Radiation Report

Single-Event Effects (SEE) Radiation Report of the TPS7H502x-SEP

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TPS7H502x-SEP. Heavy-ions with LET_{EFF} of 48 MeV×cm^2/mg were used to irradiate 8 pre-production devices. Flux of 8.83 × 10^4 to 1.26 × 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 TPS7H502x-SEP is SEL-free up to 48 MeV·cm^2/mg at T = 125°C and SEB/SEGR free up to 48 MeV·cm^2/mg at T = 25°C. SET transients performance for output pulse-width excursions ≥ |20%| from the nominal pulse-width in an open-loop configuration are discussed.

Table of Contents

List of Figures

List of Tables

Trademarks

LabVIEW™ is a trademark of National Instruments.
All trademarks are the property of their respective owners.

1 Introduction

The TPS7H502x-SEP is a radiation-tolerant, current mode, single-ended PWM controller with an integrated gate driver that can be utilized in both silicon and gallium nitride (GaN) power semiconductor based converter designs. The TPS7H502x-SEP integrates several key functions such as:

- Soft-start, enable, and adjustable slope compensation
- 0.6V ±1% voltage reference tolerance
- Internal oscillator through the RT pin or external frequency control through the SYNC pin
- Switching frequencies up to 1MHz
- Input voltage range from 4.5V to 14V
- Programmable VLDO voltage (4.5V to 5.5V) that can be connected directly to driver stage input (PVIN) for operation with GaN FETs

The TPS7H5020 has a maximum duty cycle of 100% while the TPS7H5021 has a maximum duty cycle of 50%. The controller supports numerous power converter topologies, including flyback, forward, and boost.

The device is offered in a 24-pin plastic package. General device information and test conditions are listed in the overview information table. For more detailed technical specifications, user-guides, and application notes please go to device product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H502x-SEP
Orderable Part Number	TPS7H5020MPWPTSEP or TPS7H5021MPWTSEP
Device Function	PWM Controller with Integrated Gate Driver
Technology	LBC7 (Linear BiCMOS 7)
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/nucleon) and Facility for Rare Istotope Beams, K500 Cyclotron (KSEE), Michigan State University (19.5MeV/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)

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

2 Single-Event Effects (SEE)

The primary concern for the TPS7H502x-SEP is the robustness against the destructive single-event effects (DSEE): single-event latch-up (SEL), single-event burnout (SEB), and single-event gate rupture (SEGR). In mixed technologies such as the BiCMOS process used on the TPS7H502x-SEP , the CMOS circuitry introduces a potential for SEL susceptibility.

SEL can occur if excess current injection caused by the passage of an energetic ion is high enough to trigger the formation of a parasitic cross-coupled PNP and NPN bipolar structure (formed between the p-sub and n-well and n+ and p+ contacts) [1,2]. The parasitic bipolar structure initiated by a single-event creates a high-conductance path (inducing a steady-state current that is typically orders-of-magnitude higher than the normal operating current) between power and ground that persists (is “latched”) until power is removed, the device is reset, or until the device is destroyed by the high-current state. The TPS7H502x-SEP was tested for SEL at the maximum recommended operating conditions of VIN=PVIN=14V and VLDO=5.5V for the silicon mode and VIN=14V and PVIN=VLDO=5.5V for the GaN mode. During testing of the 8 devices, the TPS7H502x-SEP did not exhibit any SEL with heavy-ions with LET_{EFF} = 48 MeV·cm^2 /mg at flux ≈10^5 ions/(cm^2×s), fluence of ≈10^7 ions/cm^2, and a die temperature of 125°C.

The TPS7H502x-SEP was evaluated for SEB/SEGR at a maximum voltage of 14V in the enabled and disabled mode. Because it has been shown that the MOSFET susceptibility to burnout decrement with temperature [5], the device was evaluated while operating under room temperatures. The device was tested with no external thermal control device. The TPS7H502x-SEP was tested for SEB at the maximum recommended operating conditions of VIN=PVIN=14V and VLDO=5.5V for the silicon mode and VIN=14V and PVIN=VLDO=5.5V for the GaN mode. The device was also tested for SEB Off by disabling the device. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H502x-SEP is SEB/SEGR-free up to LET_{EFF} = 48 MeV·cm^2/mg at a flux of ≈10^5 ions/(cm^2×s), fluences of ≈10^7 ions/cm^2, and a die temperature of ≈25°C.

The TPS7H502x-SEP was characterized for SET at flux of ≈1 × 10^5 ions/(cm^2×s) , fluences of 10^7 ions/cm^2, and room temperature. The device was characterized at V_{IN} of 12V for the silicon mode and 5V for the GaN mode. Heavy-ions with LET_{EFF} of 48 MeV·cm^2/mg were used to characterize the transient performance. To see the SET results of the TPS7H502x-SEP, please refer to Single-Event Transients (SET).

3 Device and Test Board Information

The TPS7H502x-SEP is packaged in a *24*-pin HTSSOP PWP plastic package as shown in Figure 3-1. A custom TPS7H502x-SEP evaluation module, designed for open-loop SEE testing was used to evaluate the performance and characteristics of the TPS7H502x-SEP under heavy ion radiation. The evaluation module is shown in Figure 3-2. The schematics are shown in Figure 3-2 and Figure 3-4.

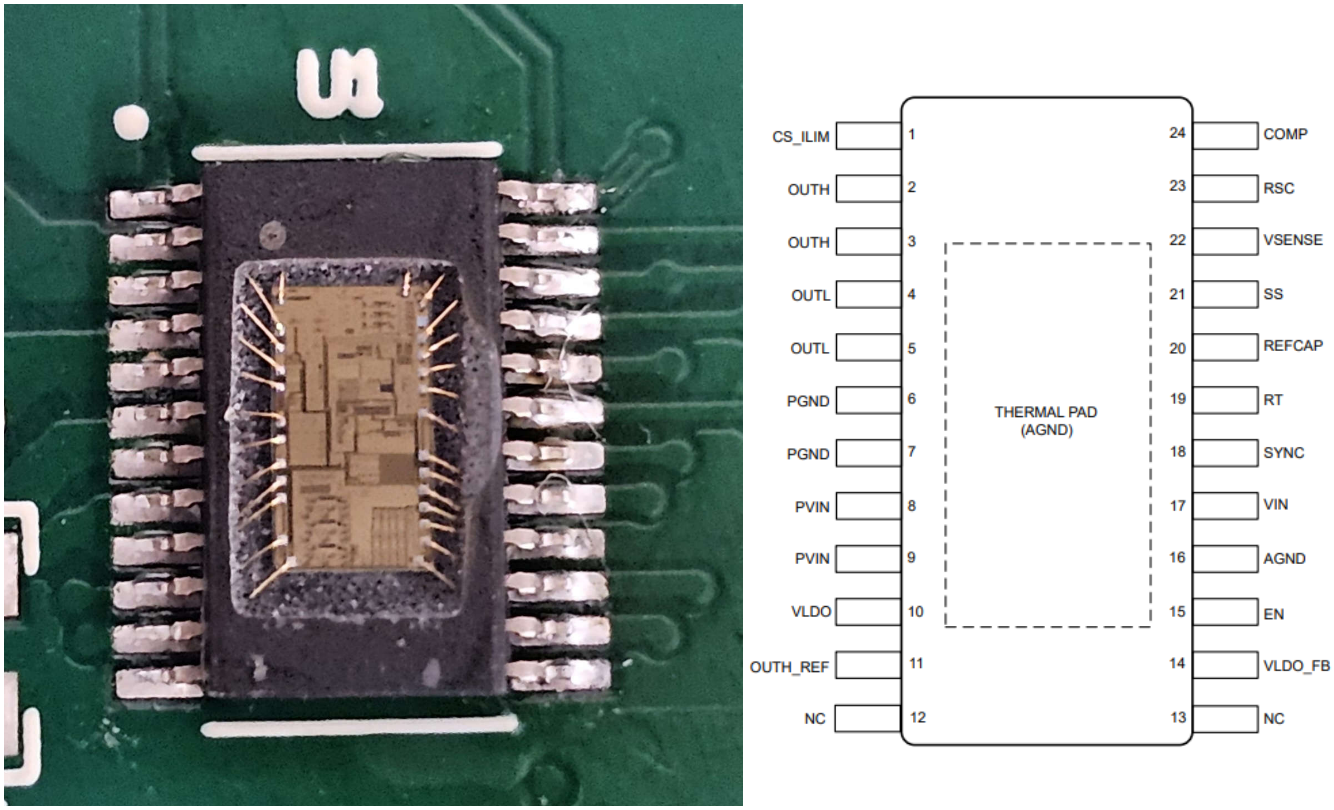

Figure 3-1. Photograph of Delidded TPS7H502x-SEP [Left] and Pinout Diagram [Right]

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

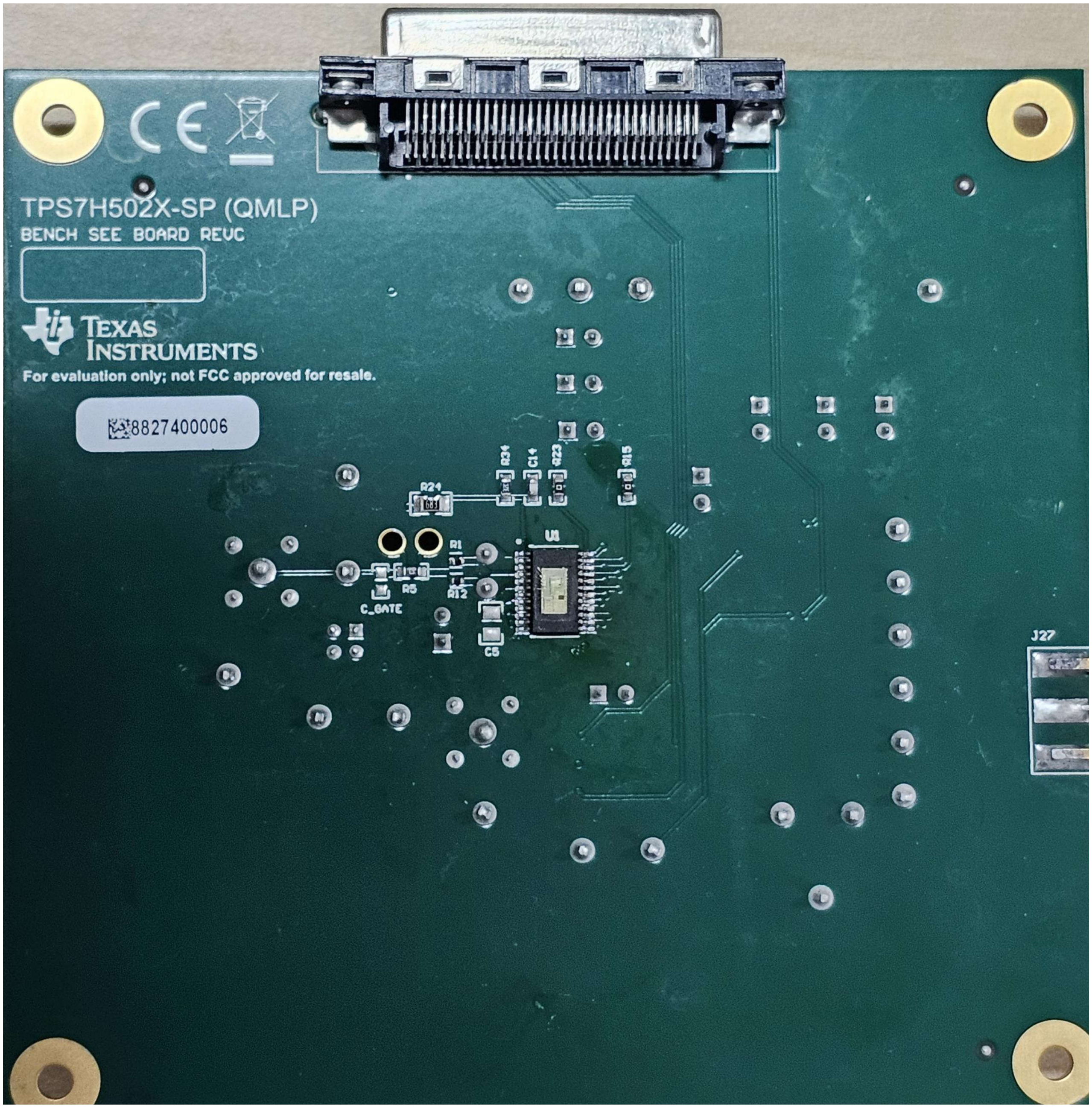

Figure 3-2. TPS7H502x-SEP Custom EVM Top View

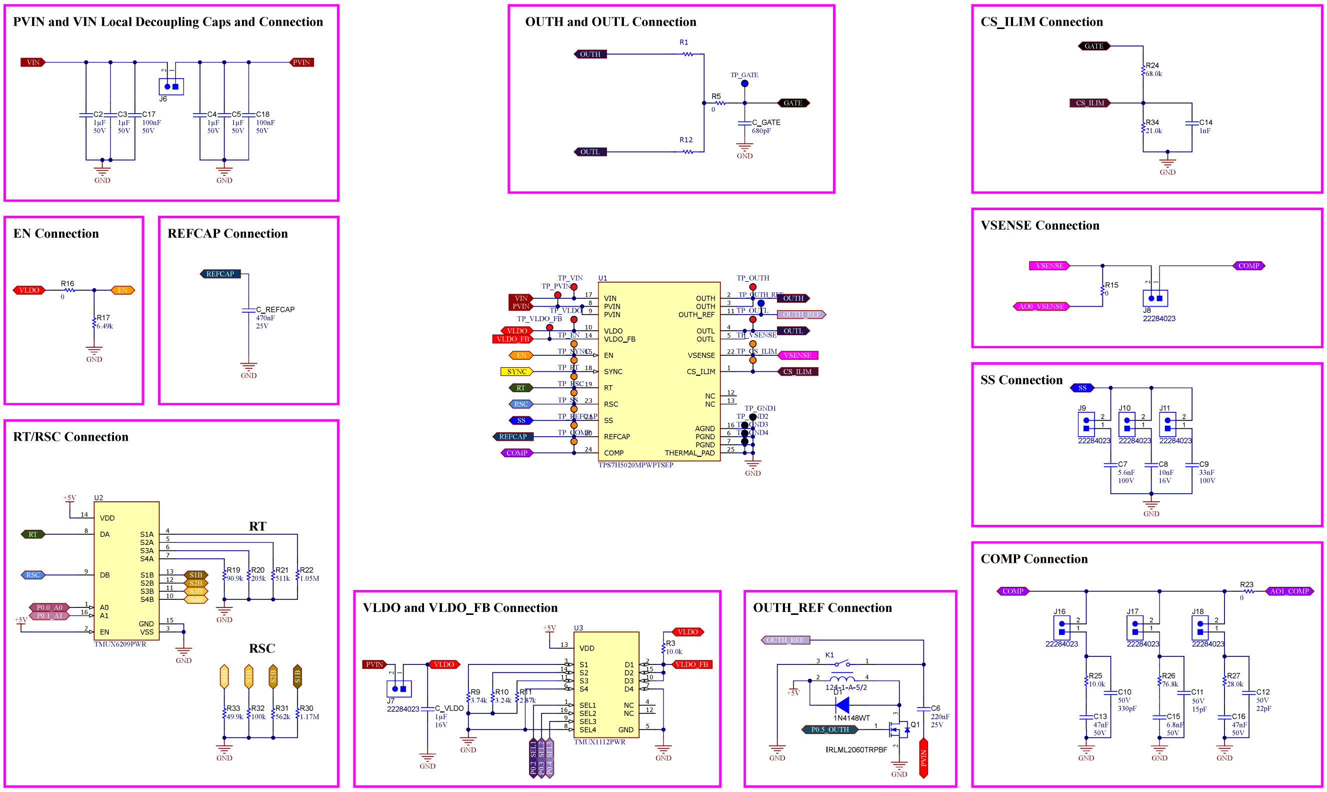

Figure 3-3. TPS7H502x-SEP EVM Schematics

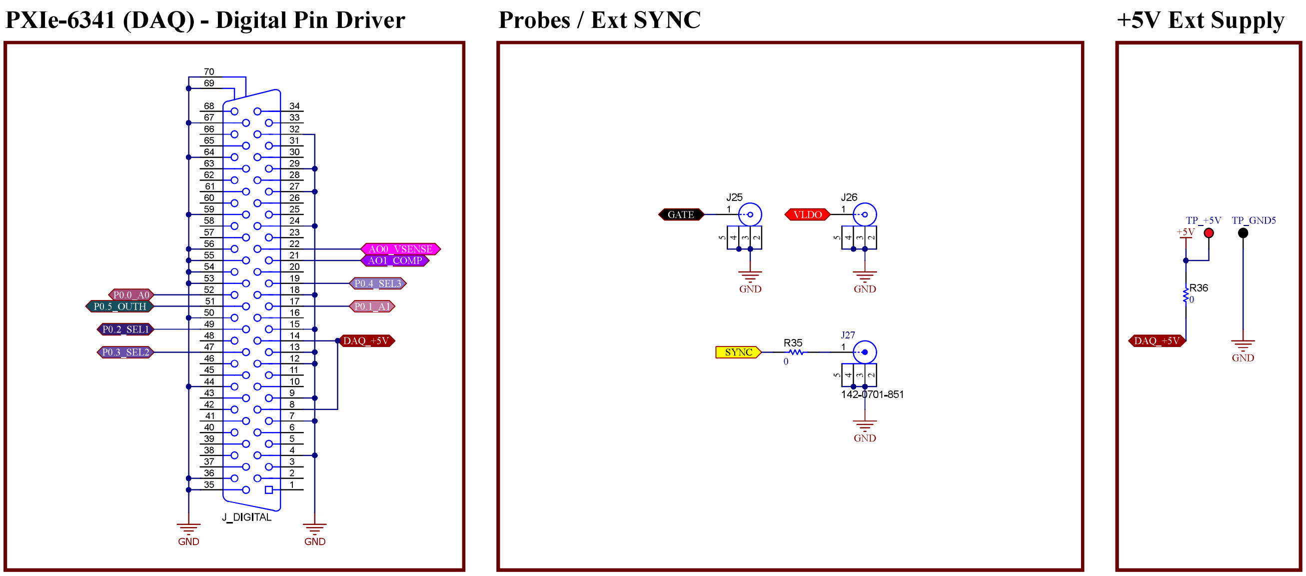

Figure 3-4. TPS7H502x-SEP Custom EVM Auxiliary Schematic

4 Irradiation Facility and Setup

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

- Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a K500 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 9.14×10^4 to 1.26×10^5 ions/(cm^2×s) was used to provide heavy-ion fluences of 1.00×10^7 ions/cm^2. The TAMU facility uses a beam port that has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.
- Michigan State University (MSU) Facility for Rare Isotope Beams (FRIB) using a K500 superconducting cyclotron (KSEE) and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity as the beam is collimated to a maximum of 40mm × 40mm square cross-sectional area for the in-air and vacuum scintillators. Uniformity is achieved by scattering on a Cu foil and then performing magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of $\approx 10^5$ ions/(cm^2×s) was used to provide heavy-ion fluences of 1.00×10^7 ions/cm^2. The KSEE facility uses a beam port that has a 3-mil polyethylene naphthalate (PEN) window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 60mm for all runs.

For the experiments conducted on this report, 2 ions were used; ^{109}Ag (TAMU) and ^{109}Ag (KSEE). Both were used to obtain LET_{EFF} of ≈48 MeV·cm^2/mg. The total kinetic energies for the ions were:

- ^{109}Ag (TAMU) = 1.635GeV (15MeV/nucleon)
  - Ion uniformity for these experiments was 94%
- ^{109}Ag (KSEE) = 2.125GeV (19.5MeV/nucleon)
  - Ion uniformity for these experiments was 91%

Figure 4-1 shows the open-loop custom SEE evaluation module in front of the beam line at the TAMU facility.

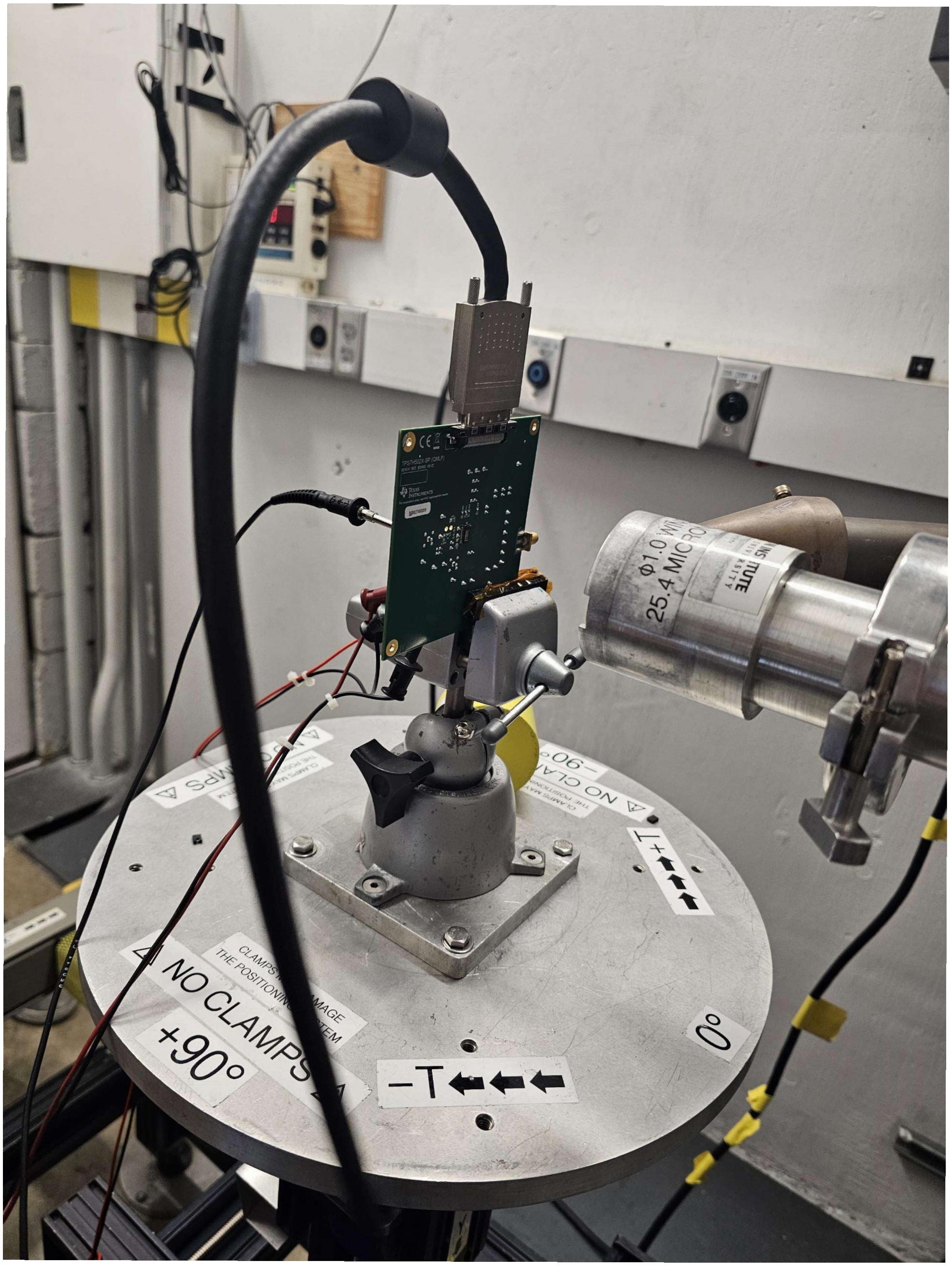

Figure 4-1. TPS7H502x-SEP EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 LET$_{EFF}$ and Range Calculation

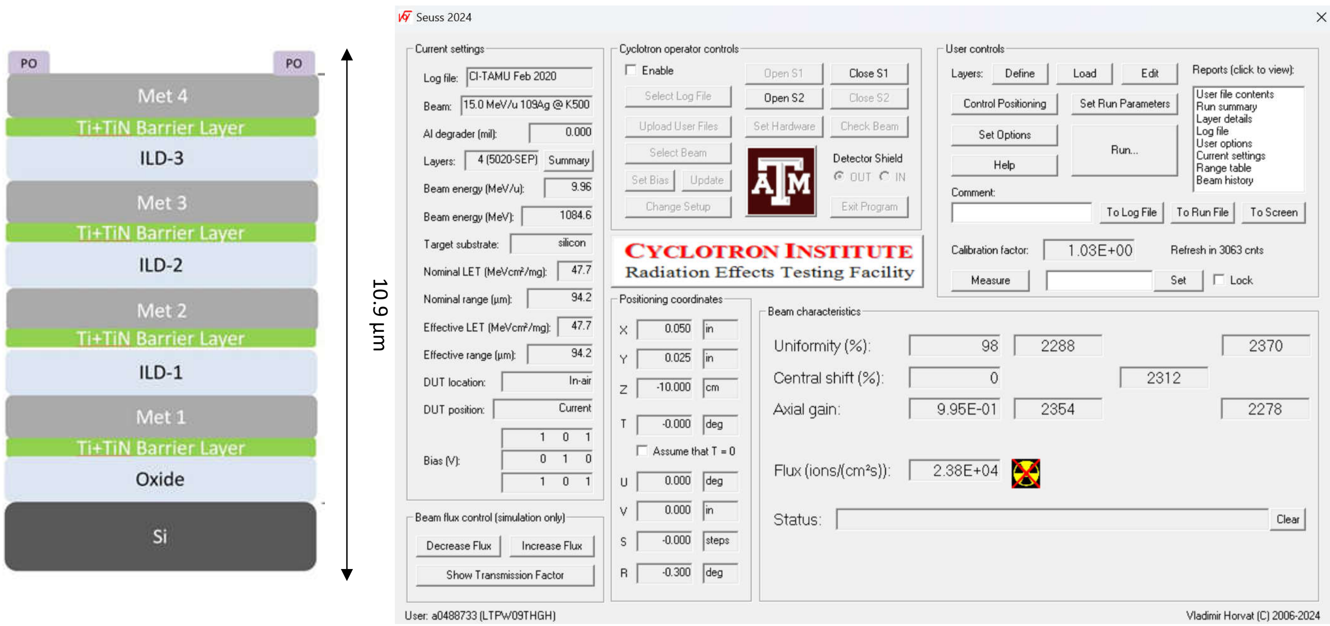

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H502x-SEP [Left] and SEUSS 2024 Application Used to Determine Key Ion Parameters [Right]

The TPS7H502x-SEP is fabricated in the TI Linear BiCMOS 250-nm process with a back-end-of-line (BEOL) stack consisting of 4 levels of standard thickness aluminum. The total stack height from the surface of the passivation to the silicon surface is 10.9 µm based on nominal layer thickness as shown in Figure 5-1.

Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the TPS7H502x-SEP, the effective LET (LET$_{EFF}$) at the surface of the silicon substrate and the range was determined with:

- SEUSS 2022 software (provided by TAMU and based on the latest SRIM-2013 [7] models)
- MSU Stack-Up Calculator (provided by MSU FRIB and based on latest SRIM-2013 [7] models)

The results are shown in Table 5-1.

Table 5-1. Ion LET$_{EFF}$ and Range in Silicon

Facility	Beam Energy (MeV/ nucleon)	Ion Type	Degrader Steps (#)	Degrader Angle (°)	Copper Foil Width (µm)	Beam Port Window	Air Gap (mm)	Angle of Incidence	LET$_{EFF}$ (MeV·cm^2/ mg)	Range in Silicon (µm)
TAMU	15	^{109}Ag	0	0	-	1-mil Aramica	40	0	47.7	94.2
KSEE	19.5	^{109}Ag	-	-	5	3-mil PEN	60	0	49.1	86.6

6 Test Setup and Procedures

There were two input supplies used to power the TPS7H502x-SEP which provided V_{IN} and EN. The V_{IN} for the device was provided via Ch. 3 of an N6705C power module and ranged from 4.5V to 14V for SEL, SEB/SEGR, and SET testing. The EN of the device was driven by an E36311A power supply and was either forced to 0V or 5V to enable or disable the device. A NI PXIe-6341 DAQ was used to drive V_{SNS} and V_{COMP}. V_{LDO} had 3 programmable voltages, 4.5V, 5V, or 5.5V and were selected by closing relays to connect to a feedback network on the EVM to select the required V_{LDO} voltage. Input ranges for the different modes and switching frequencies are shown below. Note that the P_{VIN} column denotes whether or not P_{VIN} (the driver stage input) was tied to V_{IN} or V_{LDO}.

Table 6-1. TPS7H502x-SEP Mode Bias Ranges

Mode	V_{IN} (V)	P_{VIN}	V_{LDO} (V)	V_{SNS} (V)	V_{COMP} (V)	EN (V)	RT (Ω)	FSW (Hz)
Silicon	4.5-14	VIN	4.5-5.5	0.6	0.8	0/5	205k	500k
GaN	4.5-14	VLDO	4.5-5.5	0.6	0.8	0/5	205k	500k

The primary signal monitored during testing was GATE (OUTH and OUTL tied together on the EVM) and this was done so using a PXIe-5110 triggering using a pulse-width trigger at 20%.

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 6-2 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 TPS7H502x-SEP.

Note that only the relay for the correct feedback network was driven by the PXIe-6341 for V_{LDO}, not the actual V_{LDO} voltage.

Table 6-2. Equipment Settings and Parameters Used During the Open-Loop SEE Testing of the TPS7H502x-SEP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{IN}	N6705C (CH # 3)	20.4V, 50A	5A	2.5 to 7V
EN	E36311A (CH # 1)	5V,5A	0.1A	0V, 5V
V_{SNS}	PXIe-6341	±10V, ±5mA	N/A	0.6V
V_{COMP}	PXIe-6341	±10V, ±5mA	N/A	0.45V to 1.45V
V_{LDO}	PXIe-6341	±10V, ±5mA	N/A	0V, 5V
GATE	PXIe-5110	100 MS/s	—	100 MS/s

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to verify 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 TPS7H502x-SEP 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 pulse-width 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.

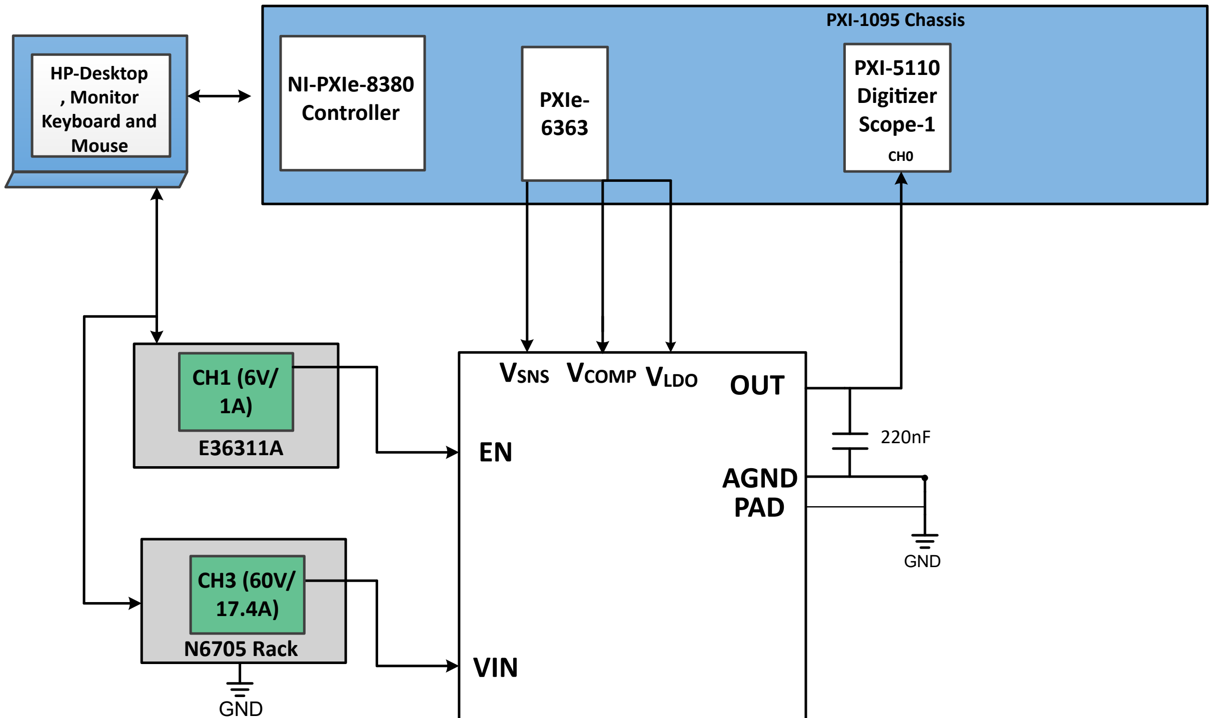

Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H502x-SEP

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

The species used for the SEL testing was ^{109}Ag (TAMU) at 15MeV/nucleon and ^{109}Ag (KSEE) at 19.5MeV/nucleon. For both ions an angle of incidence of 0° was used to achieve a LET_{EFF} of ≈ 48MeV·cm^2/mg (for more details refer to Table 7-1). The kinetic energy in the vacuum for ^{109}Ag (TAMU) is 1.635 GeV and ^{109}Ag (KSEE) is 2.125GeV. Flux of ≈8.96×10^4 to 1.26×10^5 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 8 devices were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 14V and max programmable V_{LDO} voltage of 5.5V. Depending on the operational mode PVIN was either tied to VIN or VLDO, for more information refer to the Table 6-1. No SEL events were observed during all six runs, indicating that the TPS7H502x-SEP is SEL-free up to 48 MeV·cm^2/mg.Table 7-1 shows the SEL test conditions and results. Figure 7-1 and Figure 7-1 show a plot of the current versus time for runs #1 and #3, respectively.

Table 7-1. Summary of TPS7H502x-SEP SEL Test Condition and Results

Run #	Unit #	Facility	Device Type	Mode	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions/(cm^2×s))	Fluence (ions/cm^2)	V_{IN} (V)	P_{VIN} (V)	V_{LDO}	SEL (# Events)
1	1	TAMU	TPS7H5020-SEP	Silicon	^{109}Ag	47.7	9.15×10^4	1×10^7	14	14	5.5	0
2	2	TAMU	TPS7H5020-SEP	Silicon	^{109}Ag	47.7	1.09×10^5	1×10^7	14	14	5.5	0
3	3	TAMU	TPS7H5020-SEP	GaN	^{109}Ag	47.7	1.13×10^5	1×10^7	14	5.5	5.5	0
4	4	TAMU	TPS7H5020-SEP	GaN	^{109}Ag	47.7	1.16×10^5	1×10^7	14	5.5	5.5	0
5	5	KSEE	TPS7H5020-SEP	Silicon	^{109}Ag	49.1	1.06×10^5	1×10^7	14	14	5.5	0
6	6	KSEE	TPS7H5020-SEP	GaN	^{109}Ag	49.1	1.10×10^5	1×10^7	14	5.5	5.5	0
25	7	KSEE	TPS7H5021-SEP	Silicon	^{109}Ag	49.1	9.49×10^4	1×10^7	14	14	5.5	0
26	8	KSEE	TPS7H5021-SEP	GaN	^{109}Ag	49.1	8.96×10^4	1×10^7	14	5.5	5.5	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the eight runs at 125°C (8×10^7), the upper-bound cross-section (using a 95% confidece level) is calculated as:

$\sigma_{SEL} \leq 4.61 \times 10^{-8}$ cm^2/device for LET_{EFF} = 48 MeV·cm^2/mg and T = 125°C.

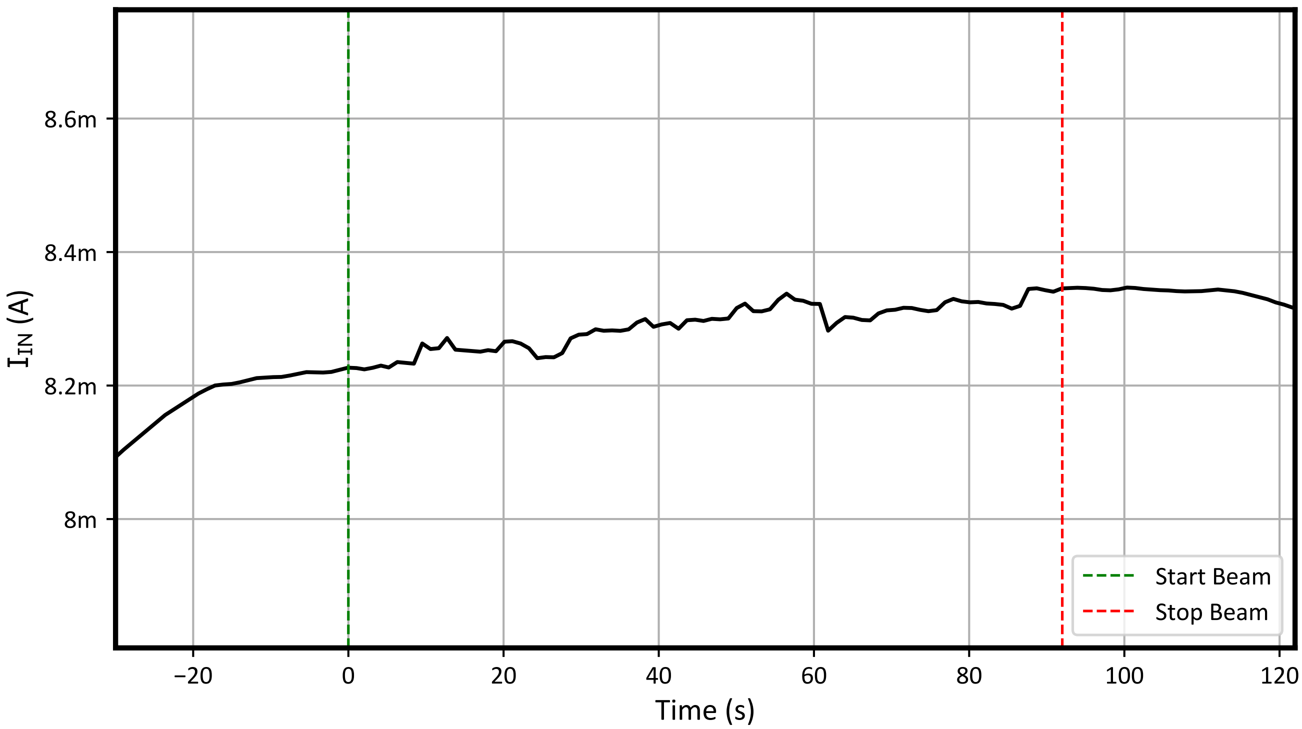

Figure 7-1. Current vs Time for Run #1 of the TPS7H502x-SEP at T = 125°C in Silicon Mode

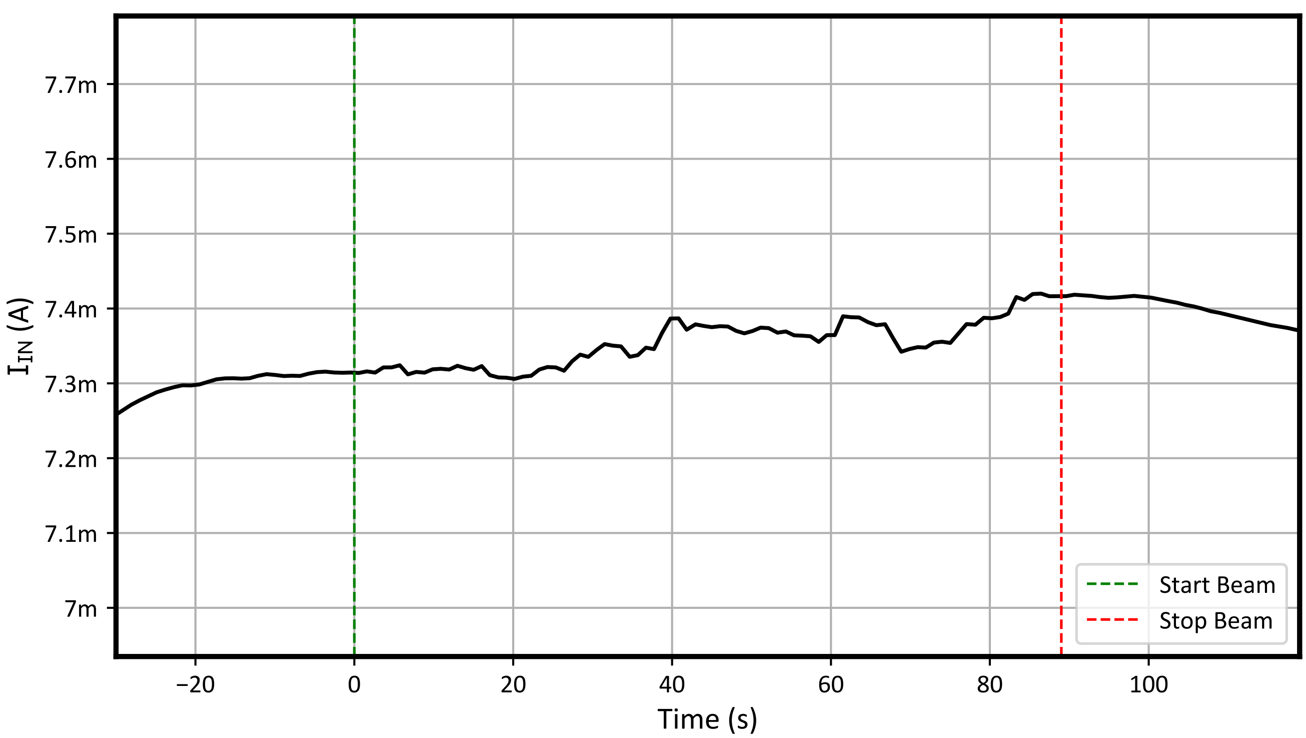

Figure 7-2. Current Versus Time for Run #3 of the TPS7H502x-SEP at T = 125°C in GaN Mode

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 mode the device was disabled using the EN-pin by forcing 0V (using CH # 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 ^{109}Ag (TAMU) at 15MeV/nucleon and ^{109}Ag (KSEE) at 19.5 MeV/nucleon. For both ions an angle of 0° was used to achieve a LET_{EFF} of ≈ 48MeV·cm^2/mg (for more details refer to Table 5-1). The kinetic energy in the vacuum for ^{109}Ag (TAMU) is 1.635GeV and ^{109}Ag (KSEE) is 2.125GeV. Flux of ≈ 8.83 × 10^4 to 1.26 × 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 8 devices (same as used in SEL testing) were powered up and exposed to the heavy-ions using the maximum recommended bias conditions. No SEB/SEGR current events were observed during the 16 runs, indicating that the TPS7H502x-SEP is SEB/SEGR-free up to LET_{EFF} = 48MeV·cm^2/mg and across the full electrical specifications. Table 7-2 shows the SEB/SEGR test conditions and results.

Table 7-2. Summary of TPS7H502x-SEP SEB/SEGR Test Condition and Results

RUN #	UNIT #	Facility	Device Type	Mode	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/(cm^2×s))	FLUENCE (ions/cm^2)	ENABLED STATUS	V_{IN} (V)	P_{VIN} (V)	V_{LDO} (V)	SEB EVENT?
7	1	TAMU	TPS7H5020-SEP	Silicon	^{109}Ag	47.7	9.67 x 10^4	9.99 x 10^6	EN	14	14	5.5	No
8	1	TAMU	TPS7H5020-SEP	Silicon	^{109}Ag	47.7	9.77 x 10^4	9.99 x 10^6	DIS	14	14	5.5	No
9	2	TAMU	TPS7H5020-SEP	Silicon	^{109}Ag	47.7	1.00 x 10^5	1.00 x 10^7	EN	14	14	5.5	No
10	2	TAMU	TPS7H5020-SEP	Silicon	^{109}Ag	47.7	1.12 x 10^5	1.00 x 10^7	DIS	14	14	5.5	No
11	3	TAMU	TPS7H5020-SEP	GaN	^{109}Ag	47.7	1.13 x 10^5	1.00 x 10^7	EN	14	5.5	5.5	No
12	3	TAMU	TPS7H5020-SEP	GaN	^{109}Ag	47.7	1.18 x 10^5	1.00 x 10^7	DIS	14	5.5	5.5	No
13	4	TAMU	TPS7H5020-SEP	GaN	^{109}Ag	47.7	1.18 x 10^5	1.00 x 10^7	EN	14	5.5	5.5	No
14	4	TAMU	TPS7H5020-SEP	GaN	^{109}Ag	47.7	1.26 x 10^5	1.00 x 10^7	DIS	14	5.5	5.5	No
15	5	KSEE	TPS7H5020-SEP	Silicon	^{109}Ag	49.1	1.02 x 10^5	1.00 x 10^7	EN	14	14	5.5	No
16	5	KSEE	TPS7H5020-SEP	Silicon	^{109}Ag	49.1	9.54 x 10^4	1.00 x 10^7	DIS	14	14	5.5	No
17	6	KSEE	TPS7H5020-SEP	GaN	^{109}Ag	49.1	1.15 x 10^5	1.00 x 10^7	EN	14	5.5	5.5	No
18	6	KSEE	TPS7H5020-SEP	GaN	^{109}Ag	49.1	1.18 x 10^5	1.00 x 10^7	DIS	14	5.5	5.5	No

Table 7-2. Summary of TPS7H502x-SEP SEB/SEGR Test Condition and Results (continued)

RUN #	UNIT #	Facility	Device Type	Mode	ION	LET_{EFF} (MeV·cm²/mg)	FLUX (ions/(cm²×s))	FLUENCE (ions/cm²)	ENABLED STATUS	V_{IN} (V)	P_{VIN} (V)	V_{LDO} (V)	SEB EVENT?
27	7	KSEE	TPS7H5021-SEP	Silicon	^{109}Ag	49.1	1.05×10^5	1.00×10^7	EN	14	14	5.5	No
28	7	KSEE	TPS7H5021-SEP	Silicon	^{109}Ag	49.1	8.99×10^4	1.00×10^7	DIS	14	14	5.5	No
29	8	KSEE	TPS7H5021-SEP	GaN	^{109}Ag	49.1	9.44×10^4	1.00×10^7	EN	14	5.5	5.5	No
30	8	KSEE	TPS7H5021-SEP	GaN	^{109}Ag	49.1	8.83×10^4	1.00×10^7	DIS	14	5.5	5.5	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:

$\sigma_{SEB} \leq 2.31 \times 10^{-8}$ cm²/device for LET_{EFF} = 75 MeV·cm²/mg and T = 25°C.

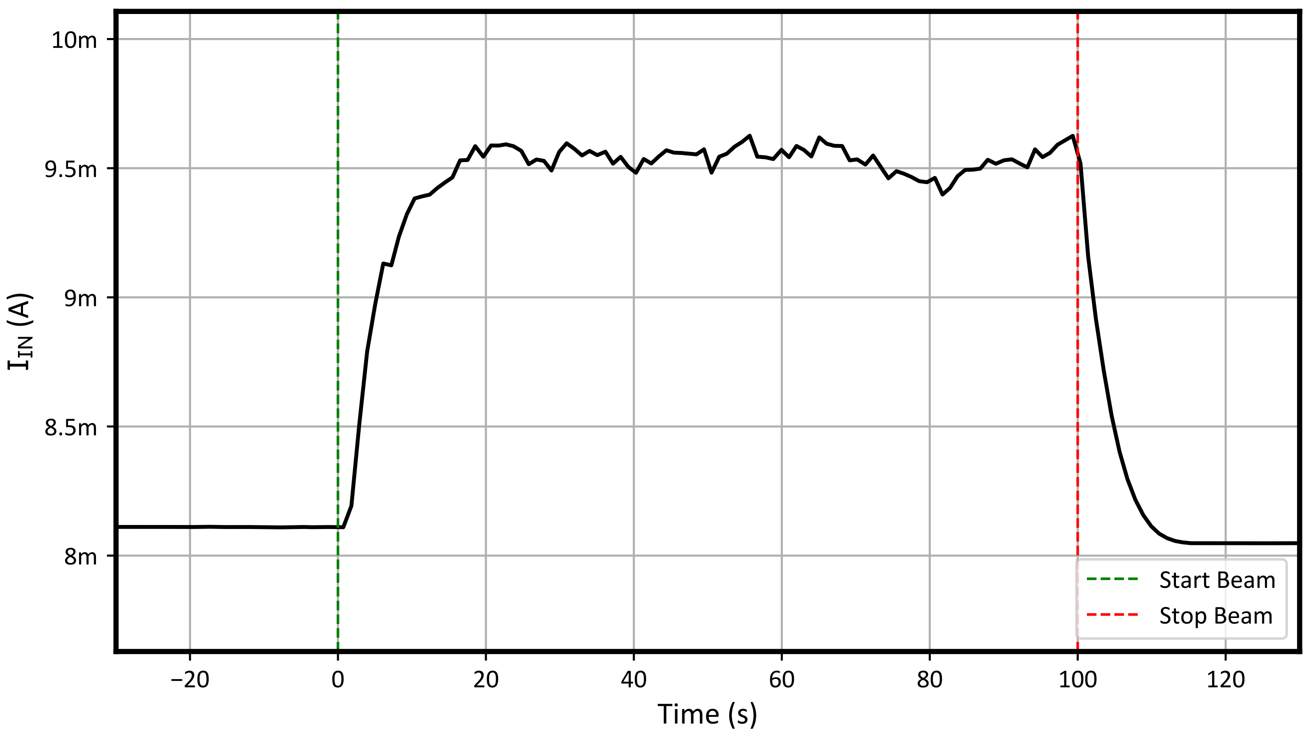

Figure 7-3. SEB On Run #7 TPS7H5020-SEP Silicon Mode

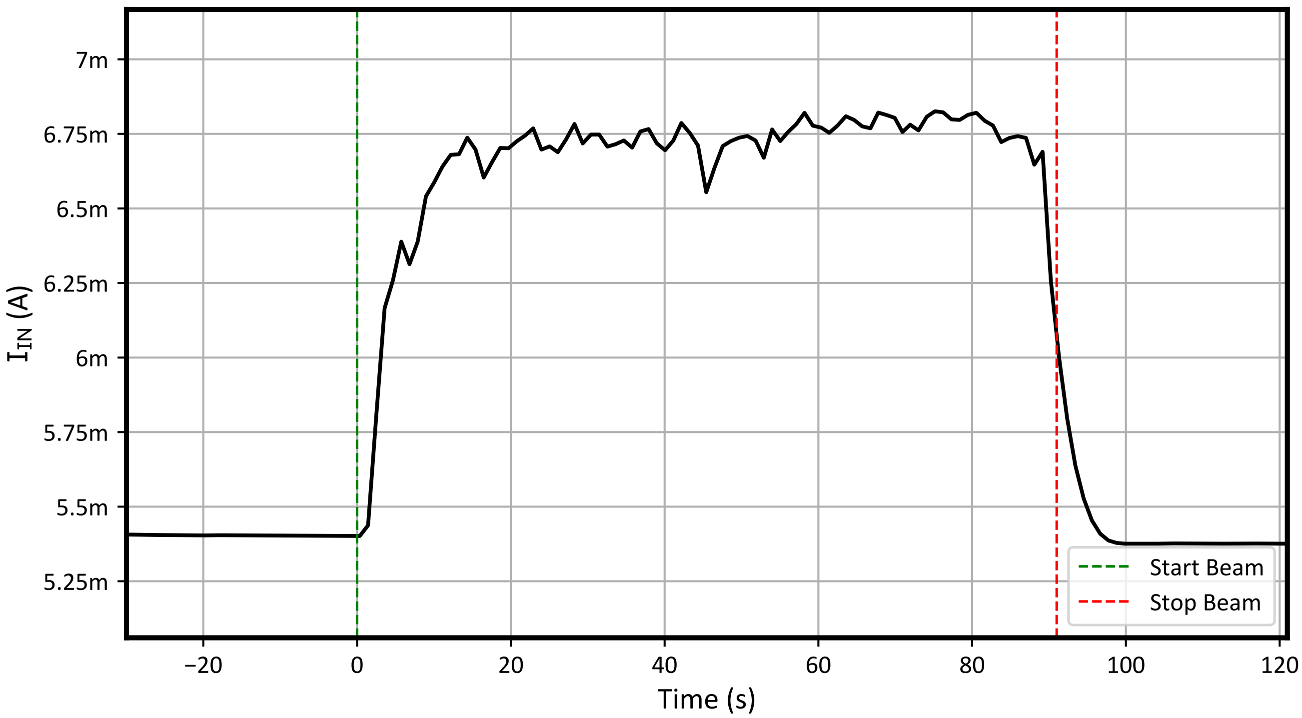

Figure 7-4. SEB Off Run #8 TPS7H5020-SEP Silicon Mode

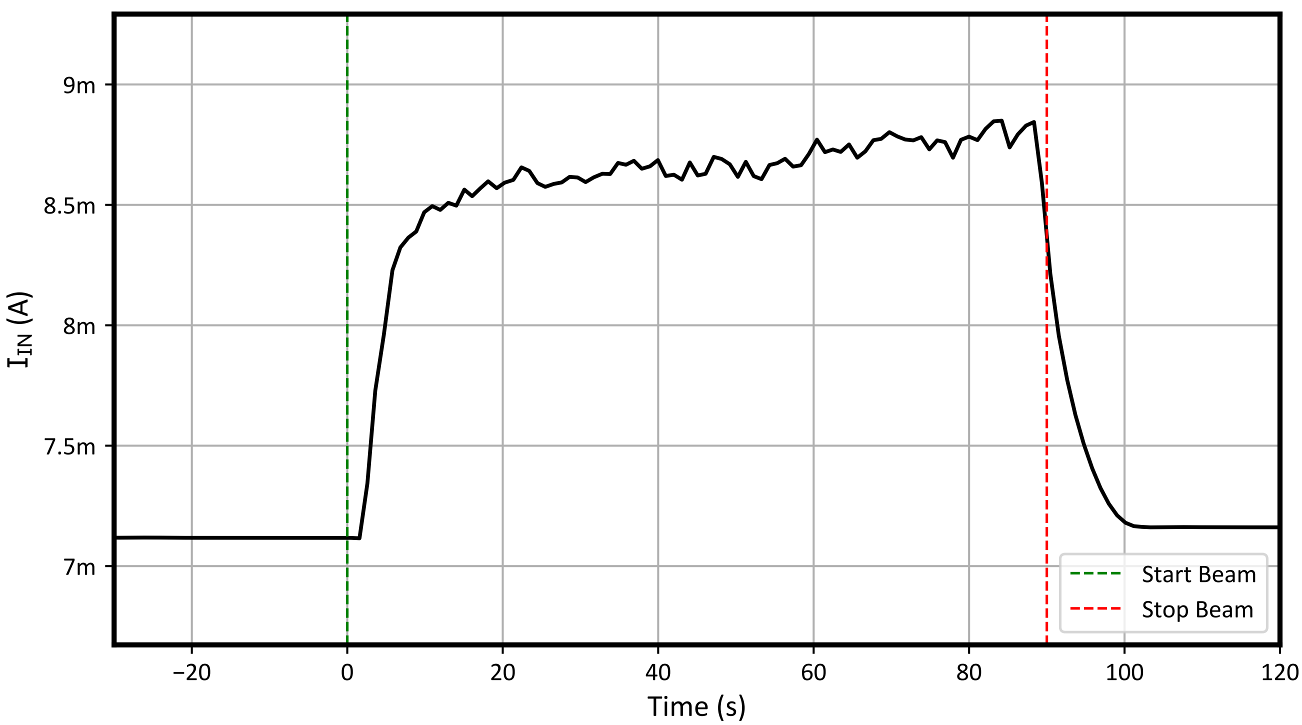

Figure 7-5. SEB On Run #15 TPS7H5020-SEP GaN Mode

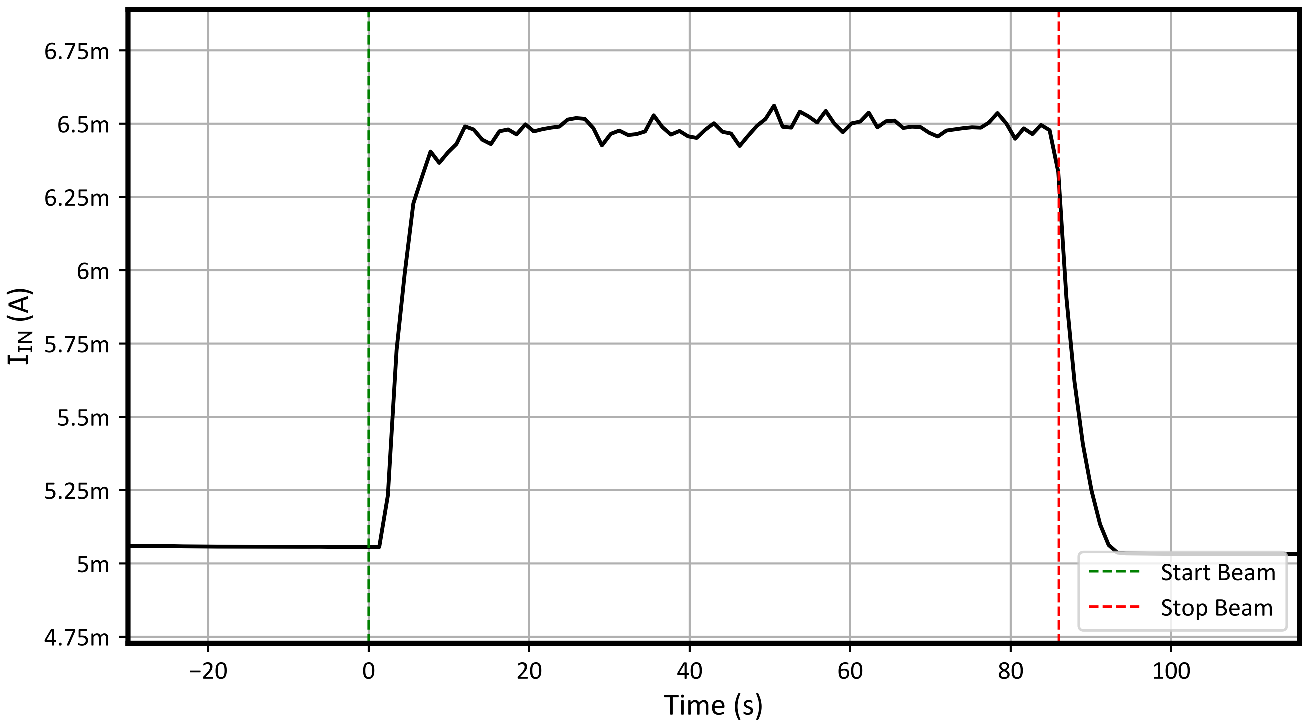

Figure 7-6. SEB Off Run #16 TPS7H5020-SEP GaN Mode

8 Single-Event Transients (SET)

SETs are defined as heavy-ion-induced transient upsets on the GATE (OUTH and OUTL tied together) of the TPS7H502x-SEP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for the SET testing was ^{109}Ag (TAMU) at 15MeV/nucleon and ^{109}Ag (KSEE) at 19.5MeV/nucleon (for more details refer to Table 5-1). Flux of $\approx 10^5$ ions/($cm^2 \times s$) and a fluence of $\approx 10^7$ ions/cm^2 per run were used for the SET characterization discussed in this chapter.

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

Table 8-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
PXIe-5110	GATE	Pulse-Width	± 20%	50k	100MS/s

Open-Loop Configuration

The primary focus of SETs were heavy-ion-induced transient upsets on output signal GATE (OUTH and OUTL tied together). SET testing was done at room temperature at ^{109}Ag (TAMU) and ^{109}Ag (KSEE) which produced a LET_{EFF} of ≈48MeV·cm^2/mg. GATE was monitored using a NI PXIe-5110. During testing the scope was set to trigger if the signal exceeded |20%| from nominal using a pulse width trigger. During all SET testing, there was one type of transient recorded that was self-recoverable.

The SET results for 8 devices are shown below in Table 8-2. The transient signature on GATE is shown and the number of transients across the runs and voltages are shown. Since only this transient signature occurred there is high confidence that the TPS7H502x-SEP is SEFI free and the recorded transient signature does not show any overshoot indicating that the TPS7H502x-SEP is safe for GaN operations. Note that for all testing V_{LDO} was programmed to be 5V.

The upper-bound cross-sections for all bias conditions are shown in Table 8-2.

Table 8-2. Summary of TPS7H502x-SEP Open-Loop SET Test Condition and Results

RUN #	UNIT #	Facility	Device Type	Mode	V_{IN} (V)	F_{SW} (Hz)	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/(cm^2×s))	FLUENCE (ions/cm^2)	# GATE ≥ |20%|
19	1	TAMU	TPS7H5020-SEP	Silicon	12	500k	^{109}Ag	47.7	9.88× 10^4	1.00 × 10^7	20
20	2	TAMU	TPS7H5020-SEP	Silicon	12	500k	^{109}Ag	47.7	1.07 × 10^5	1.00 × 10^7	18
21	3	TAMU	TPS7H5020-SEP	GaN	12	500k	^{109}Ag	47.7	1.21 × 10^5	1.00 × 10^7	68
22	4	TAMU	TPS7H5020-SEP	GaN	12	500k	^{109}Ag	47.7	1.22 × 10^5	1.00 × 10^7	55
23	5	KSEE	TPS7H5020-SEP	Silicon	12	500k	^{109}Ag	49.1	9.70 × 10^4	1.00 × 10^7	5
24	6	KSEE	TPS7H5020-SEP	GaN	12	500k	^{109}Ag	49.1	1.20 × 10^5	1.00 × 10^7	44
31	7	KSEE	TPS7H5021-SEP	Silicon	12	500k	^{109}Ag	49.1	9.51 × 10^4	1.00 × 10^7	12
32	8	KSEE	TPS7H5021-SEP	GaN	12	500k	^{109}Ag	49.1	8.86 × 10^4	1.00 × 10^7	55

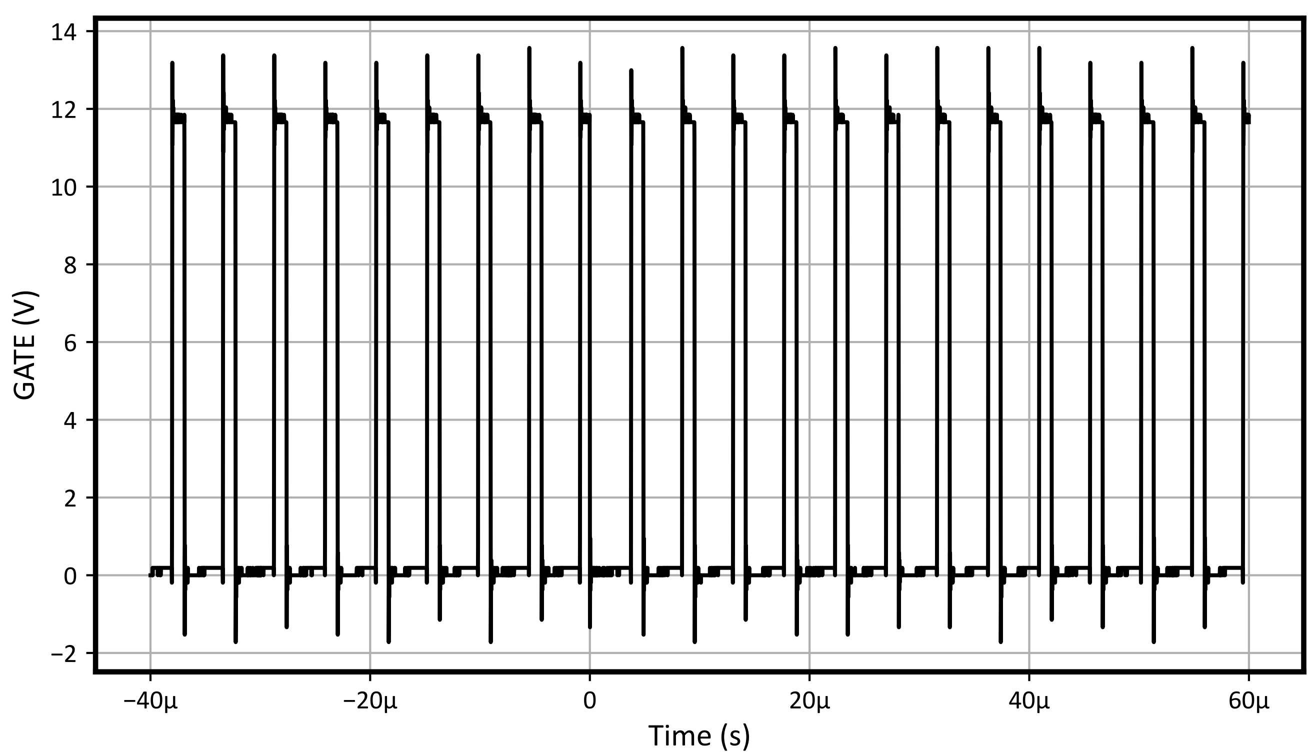

Figure 8-1. TPS7H5020-SEP Silicon Mode GATE Pulse-Width Transient (Run #19)

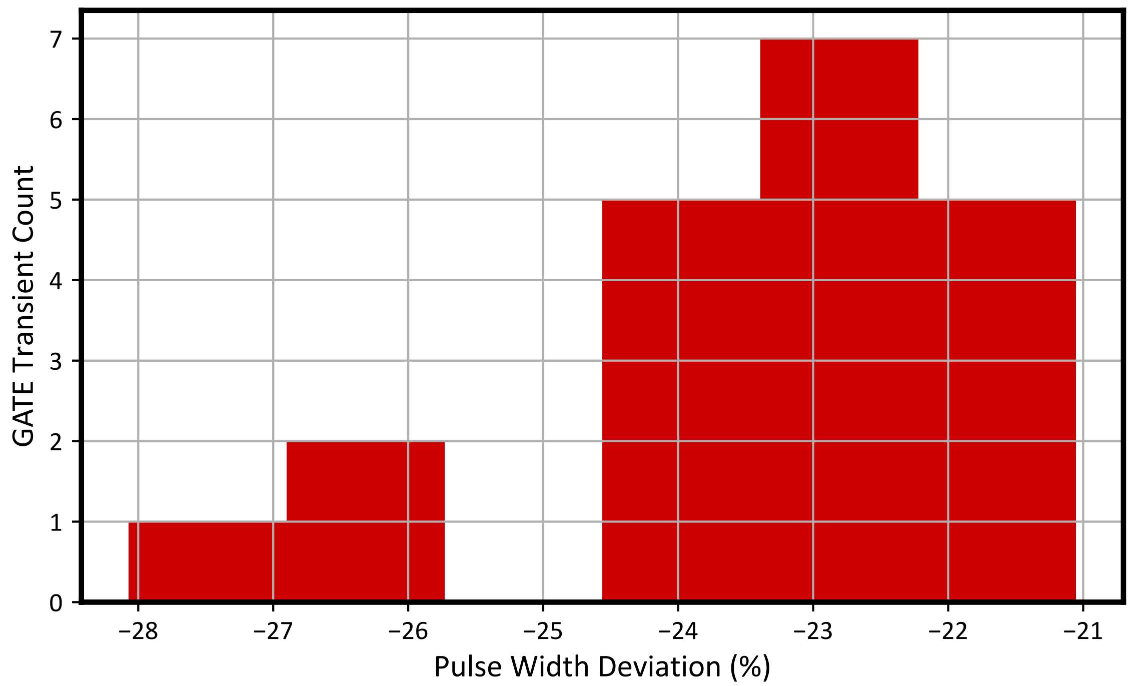

Figure 8-2. TPS7H5020-SEP Silicon Mode GATE Pulse-Width Deviation Histogram (Run #19)

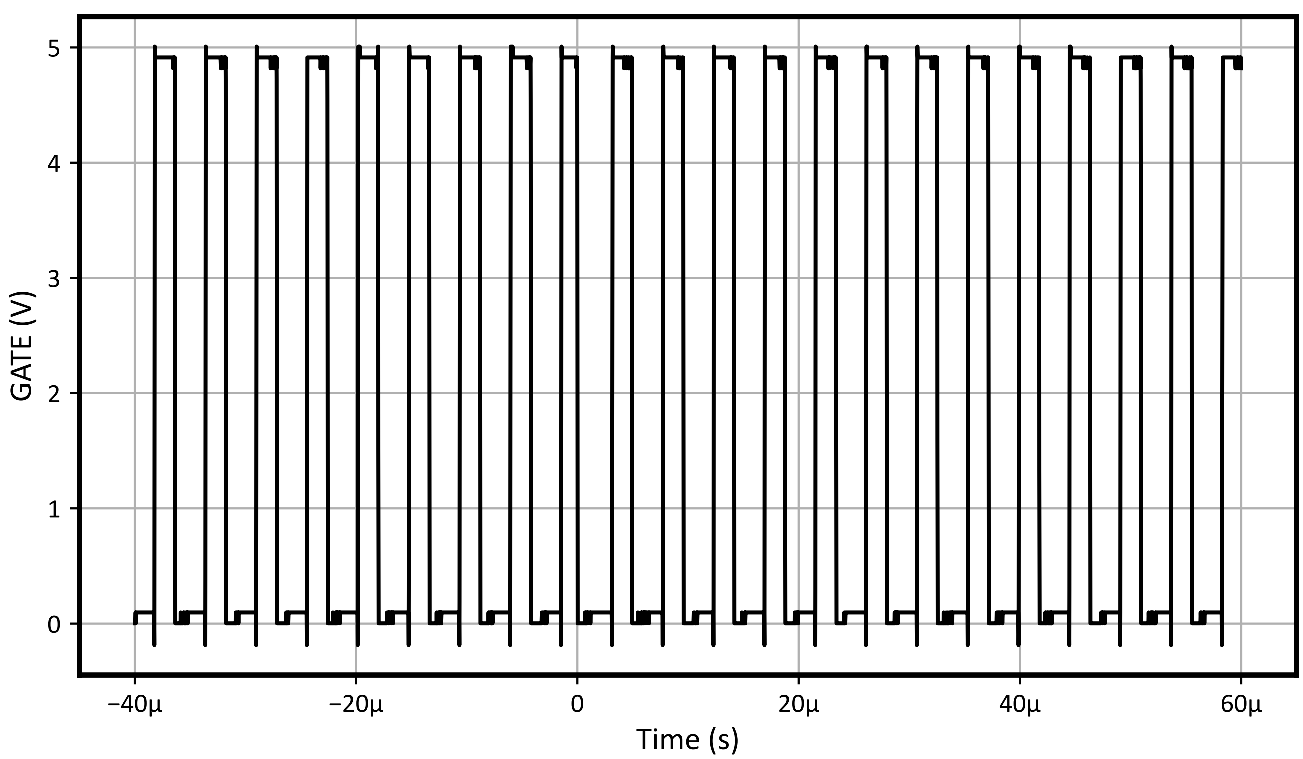

Figure 8-3. TPS7H5020-SEP GaN Mode GATE Pulse-Width Transient (Run #21)

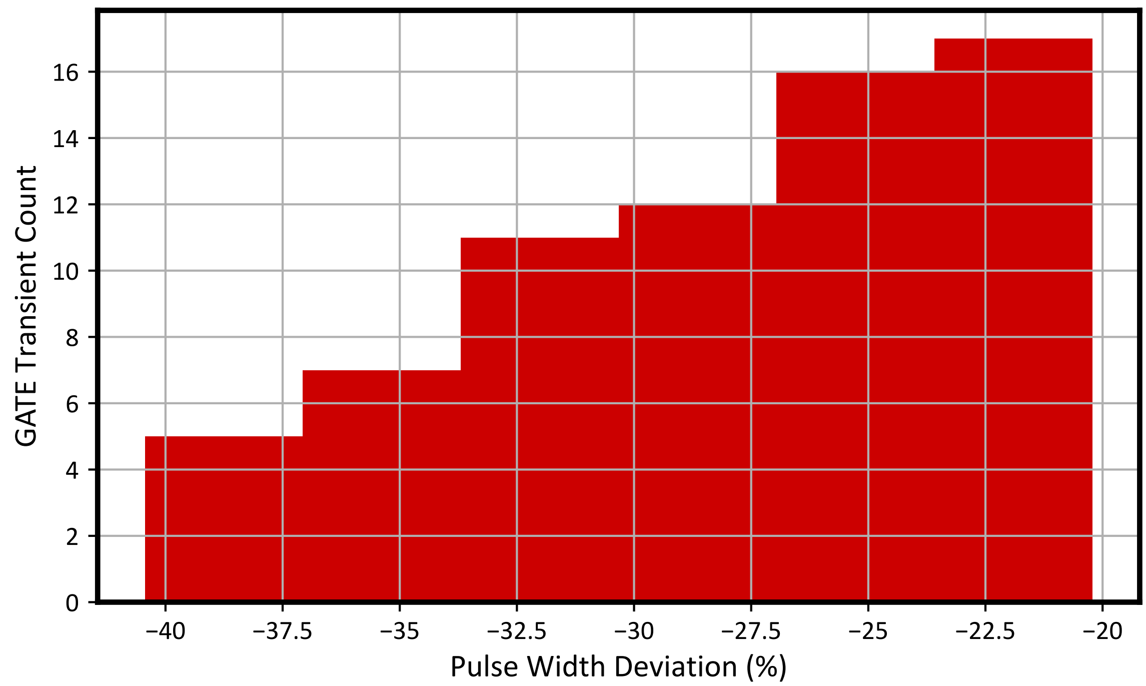

Figure 8-4. TPS7H5020-SEP GaN Mode GATE Pulse-Width Deviation Histogram (Run #21)

Table 8-3. TPS7H502x-SEP SET Cross-Sections

LET_{EFF} (MeV·cm^2/mg)	Mode	Parameters	V_{IN} (V)	Fluence (ions/ cm^2)	# Transients	Upper-Bound Cross-Section (cm^2)
48	Silicon	500k	12	4×10^7	55	8.95×10^{-7}
	GaN	500k	12	4×10^7	222	3.17×10^{-6}

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. **Note that this number is for reference since no SEL or SEB/SEGR 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)	47.7	4.59×10^{-4}	4.61×10^{-8}	2.12×10^{-11}	8.82×10^{-4}	1.29×10^{8}
GEO		1.51×10^{-3}		6.95×10^{-11}	2.90×10^{-3}	3.94×10^{7}

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

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	47.7	4.59×10^{-4}	2.31×10^{-8}	1.06×10^{-11}	4.41×10^{-4}	2.59×10^{8}
GEO		1.51×10^{-3}		3.48×10^{-11}	1.45×10^{-3}	7.88×10^{7}

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 TPS7H502x-SEP radiation-tolerant, current mode, single-ended PWM controller with an integrated gate driver. Heavy-ions with LET_{EFF} = 48MeV·cm^2/mg were used for the SEE characterization campaign. Flux of 9.14 × 10^4 to 1.26 × 10^5 ions/(cm^2×s) and fluences of ≈ 1x10 ^{7} ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H502x-SEP is free of destructive SEL and SEB at LET_{EFF} = 48MeV·cm^2/mg and across the full electrical specifications. Transients at LET_{EFF} = 48MeV·cm^2/mg were monitored and discussed CREME96-based worst week event-rate calculations for LEO(ISS) and GEO orbits for DSEE are presented for reference.

A References

1. M. Shoga and D. Binder, "Theory of Single Event Latchup in Complementary Metal-Oxide Semiconductor Integrated Circuits", *IEEE Trans. Nucl. Sci., Vol. 33(6)*, Dec. 1986, pp. 1714-1717.
2. G. Bruguier and J. M. Palau, "Single particle-induced latchup", *IEEE Trans. Nucl. Sci., Vol. 43(2)*, Mar. 1996, pp. 522-532.
3. G. H. Johnson, J. H. Hohl, R. D. Schrimpf and K. F. Galloway, "Simulating single-event burnout of n-channel power MOSFET's," in IEEE Transactions on Electron Devices, vol. 40, no. 5, pp. 1001-1008, May 1993.
4. J. R. Brews, M. Allenspach, R. D. Schrimpf, K. F. Galloway,J. L. Titus and C. F. Wheatley, "A conceptual model of a single-event gate-rupture in power MOSFETs," in IEEE Transactions on Nuclear Science, vol. 40, no. 6, pp. 1959-1966, Dec. 1993.
5. G. H. Johnson, R. D. Schrimpf, K. F. Galloway, and R. Koga,"Temperature dependence of single event burnout in n-channel power MOSFETs [for space application]," IEEE Trans. Nucl. Sci., 39(6), Dec. 1992, pp.1605-1612.
6. TAMU Radiation Effects Facility website. http://cyclotron.tamu.edu/ref/
7. "The Stopping and Range of Ions in Matter" (SRIM) software simulation tools website. www.srim.org/index.htm#SRIMMENU
8. D. Kececioglu, "Reliability and Life Testing Handbook", Vol. 1, PTR Prentice Hall, New Jersey,1993, pp. 186-193.
9. ISDE CRÈME-MC website.https://creme.isde.vanderbilt.edu/CREME-MC
10. A. J. Tylka, J. H. Adams, P. R. Boberg, et al.,"CREME96: A Revision of the Cosmic Ray Effects on Micro-Electronics Code", *IEEE Trans. on Nucl. Sci., Vol. 44(6)*, Dec. 1997, pp. 2150-2160.
11. A. J. Tylka, W. F. Dietrich, and P. R. Boberg, "Probability distributions of high-energy solar-heavy-ion fluxes from IMP-8: 1973-1996", *IEEE Trans. on Nucl. Sci.,Vol. 44(6)*, Dec. 1997, pp. 2140-2149.

12 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (August 2025) to Revision A (February 2026)	Page
• Updated the SEL, SEB, and SET sections to include TPS7H5021-SEP data	13