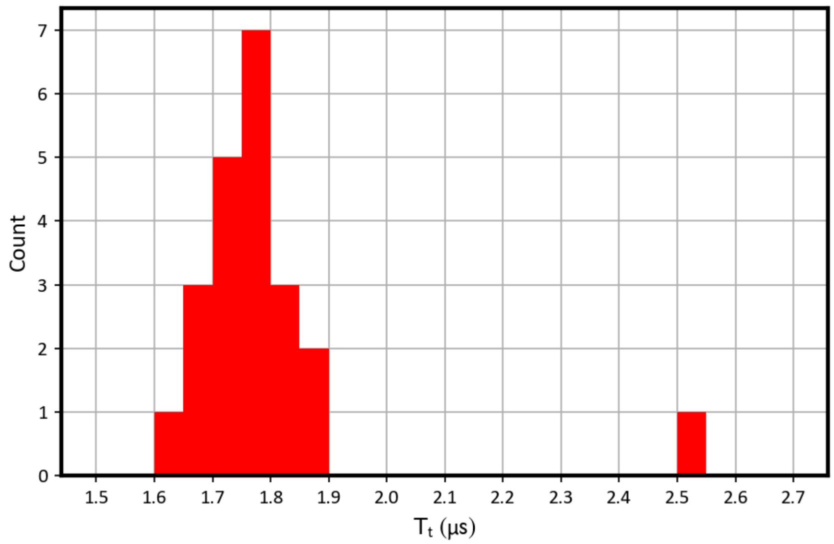


Figure 8-12. OUTA Duration of Triggers (µs) With External Clock

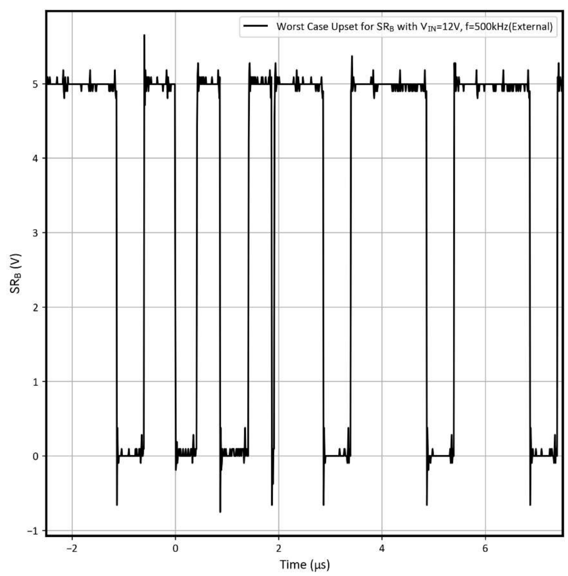


Figure 8-13. Worst Case SRB Time Domain Upset (Run Number 48)

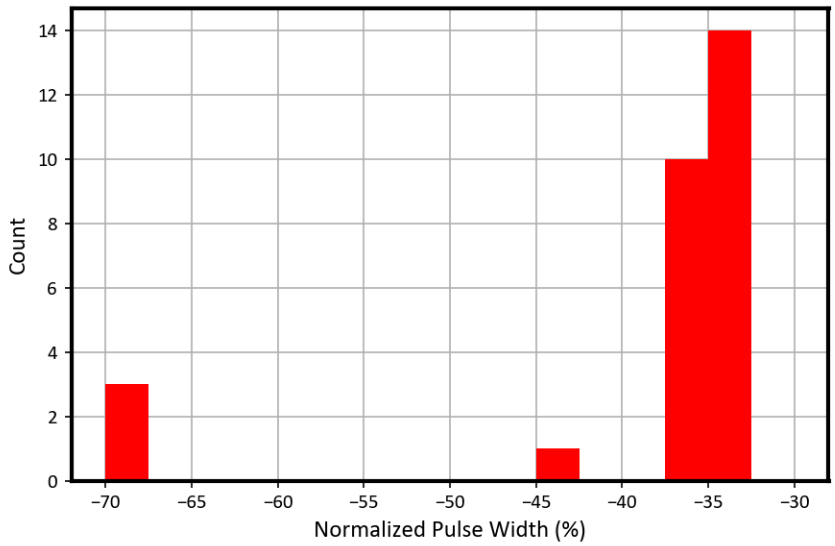


Figure 8-14. SRB Normalized Percentage Pulse Width Deviation During Trigger With External Clock

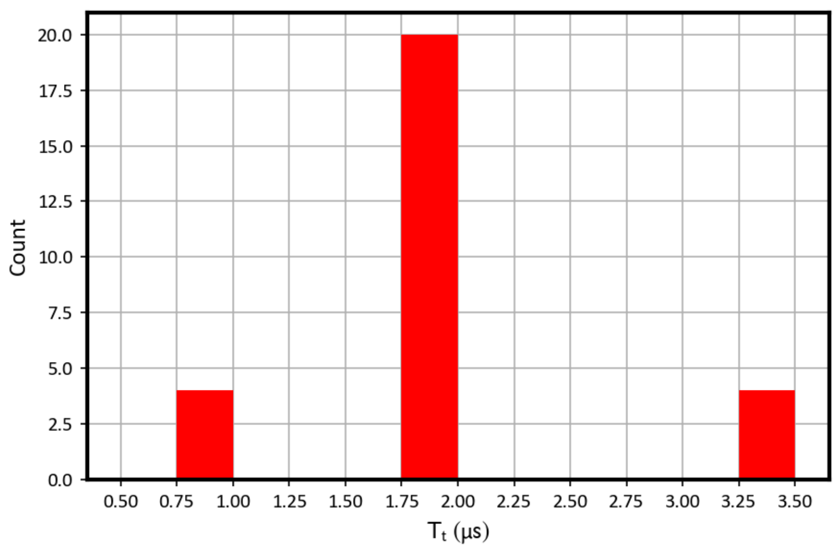


Figure 8-15. SRB Duration of Triggers (µs) With External Clock

F_{SW} = 1 MHz Using an Internal Clock with R_T = 90.9 kΩ

Table 8-11. Summary of TPS7H5001-SP SET Test Condition and Results Frequency = 1 MHz

Run Number	Unit Number	V_{IN} (V)	Ion	LET_{EFF} (MeV·cm²/mg)	Flux (ions·cm²/mg)	Fluence (Number of Ions)	Number DPO7104C ≥ 30% (OUTA)	Number PXI 5110 ≥ 30% (SRB)
56	5	4	^{141}Pr	75	8.52×10^4	1.00×10^7	101	443
57	5	12	^{141}Pr	75	8.29×10^4	9.99×10^6	78	422
58	5	14	^{141}Pr	75	8.85×10^4	9.98×10^6	67	402
59	5	4	^{141}Pr	65	8.42×10^4	1.01×10^7	53	381
60	5	12	^{141}Pr	65	8.99×10^4	9.98×10^6	46	328
61	5	14	^{141}Pr	65	1.00×10^5	1.00×10^7	55	342
62	5	4	^{109}Ag	48	9.72×10^4	9.97×10^6	5	273
63	5	12	^{109}Ag	48	9.70×10^4	9.99×10^6	1	260
64	5	14	^{109}Ag	48	8.28×10^4	1.00×10^7	1	247

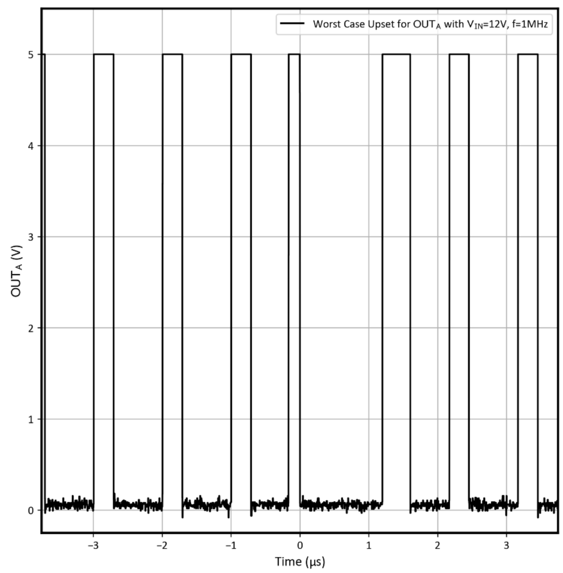


Figure 8-16. Worst Case OUTA Time Domain Upset (Run Number 57)

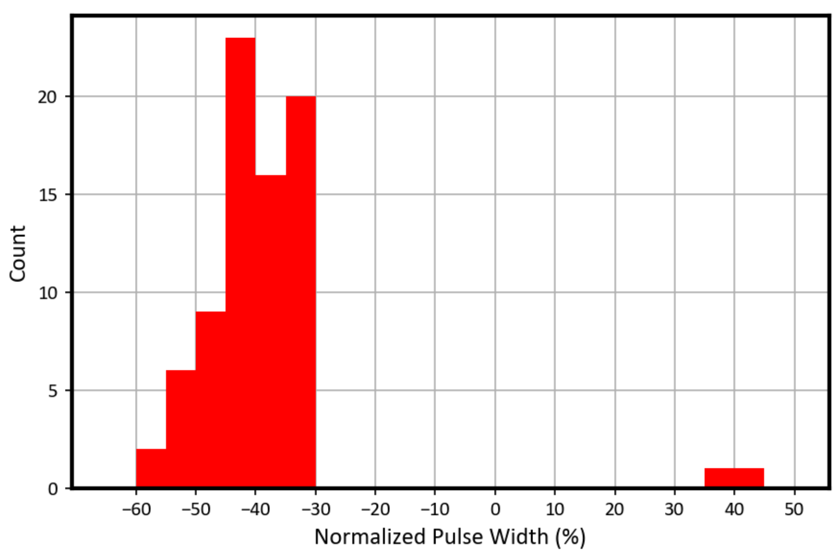


Figure 8-17. OUTA Normalized Percentage Pulse Width Deviation During Trigger With 1-MHz Internal Clock

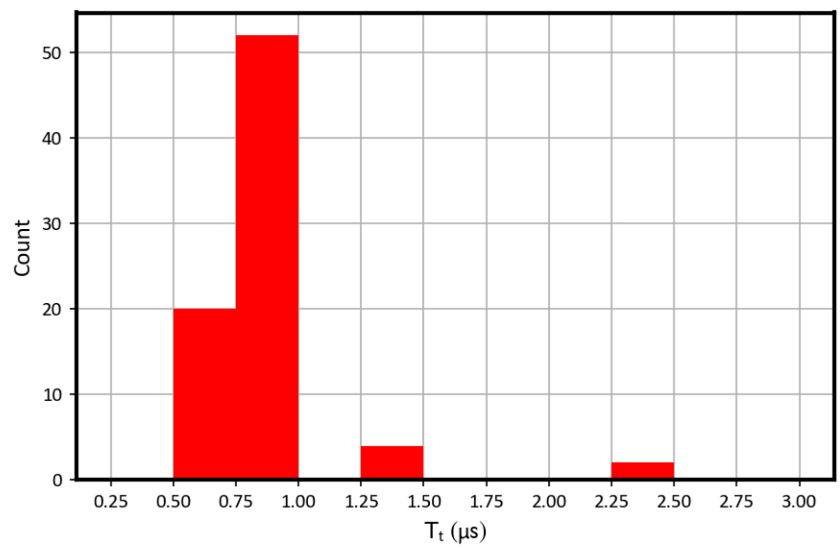


Figure 8-18. OUTA Duration of Triggers (µs) With 1-MHz Internal Clock

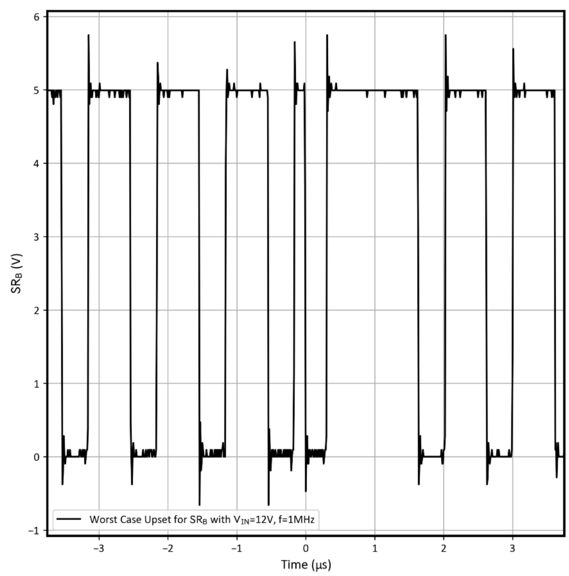


Figure 8-19. Worst Case SRB Time Domain Upset (Run Number 57)

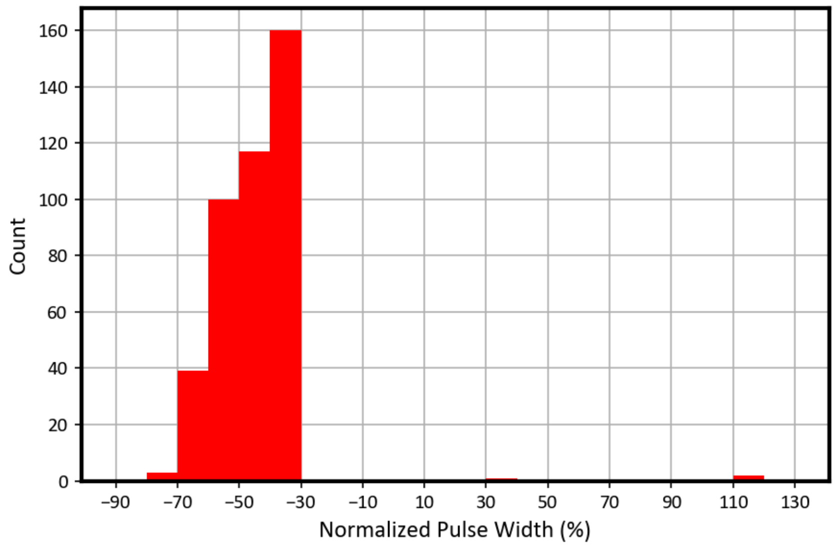


Figure 8-20. SRB Normalized Percentage Pulse Width Deviation During Trigger With 1-MHz Internal Clock

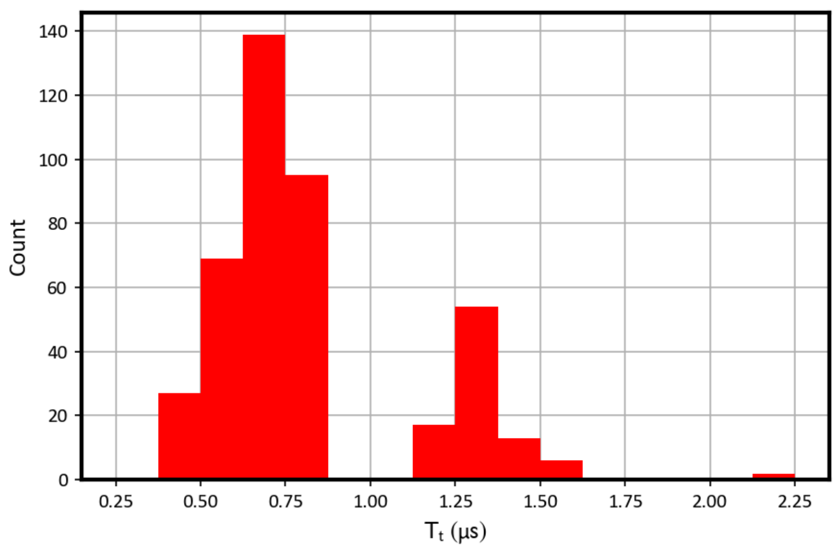


Figure 8-21. SRB Duration of Triggers (µs) With 1MHz Internal Clock

F_{SW} = 2 MHz Using an Internal Clock with R_T = 38.3 kΩ

Table 8-12. Summary of TPS7H5001-SP SET Test Condition and Results Frequency = 2 MHz

Run Number	Unit Number	V_{IN} (V)	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions·cm^2/mg)	Fluence (Number of Ions)	Number of DPO7104C ≥ 30% (OUTA)	Number of PXI 5110 ≥ 30% (SRB)
65	6	4	^{141}Pr	75	1.05×10^5	9.97×10^6	144	379
66	6	12	^{141}Pr	75	9.89×10^4	9.99×10^6	10	299
67	6	14	^{141}Pr	75	1.02×10^5	9.97×10^6	11	492
68	6	12	^{141}Pr	65	1.06×10^5	1.00×10^7	24	245
69	6	14	^{141}Pr	65	1.07×10^5	1.00×10^7	9	260
70	6	12	^{141}Pr	65	1.03×10^5	1.00×10^7	12	229
71	6	12	^{109}Ag	48	8.82×10^4	1.00×10^7	9	235
72	6	14	^{109}Ag	48	8.79×10^4	9.98×10^6	12	534

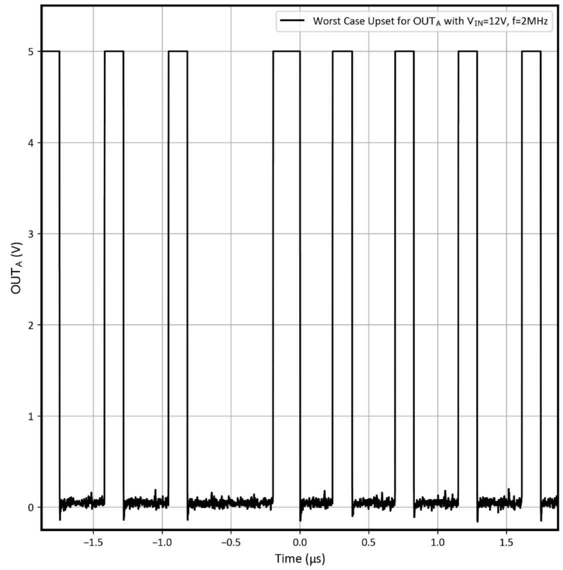


Figure 8-22. Worst Case OUTA Time Domain Upset (Run Number 66)

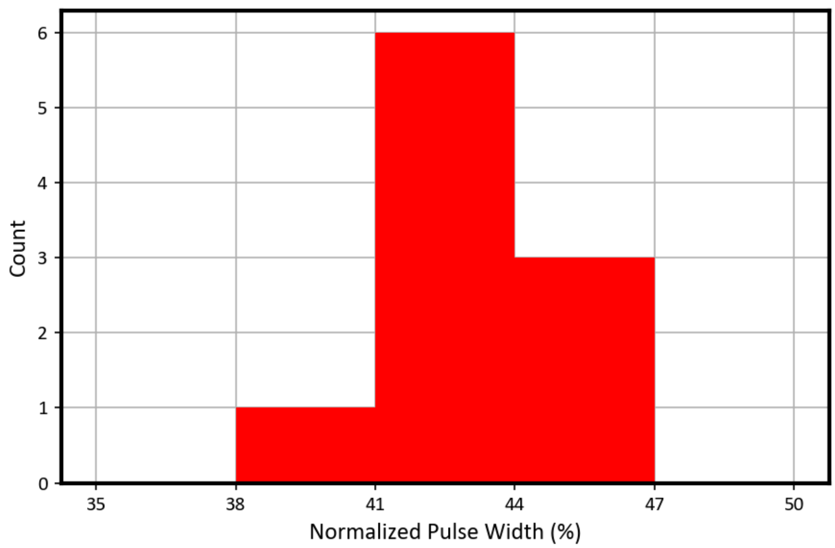


Figure 8-23. OUTA Normalized Percentage Pulse Width Deviation During Trigger With 2-MHz Internal Clock

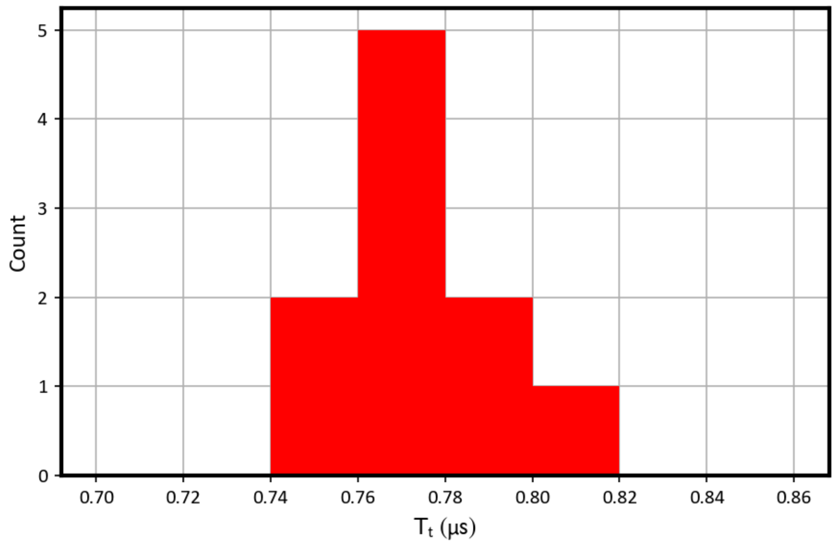


Figure 8-24. OUTA Duration of Triggers (μs) With 2-MHz Internal Clock

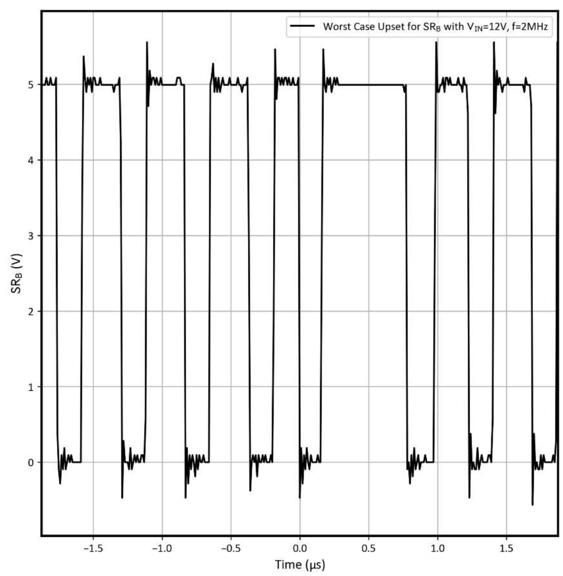


Figure 8-25. Worst Case SRB Time Domain Upset (Run Number 66)

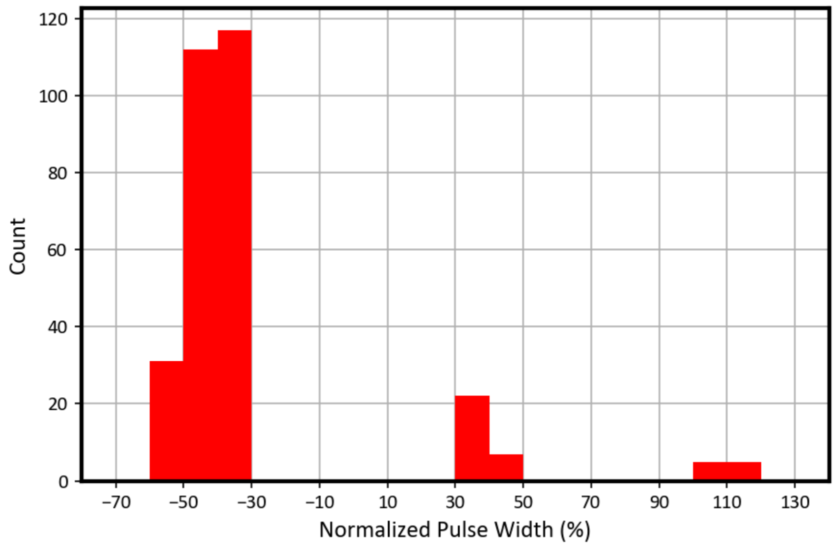


Figure 8-26. SRB Normalized Percentage Pulse Width Deviation During Trigger With 2-MHz Internal Clock

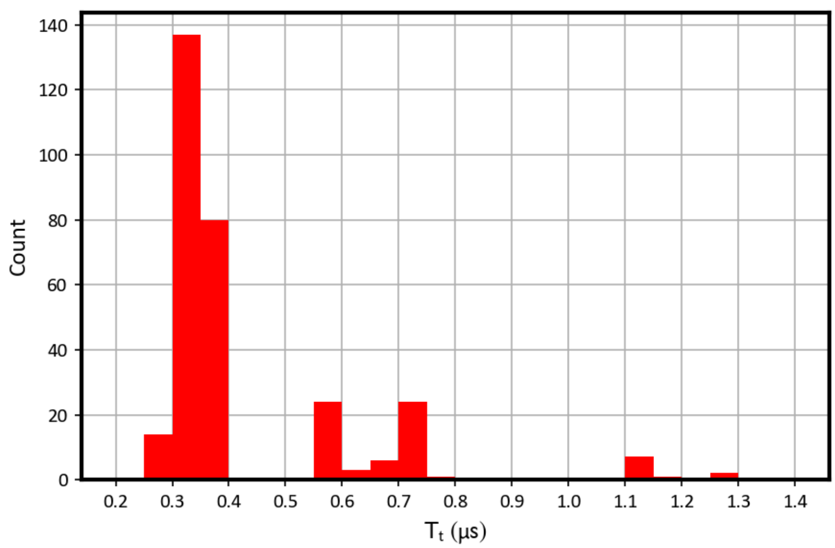


Figure 8-27. SRB Duration of Triggers (µs) With 2-MHz Internal Clock

8.1 System Level Implications

To promote a better understanding of the above SET results, this section will look to dissect the results from a system level point of view. One such system level observation is the difference between OUTX and SRX transients in that the OUTX transients have a higher focus than the SRX transients. This is because the primary output of the device has a greater implication on the system as a whole than the synchronous rectifier output does. A second system level observation is that all testing in this report was performed open-loop which is the worst case test-setup for this device. During testing using prototype devices, closed-loop testing was done to validate this idea, the results are presented in the table below.

Table 8-13. Closed-Loop Push-Pull DC-DC Converter at F_{SW} = 1 MHz

The testing was conducted using prototype devices. A specially designed push-pull converter evaluation module (EVM) was developed in order to observe the device behavior in a closed-loop DC-DC converter configuration similar to its intended use case. Please refer to Figures 3-4 and 3-5 for an image of the Push-Pull EVM and its schematic.

Ion	LETEFF (MeV·cm²/mg)	FLUX (ions·cm²/mg)	FLUENCE (# ions)	PXIe-5172 Triggering from VOUT at ± ≥ |5|%	PXI 5110 OUTA# ≥ 30%	PXI 5110 OUTA# ≥ 40%	PXI 5110 OUTA# ≥ 50%
^{141}Pr	64.7	1.10 x 10^5	1.01 x 10^7	0	80	30	0
^{141}Pr	64.7	1.30 x 10^5	9.94 x 10^6	0	76	34	0
^{141}Pr	64.7	1.04 x 10^5	9.99 x 10^6	0	72	38	0
^{141}Pr	75	1.30 x 10^5	3.72 x 10^6	0	35	17	0
^{141}Pr	75	1.21 x 10^5	9.96 x 10^6	0	99	57	0

One main thing to note during the closed-loop testing is that there were no V_{OUT} triggers when using a 5% tolerance. This is important with respect to the device's use case since there are no V_{OUT} transient issues at a system level.

For the open-loop test cases, it is important to demonstrate the difference in device behavior across switching frequency. The SET results of the 500 kHz, 1 MHz, and 2 MHz switching frequencies can best be described by the figure below.

This graph shows that as frequency increases the mean cross-section improves for the nominal V_{IN} case.

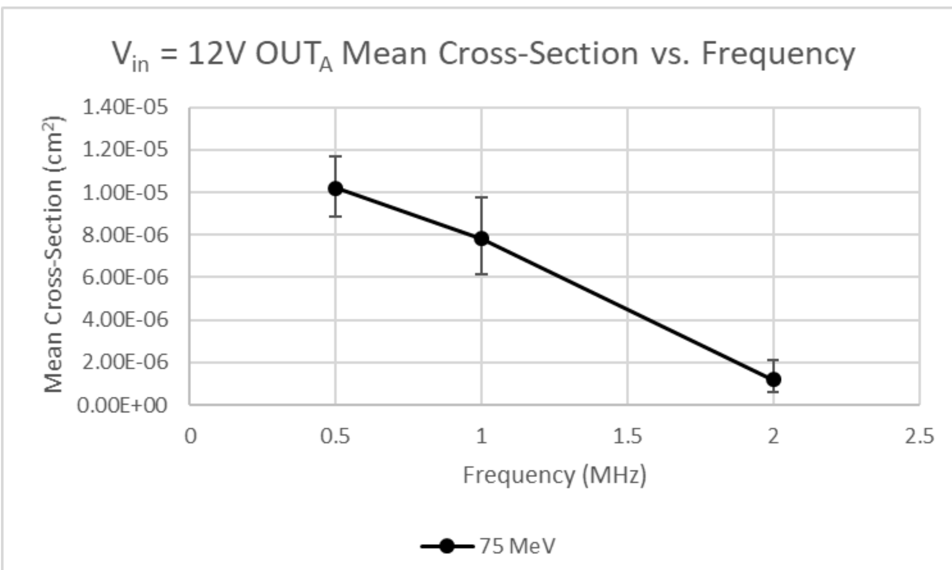


Figure 8-28. Mean Cross-Section vs. Frequency at Nominal V_{IN}

The figure shows that as the frequency increases, so does the performance of the device. The mean cross-section decreases from 500 kHz, to 1 MHz, to 2 MHz which correlates with the expected performance of the device at a system level.

9 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations and simplified SEE cross-sections according to methods described in *Heavy Ion Orbital Environment Single-Event Effects Estimations* application report. We assume a minimum shielding configuration of 100 mils (2.54 mm) of aluminum, and "worst-week" solar activity (this is similar to a 99% upper bound for the environment). Using the 95% upper-bounds for the SEL and the SEB/SEGR, the event rate calculation for the SEL and the SEB/SEGR is shown on Table 9-1 and Table 9-2, respectively. **It is important to note that this number is for reference since no SEL or SEB/SEGR events were observed.** SET orbit rate for OUTA at V_{IN}=12-V and F_{SW} = 500 kHz is presented on SEB/SEGR Event Rate Calculations for Worst-Week LEO and GEO Orbits. The SET orbit rate calculations are based on the TPS7H5001-SP device as this is the device with the most data and as mentioned earlier in the report there is high confidence that the TPS7H5002/3/4-SP devices correlate with the TPS7H5001-SP.

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}	1.23×10^{-7}	7.69×10^{-12}	3.20×10^{-4}	3.55×10^{8}
GEO		1.77×10^{-4}		2.17×10^{-11}	9.06×10^{-4}	1.25×10^{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}	5.27×10^{-8}	3.29×10^{-12}	1.37×10^{-4}	8.30×10^{8}
GEO		1.77×10^{-4}		9.31×10^{-12}	3.88×10^{-4}	2.94×10^{8}

Table 9-3. SET (OUTA @ V_{IN}=12-V , F_{SW}=500 KHz at Upsets ≥ 30 %) Event Rate Calculations for Worst-Week LEO and GEO Orbits

The cross section of 1.06 x 10^{-5} is based on the Onset LET_{EFF} of 37.3 MeV-cm^2/mg found in table 8-3.

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)	37.3	1.15 x 10^{-3}	1.06×10^{-5}	1.22×10^{-8}	5.11×10^{-1}	2.23×10^{5}
GEO		4.43 x 10^{-3}		4.70×10^{-8}	1.95×10^{0}	5.82×10^{4}

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 TPS7H500x-SP series of PWM controllers. Heavy-ions with LET_{EFF} = 30 to 75 MeV·cm^2/mg were were used for the SEE characterization campaign. Flux of 7.26 × 10^4 to 1.65 × 10^5 ions/cm^2·s and fluences ranging from 9.96 × 10^6 to 1.01 × 10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H5001-SP is free of destructive SEL, SEB, and cross conduction up to LET_{EFF} = 75 MeV·cm^2/mg and across the full electrical specifications. Transients at LET_{EFF} = 30 to 75 MeV·cm^2/mg on OUTX, SRX, VLDO, REFCAP, SS, COMP, and V_{OUT} are presented and discussed. CREME96-based worst-week event-rate calculations for LEO(ISS) and GEO orbits for the DSEE and SET (at V_{IN}= 12 V and F_{SW}= 500 KHz) are presented for reference.

A Total Ionizing Dose from SEE Experiments

The production TPS7H500x-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 ten TPS7H500x-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 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. Cyclotron Institute, Texas A&M University, *Texas A&M University Cyclotron Institute Radiation Effects*, website.
7. James F. Ziegler, SRIM- The Stopping and Range of Ions in Matter, webpage.
8. D. Kececioglu, “Reliability and Life Testing Handbook”, Vol. 1, PTR Prentice Hall, New Jersey,1993, pp. 186-193.
9. ISDE CRÈME-MC, Vanderbilt University, *ISDE Crème-MC* webpage.
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.

C Revision History

Changes from Revision A (July 2022) to Revision B (September 2023)	Page
• Updated Abstract to include QMLP device	1

Changes from Revision * (March 2022) to Revision A (July 2022)	Page
• Added TPS7H5002-SP, TPS7H5003-SP and TPS7H5004-SP devices to the document	3

IMPORTANT NOTICE AND DISCLAIMER