Radiation Report

Single-Event Effects (SEE) Radiation Report of the TPS7H6101-SEP

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TPS7H6101-SEP. Heavy-ions with LET_{EFF} of 48MeV·cm^2/mg were used to irradiate six devices. Flux of 8.13×10^4 to 1.18×10^5ions/cm^2/s and fluence of approximately 10^7ions/cm^2 per run were used for the characterization. The results demonstrated that the TPS7H6101-SEP is SEL-free up to 48MeV·cm^2/mg at T = 125°C and SEB/SEGR-free up to 48MeV·cm^2/mg at T = 25°C. Output signals including VOUT (3% window) and SW (20% pulse-width) were monitored to check for transients and SEFIs. The device showed to be SET and SEFI free up to 48MeV·cm^2/mg at T = 25°C.

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1 Introduction

The TPS7H6101-SEP is a radiation-tolerant 200V, 10A, power stage incorporating two enhancement mode gallium nitride (e-mode GaN) with an integrated half-bridge gate driver. The incorporated gate driver has features such as low propagation delay, configurable dead time control and shoot through interlock protections, and two operational modes. Additionally, the integration of the e-mode GaN FETs and gate driver simplifies the design and reduces component count as well as board space, making the device appropriate for space satellite power management and distribution.

The device is offered in a 12mm by 9mm 64-pin LGA 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	TPS7H6101-SEP	
Orderable Part Number	TPS7H6101MNPRNSEP	
Device Function	PWM controller with integrated gate driver	
Technology	Driver	LBC7 (LinBiCMOS™ 7)
	Power stage	E-mode GaN
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15MeV/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)	

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2 Single-Event Effects (SEE)

The primary concern for the driver in the TPS7H6101-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 in the driver of the TPS7H6101-SEP, the CMOS circuitry introduces a higher potential for SEL susceptibility. Separately, the incorporated e-mode GaN are susceptible to increased drain-source leakage currents and SEB due to high voltage.

SEL in the driver of the TPS7H6101-SEP 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 TPS7H6101-SEP driver was tested for SEL with PVIN= 150V, DVIN = 12V; moreover, a 100kHz square wave switching from 0V to 14V was supplied to PWM_LI and the duty cycle was adjusted to allow the power stage to output 28V. During testing of the six devices, the TPS7H6101-SEP driver did not exhibit any SEL with heavy-ions with LET_{EFF} = 48MeV·cm^2/mg at a flux of aproximately10^5 ions/cm^2/s, fluence of approximately10^7 ions/cm^2, and a die temperature of 125°C.

Because it has been shown that the MOSFET susceptibility to burnout decrement with temperature [5], TPS7H6101-SEP driver was evaluated for SEB/SEGR while operating under room temperatures. On the other hand, e-mode GaN, and therefore the TPS7H6101-SEP power stage, is inherently not susceptible to SEGR as it does not have a gate oxide; however, it could be susceptible to SEB. The TPS7H6101-SEP driver and power stage were tested for SEB at the operating conditions of PVIN = 150V, DVIN = 12V, along with a 100kHz square wave switching from 0V to 14V supplied to PWM_LI, which had the duty cycle adjusted to allow the power stage to output 28V. 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 TPS7H6101-SEP driver is SEB/SEGR-free up to LET_{EFF} = 48MeV·cm^2/mg at a flux of approximately 10^5 ions/cm^2/s, fluences of approximately10^7 ions/cm^2, and a die temperature of approximately 25°C.

Both the TPS7H6101-SEP driver and power stage were characterized for SET at flux of approximately 10^5 ions/cm^2/s , fluences of approximately 10^7 ions/cm^2, and room temperature. The device was characterized at a PVIN of 100V and 135V; DVIN was characterized to 12V, and VOUT was configured to 28V by characterizing PWM_LI to a 100kHz square wave switching from 0V to 5V with the duty cycle adjusted accordingly. Heavy-ions with LET_{EFF} of 48MeV·cm^2/mg were used to characterize the transient performance. To see the SET results of the TPS7H6101-SEP, please refer to Section 8.

3 Device and Test Board Information

The TPS7H6101-SEP is packaged in a 64-pin LGA plastic package as shown in Figure 3-1. The TPS7H6101EVM was used to evaluate the performance and characteristics of the TPS7H6101-SEP under heavy ion radiation. The evaluation module is shown in Figure 3-2. The schematics are shown in Figure 3-3.

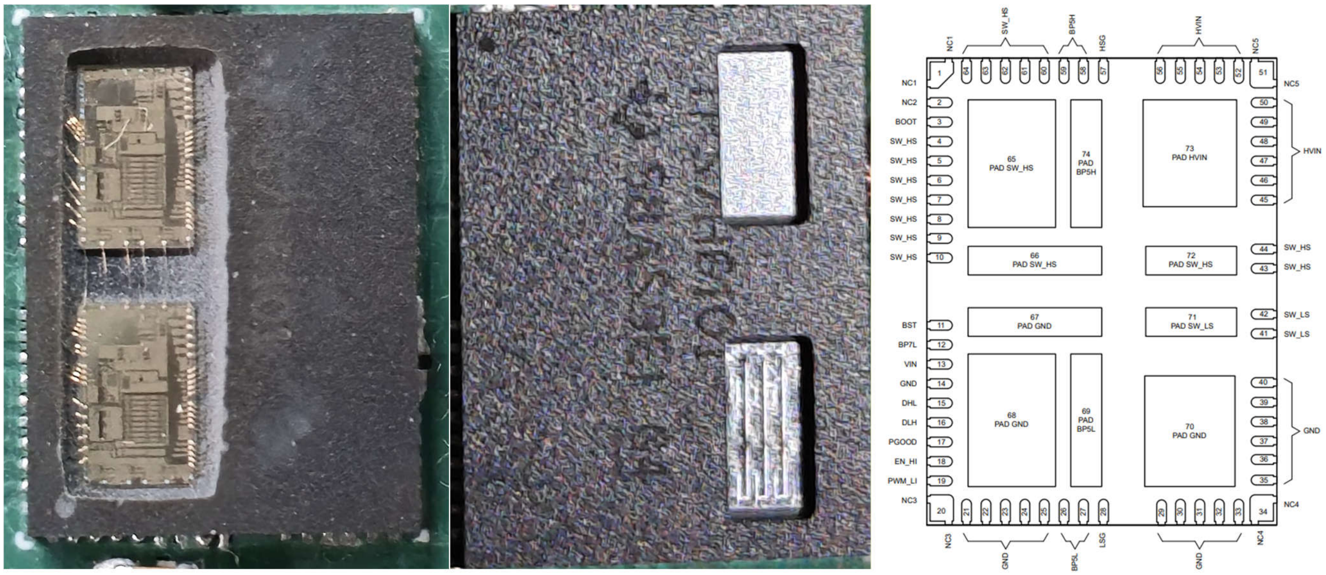


Figure 3-1. Photograph of Decapped TPS7H6101-SEP Driver [Left], TPS7H6101-SEP Power Stage [Center], and Pinout Diagram [Right]

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

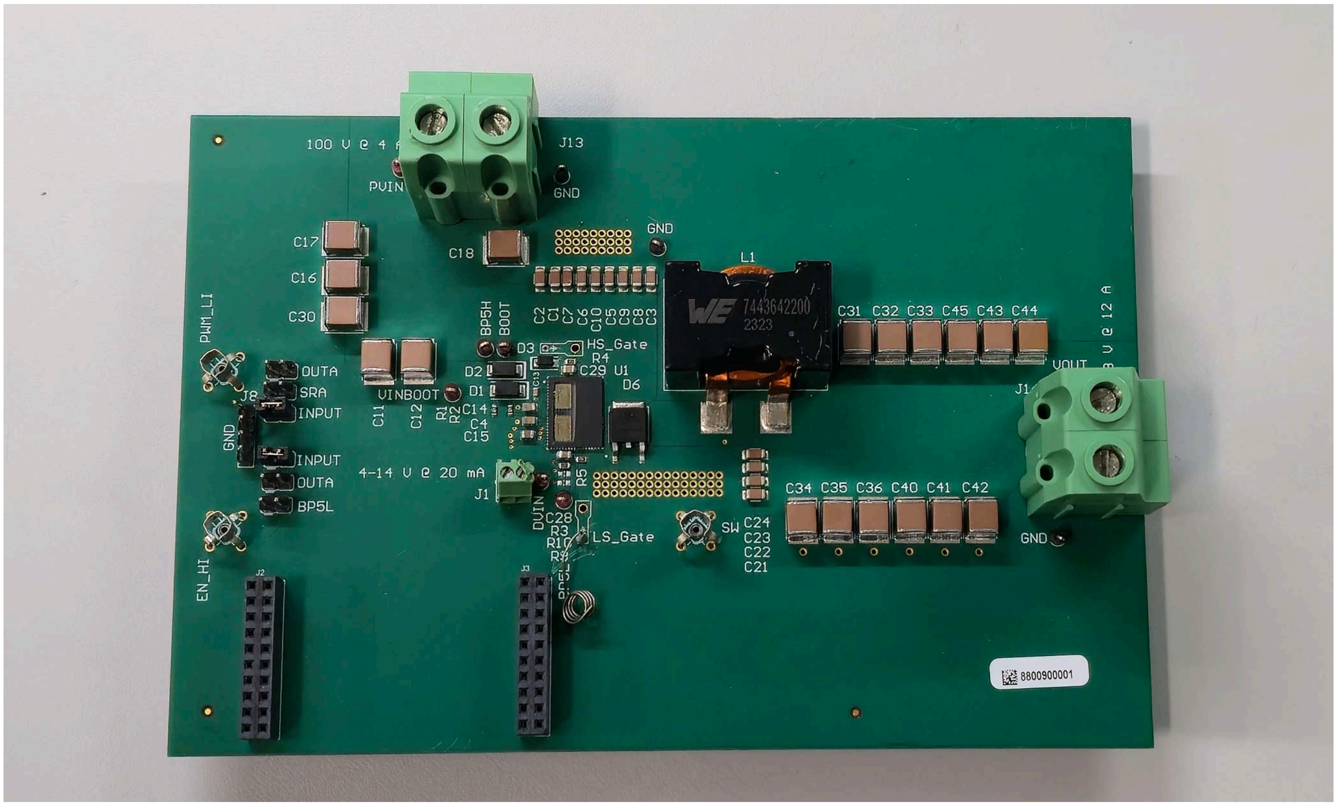
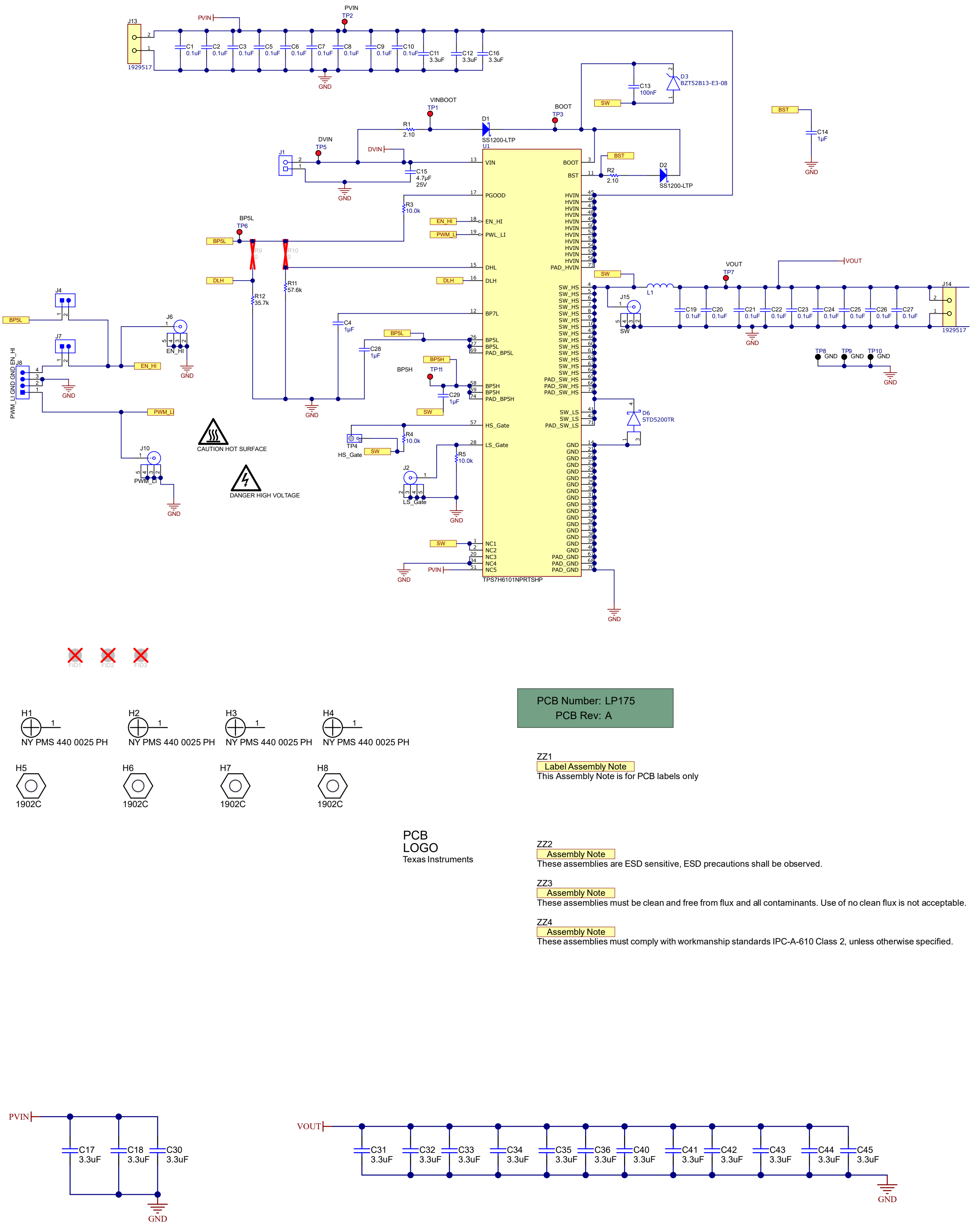


Figure 3-2. TPS7H6101-SEP EVM Top View



ZZ1
Label Assembly Note
This Assembly Note is for PCB labels only

ZZ2
Assembly Note
These assemblies are ESD sensitive, ESD precautions shall be observed.

ZZ3
Assembly Note
These assemblies must be clean and free from flux and all contaminants. Use of no clean flux is not acceptable.

ZZ4
Assembly Note
These assemblies must comply with workmanship standards IPC-A-610 Class 2, unless otherwise specified.

Figure 3-3. TPS7H6101-SEP EVM Schematics

4 Irradiation Facility and Setup

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

- 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 1.03×10^5 to 1.18×10^5ions/cm^2/s was used to provide heavy-ion fluences of approximately 10^7ions/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 8.13×10^4 to 9.96×10^4ions/cm^2/s was used to provide heavy-ion fluences of 10^7ions/cm^2. The KSEE facility uses a beam port that has a 3-mil polyethylene naphthalate (PEN) window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 50mm for all runs.

For the experiments conducted on this report, ^{109}Ag was the ion used at both facilities, which was used to obtain LET$_{EFF}$ of 48MeV·cm^2/mg. The total kinetic energies for the ions were:

- ^{109}Ag (TAMU) = 1.633GeV (15MeV/nucleon)
  - Ion uniformity for these experiments was 91%
- ^{109}Ag (KSEE) = 2.123GeV (19.5MeV/nucleon)
  - Ion uniformity for these experiments was between 89% and 92%

Figure 4-1 shows the TPS7H6101EVM used for data collection at TAMU.

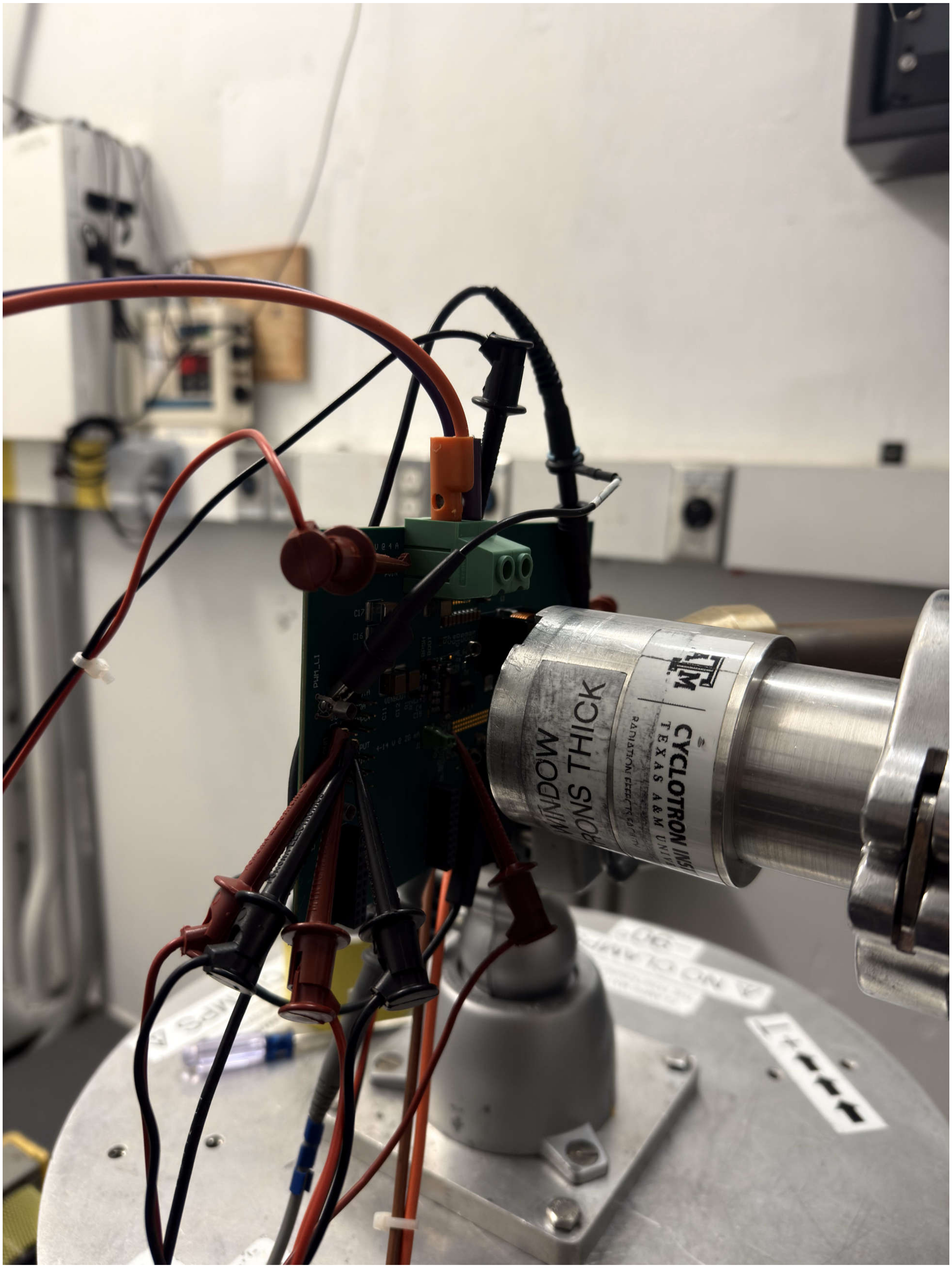
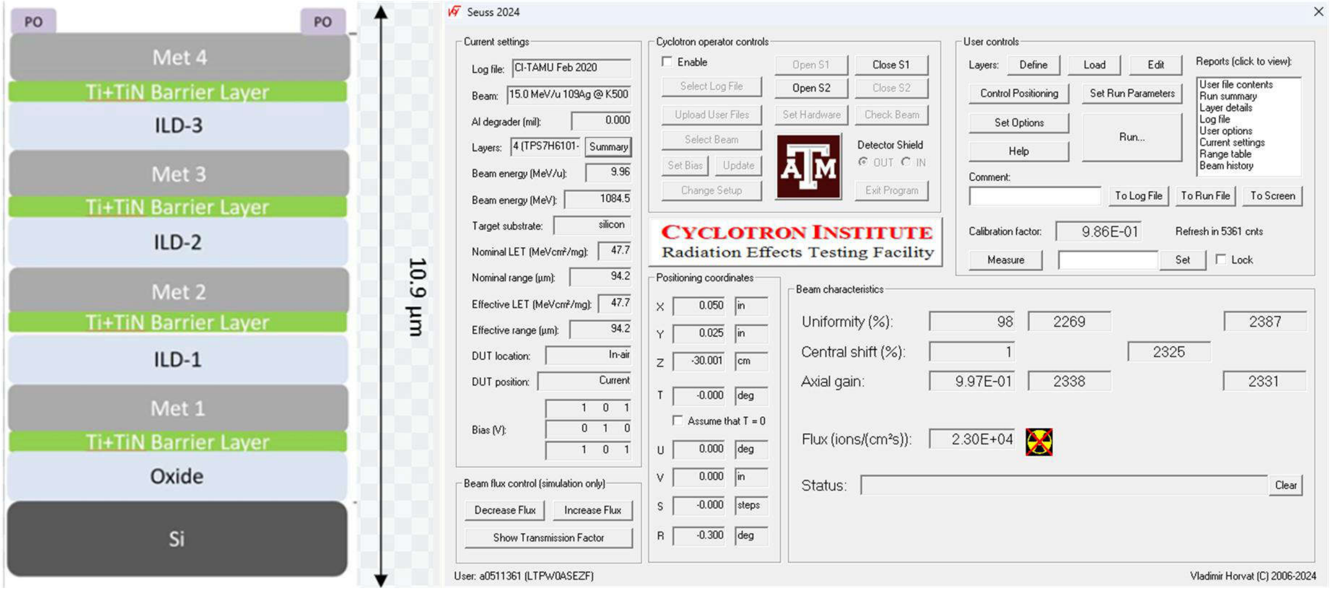


Figure 4-1. TPS7H6101-SEP EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 LET$_{EFF}$ and Range Calculation



Current settings

Log file: CI-TAMU Feb 2020
Beam: 15.0 MeV/u 109Ag @ K500
Al degrader (mil): 0.000
Layers: 4 (TPS7H6101- Summary
Beam energy (MeV/u): 9.96
Beam energy (MeV): 1084.5
Target substrate: silicon
Nominal LET (MeVcm²/mg): 47.7
Nominal range (µm): 94.2
Effective LET (MeVcm²/mg): 47.7
Effective range (µm): 94.2
DUT location: In-air
DUT position: Current
Bias (V): 1 0 1 / 0 1 0 / 1 0 1

Beam flux control (simulation only)

Detector Shield ● OUT ○ IN

Positioning coordinates

X 0.050 in
Y 0.025 in
Z -30.001 cm
T -0.000 deg
☐ Assume that T = 0
U 0.000 deg
V 0.000 in
S -0.000 steps
R -0.300 deg

Comment:

Calibration factor: 9.86E-01
Refresh in 5361 cnts

Beam characteristics

Uniformity (%): 98 2269 2387
Central shift (%): 1 2325
Axial gain: 9.97E-01 2338 2331
Flux (ions/(cm²s)): 2.30E+04
Status:

User: a0511361 (LTPW0ASEZF)
Vladimir Horvat (C) 2006-2024

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H6101-SEP [Left] and SEUSS 2024 Application Used to Determine Key Ion Parameters [Right]

The TPS7H6101-SEP driver is fabricated in the TI LinBiCMOS 250nm process with a 4LM back-end-of-line (BEOL) stack. The total stack height from the surface of the passivation to the silicon surface is 10.9µm based on nominal layer thickness as shown in Figure 5-1.

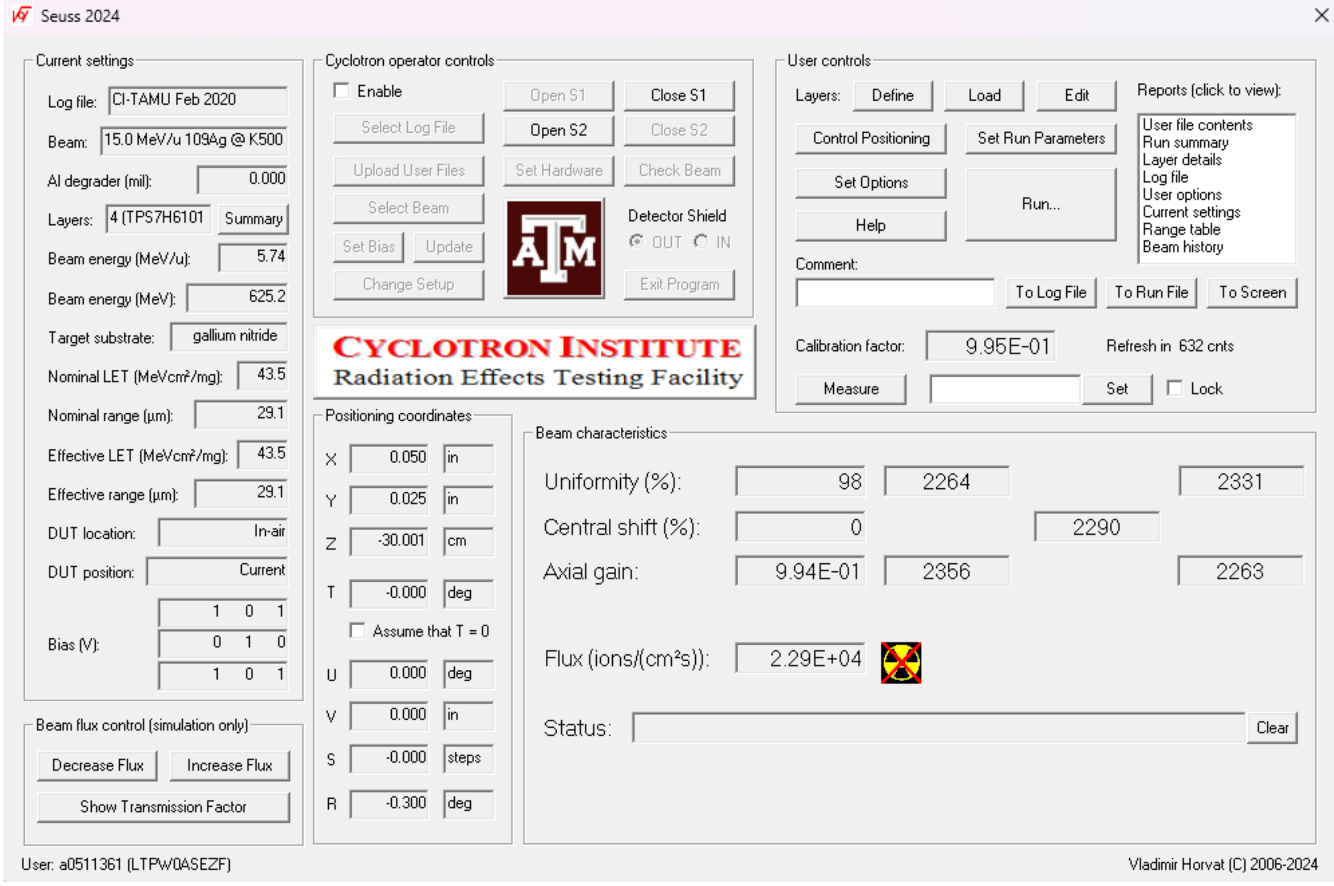
Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the TPS7H6101-SEP, the effective LET (LET$_{EFF}$) at the surface of the silicon substrate and the range was determined with:

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

The results are shown in Table 5-1.

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

Facility	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 (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	50	0	49.1	86.6



Log file: CI-TAMU Feb 2020
Beam: 15.0 MeV/u 109Ag @ K500
Al degrader (mil): 0.000
Layers: 4 (TPS7H6101
Beam energy (MeV/u): 5.74
Beam energy (MeV): 625.2
Target substrate: gallium nitride
Nominal LET (MeVcm²/mg): 43.5
Nominal range (µm): 29.1
Effective LET (MeVcm²/mg): 43.5
Effective range (µm): 29.1
DUT location: In-air
DUT position: Current
Bias (V): 1 0 1 / 0 1 0 / 1 0 1

☐ Enable
Detector Shield: ● OUT ○ IN

X 0.050 in
Y 0.025 in
Z -30.001 cm
T -0.000 deg
☐ Assume that T = 0
U 0.000 deg
V 0.000 in
S -0.000 steps
R -0.300 deg

Comment:
Calibration factor: 9.95E-01
Refresh in 632 cnts
☐ Lock

Uniformity (%): 98 2264 2331
Central shift (%): 0 2290
Axial gain: 9.94E-01 2356 2263
Flux (ions/(cm²s)): 2.29E+04
Status:

User: a0511361 (LTPW0ASEZF)
Vladimir Horvat (C) 2006-2024

Figure 5-2. SEUSS 2024 Application Used to Determine Key Ion Parameters for enhancement mode Gallium Nitride (e-mode GaN)

Backgrinding was performed on the TPS7H6101-SEP e-mode GaN power stage to leave 50µm of bulk Si above the die. Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the bulk Si, the surface LET and the range was determined using:

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

The results are shown in Table 5-1.

Table 5-2. Ion Surface LET and Range in Gallium Nitride (GaN)

Facility	Beam Energy (MeV/ nucleon)	Ion Type	Degrader Steps (#)	Degrader Angle (°)	Copper Foil Width (µm)	Beam Port Window	Air Gap (mm)	Angle of Incidence	Surface LET (MeV·cm^2/ mg)	Range (µm)
TAMU	15	^{109}Ag	0	0	-	1-mil Aramica	40	0	43.3	29.1
KSEE	19.5	^{109}Ag	-	-	5	3-mil PEN	50	0	43.51	28.9

6 Test Setup and Procedures

There were four input supplies used to power the TPS7H6101-SEP which provided PVIN, DVIN, PWM_LI and EN. The PVIN for the device was provided via a Chroma™ 62012 power supply and ranged from 100V to 150V 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. An NI PXIe-5433 Waveform Generator was used to drive PWM_LI to a 100kHz square wave that switched from 0V to 14V. VOUT was set to 28V by adjusting the duty cycle of the square wave accordingly. Input ranges for the different modes and switching frequencies are shown below.

The instrument used to load the TPS7H6101-SEP was a Chroma 63600 e-load that was used in constant resistance (CR) mode. The value of CR was adjusted depending on the type of test. For all SEB and SET testing the CR values were set so that the device can be loaded to 6A, which kept the device running at a temperature of 25°C. During all SEL testing, the CR value was set to achieve a maximum load of 10A.

The primary signal monitored on the EVM was VOUT, which was done using an NI PXIe-5172 set to trigger on a 3% window based on the nominal measured value of VOUT. SW (connection between SW_HS & SW_LS) was monitored as a secondary signal through an NI PXIe-5110 that was set to trigger if the signal exceeded |20%| from the nominal SW duty cycle using a pulse width trigger. During SEB Off testing, all outputs were monitored on a positive edge trigger at 500mV to detect if the device incorrectly turned on while the device was disabled.

All equipment was controlled and monitored using a custom-developed LabVIEW™ program (PXI-RadTest) running on an HP-Z4 desktop computer. The computer communicates with the PXI chassis through 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 TPS7H6101-SEP.

Table 6-1. Equipment Settings and Parameters Used During the Open-Loop SEE Testing of the TPS7H6101-SEP

Pin Name	Equipment Used	Capability	Compliance	Range of Values Used
PVIN	Chroma 62012	600V, 8A	10A	100V, 150V
DVIN	PXIe-4139	±60V, ±10A		12V
EN	E36311A (CH #1)	5V, 5A	0.1A	0V, 5V
PWM_LI	PXIe-5433	24$V_{pk\text{-}pk}$, 80MHz	—	0V, 14$V_{pk\text{-}pk}$
VOUT	PXIe-5172	100MS/s	—	100MS/s
SW	PXIe-5110	100MS/s	—	100MS/s
VOUT	Chroma 63600 E-Load	80A	High	—

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to maintain that the test system was stable under all bias and load conditions prior to being taken to the TAMU and KSEE facilities. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H6101-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 3% window trigger, |20%| pulse width trigger, or positive edge triggers, a data capture was initiated. No sudden increases in current were observed (outside of normal fluctuations) on any of the test runs and indicated that no SEL or SEB/SEGR events occurred during any of the tests.

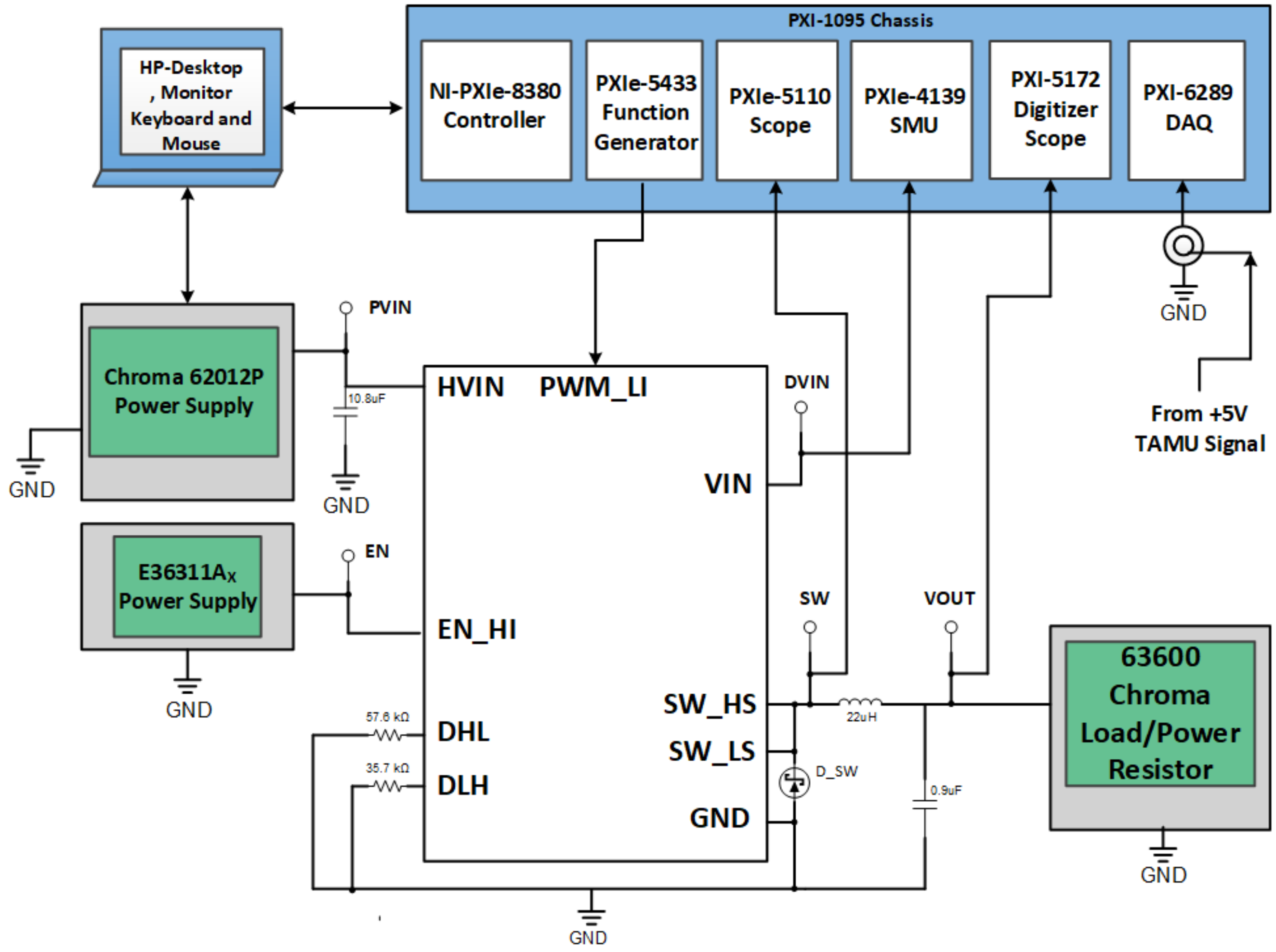


Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H6101-SEP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

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

The species used for SEL testing was Silver (^{109}Ag at 15MeV/nucleon and 19.5MeV/nucleon at TAMU and KSEE, respectively). For both ions, an incident angle of 0° was used to achieve an LET_{EFF} = 48MeV·cm^2/mg (for more details refer to Section 5). The kinetic energy in the vacuum for ^{109}Ag is 1.633GeV and 2.123GeV for TAMU and KSEE, respectively. A flux of 9.54×10^4 to 1.11×10^5 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 two minutes. The six units were powered up and exposed to the heavy-ions using a PVIN voltage of 150V. No SEL events were observed during all nine runs, indicating that the TPS7H6101-SEP is SEL-free up to 48MeV·cm^2/mg. Table 7-1 shows the SEL test conditions and results. Figure 7-1 and Figure 7-2 show plots of the current versus time for runs number 1 and number 5.

Table 7-1. Summary of TPS7H6101-SEP SEL Test Condition and Results

Run Number	Unit Number	Facility	Exposed Section	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/cm^2/s)	FLUENCE (ions/cm^2)	PVIN (V)	V_{OUT} (V)	I_{OUT} (A)	SEL (Number of Events)
1	1	TAMU	Driver	^{109}Ag	47.7	1.09×10^5	1×10^7	150	28	10	0
2	2	TAMU	Driver	^{109}Ag	47.7	1.08×10^5	1×10^7	150	28	10	0
3	3	TAMU	GaN	^{109}Ag	47.7	1.11×10^5	1×10^7	150	28	10	0
4	4	KSEE	Driver	^{109}Ag	49.1	9.96×10^4	1×10^7	150	28	10	0
5	5	KSEE	GaN	^{109}Ag	49.1	9.54×10^4	1×10^7	150	28	10	0
6	6	KSEE	GaN	^{109}Ag	49.1	9.38×10^4	1×10^7	150	28	10	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the six runs at 125°C (6×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 6.15 \times 10^{-8}$ cm^2/device for LET_{EFF} = 48MeV·cm^2/mg and T = 125°C.

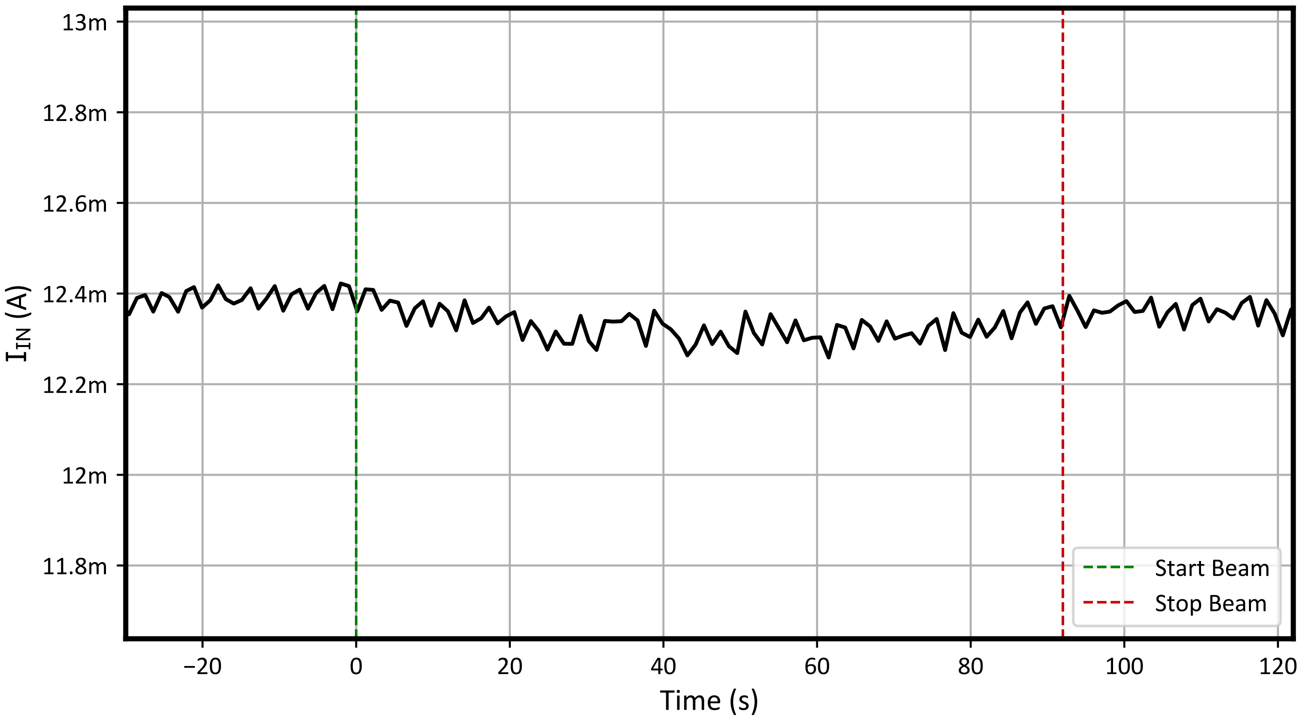


Figure 7-1. Driver current vs Time for SEL Run #1 (Driver Exposed) of the TPS7H6101-SEP at T = 125°C

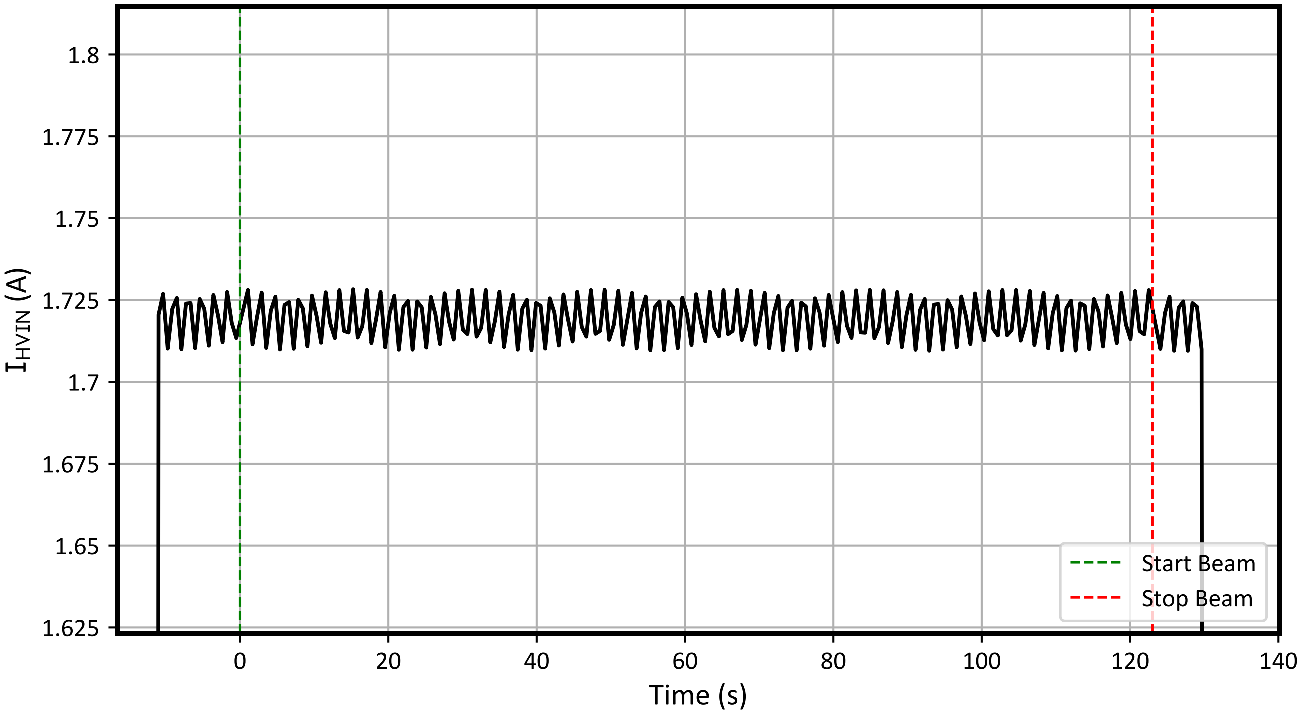


Figure 7-2. GaN Current Versus Time for SEL Run #5 (GaN Exposed) of the TPS7H6101-SEP at T = 125°C

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 or disabled, not a single input current event was observed.

The species used for SEL testing was Silver (^{109}Ag at 15MeV/nucleon and 19.5MeV/nucleon at TAMU and KSEE, respectively). For both ions, an incident angle of 0° was used to achieve an LET_{EFF} = 48MeV·cm^2/mg. The kinetic energy in the vacuum for ^{109}Ag is 1.633GeV and 2.123GeV for TAMU and KSEE, respectively. Flux of 8.67×10^4 to 1.18×10^5 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 two minutes. The six units (same as used in SEL testing) were powered up and exposed to the heavy-ions using a PVIN voltage of 150V. No SEB/SEGR current events were observed during the twelve runs, indicating that the TPS7H6101-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. Figure 7-3, Figure 7-4, and Figure 7-5 show plots of the current versus time for runs number 7, number 8, and number 18.

Table 7-2. Summary of TPS7H6101-SEP SEB/SEGR Test Condition and Results

Run Number	Unit Number	Facility	Exposed Section	ION	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/cm^2/s)	FLUENCE (ions/cm^2)	Enabled Status	PVIN (V)	V_{OUT} (V)	I_{OUT} (A)	SEB (Number of Events)
7	1	TAMU	Driver	^{109}Ag	47.7	1.18×10^5	1.00×10^7	EN	150	28	6	0
8						1.03×10^5	1.00×10^7	DIS	150	28	—	0
9	2	TAMU	Driver	^{109}Ag	47.7	1.05×10^5	1.00×10^7	EN	150	28	6	0
10						1.09×10^5	1.00×10^7	DIS	150	28	—	0
11	3	TAMU	GaN	^{109}Ag	47.7	1.11×10^5	1.00×10^7	EN	150	28	6	0
12						1.03×10^5	1.00×10^7	DIS	150	28	—	0
13	4	KSEE	Driver	^{109}Ag	49.1	9.37×10^4	1.00×10^7	EN	150	28	6	0
14						9.18×10^4	1.00×10^7	DIS	150	28	—	0
16	5	KSEE	GaN	^{109}Ag	49.1	8.67×10^4	1.00×10^7	EN	150	28	6	0
17						9.38×10^4	1.00×10^7	DIS	150	28	—	0
18	6	KSEE	GaN	^{109}Ag	49.1	9.40×10^4	1.00×10^7	EN	150	28	6	0
19						9.54×10^4	1.00×10^7	DIS	150	28	—	0

Using the MFTF method described in Single-Event Effects (SEE) Confidence Interval Calculations application report and combining (or summing) the fluences of the twelve runs at 25°C (12×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEB} \leq 3.07 \times 10^{-8}$cm^2/device for LET_{EFF} = 48MeV·cm^2/mg and T = 25°C.

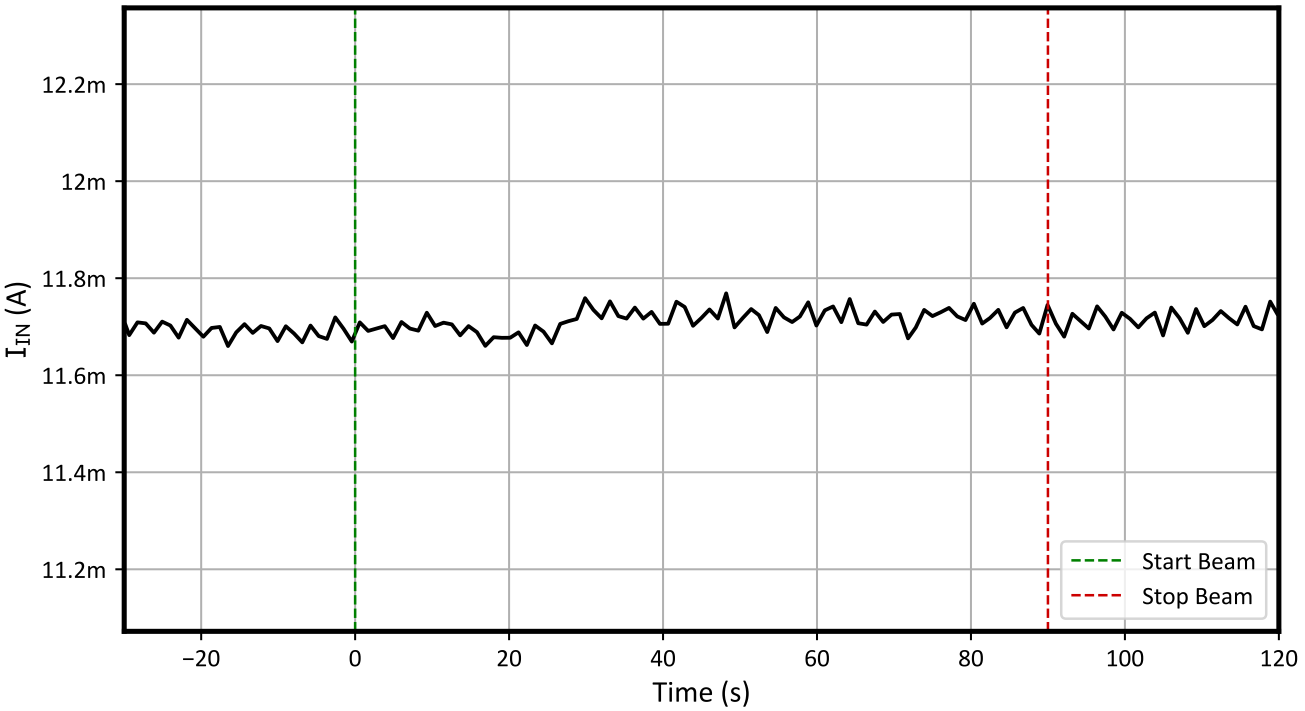


Figure 7-3. Driver Current versus Time for SEB On Run #7 (Driver Exposed) of the TPS7H6101-SEP at T = 25°C

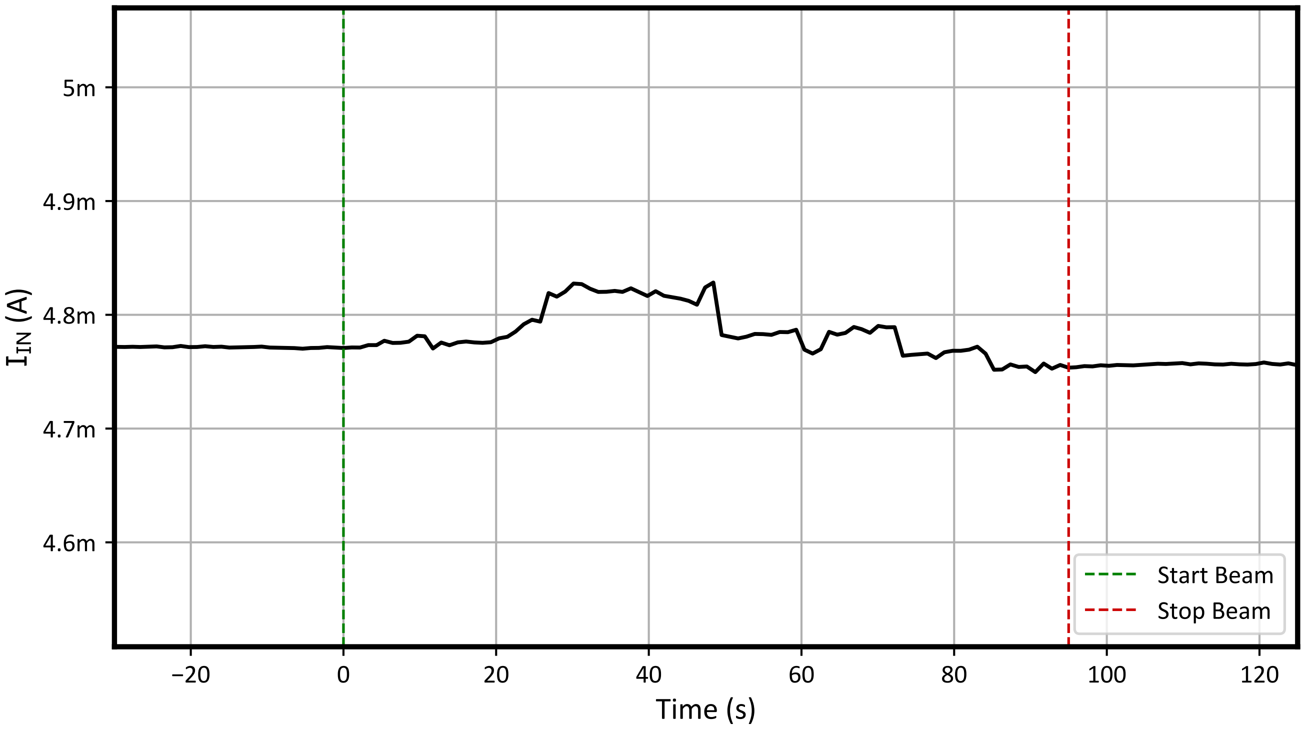


Figure 7-4. Driver Current versus Time for SEB Off Run #8 (Driver Exposed) of the TPS7H6101-SEP at T = 25°C

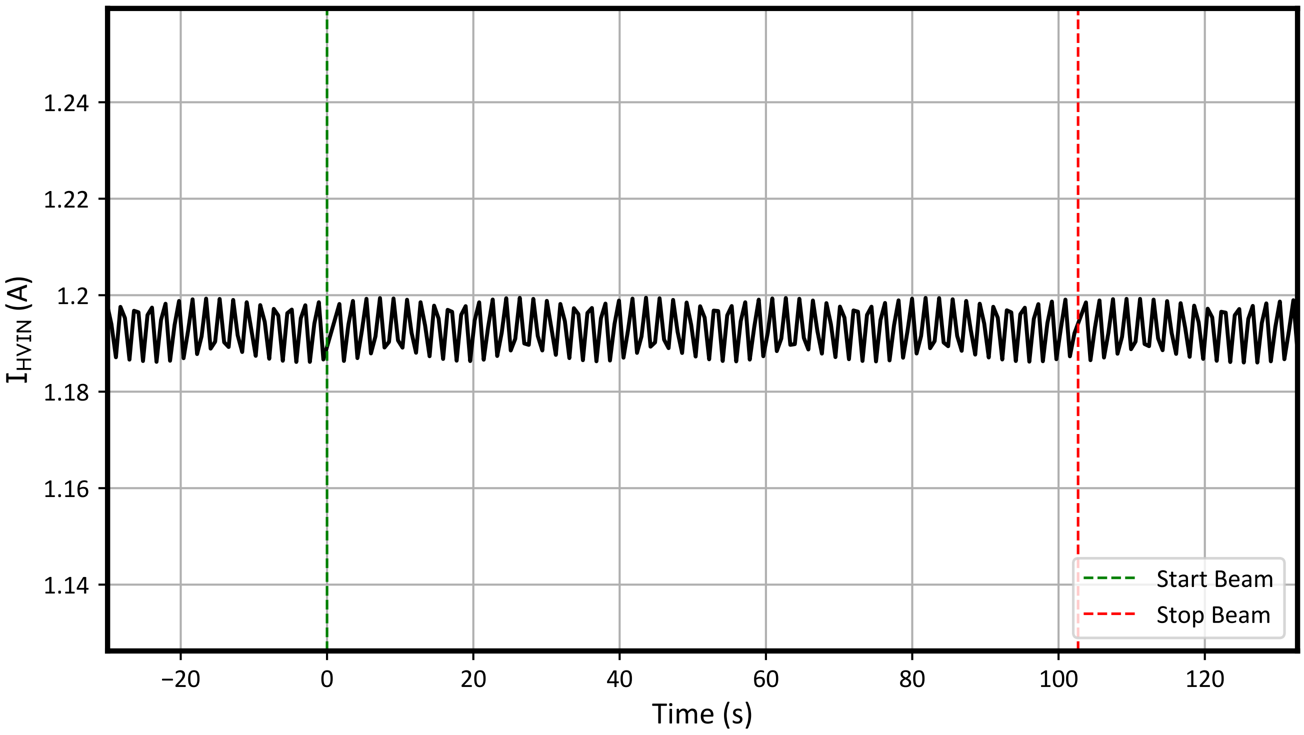


Figure 7-5. GaN Current versus Time for SEB On Run #18 (GaN Exposed) of the TPS7H6101-SEP at T = 25°C

8 Single-Event Transients (SET)

SETs are defined as heavy-ion-induced transient upsets on the VOUT and SW of the TPS7H6101-SEP.

The species used for SET testing were Silver (^{109}Ag at 15MeV/nucleon and 19.5MeV/nucleon at TAMU and KSEE, respectively). For both ions, an incident angle of 0° was used to achieve an LET_{EFF} = 48MeV·cm^2/mg (for more details refer to Section 5). The kinetic energy in the vacuum for ^{109}Ag is 1.633 GeV and 2.123 GeV for TAMU and KSEE, respectively. A flux of 8.13×10^4 to 1.19×10^5 ions/cm^2/s and fluence of 10^7 ions/cm^2 per run were used for the SET characterization discussed in this chapter. Over the course of testing six devices, not a single transient or SEFI was recorded on any of the monitored signals indicating that the TPS7H6101-SEP is SET/SEFI free up to LET_{EFF} = 48MeV·cm^2/mg.

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

Table 8-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
PXIe-5172	VOUT	Window	± 3%	50k	100MS/s
PXIe-5110	SW	Pulse-Width	± 20%	50k	100MS/s

Table 8-2. Summary of TPS7H6101-SEP SET Test Condition and Results

Run Number	Unit Number	Facility	Exposed Section	ION	LET_{EFF} (MeV·cm^2/mg)	PVIN (V)	FLUX (ions/cm^2/s)	FLUENCE (ions/cm^2)	VOUT SET ≥ |3%| (#)	SW SET ≥ |20%| (#)
20	1	TAMU	Driver	^{109}Ag	47.7	100	1.04×10^5	1.00×10^7	0	0
21						135	1.01×10^5	1.00×10^7	0	0
22	2	TAMU	Driver	^{109}Ag	47.7	100	1.12×10^5	1.00×10^7	0	0
23						135	1.19×10^5	1.00×10^7	0	0
24	3	TAMU	GaN	^{109}Ag	47.7	100	1.03×10^5	1.00×10^7	0	0
25						135	1.07×10^5	1.00×10^7	0	0
26	4	KSEE	Driver	^{109}Ag	49.1	100	9.27×10^4	1.00×10^7	0	0
27						135	8.13×10^4	1.00×10^7	0	0
28	5	KSEE	GaN	^{109}Ag	49.1	100	9.39×10^4	1.00×10^7	0	0
29						135	9.53×10^4	1.00×10^7	0	0
30	6	KSEE	GaN	^{109}Ag	49.1	100	9.73×10^4	1.00×10^7	0	0
31						135	9.40×10^4	1.00×10^7	0	0

9 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations and simplified SEE cross-sections according to methods described in *Heavy Ion Orbital Environment Single-Event Effects Estimations* application report. We assume a minimum shielding configuration of 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 the SEL, the SEB/SEGR, and the SET, the event rate calculation for the SEL, the SEB/SEGR, and the SET is shown on Table 9-1 and Table 9-2, respectively. *Note that this number is for reference since no SEL, SEB/SEGR, or SET events were observed.*

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

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	48	4.50×10^{-4}	6.15×10^{-8}	2.77×10^{-11}	1.15×10^{-3}	9.90×10^{7}
GEO		1.48×10^{-3}		9.08×10^{-11}	3.78×10^{-3}	3.02×10^{7}

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

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	48	4.50×10^{-4}	3.07×10^{-8}	1.38×10^{-11}	5.77×10^{-4}	1.98×10^{8}
GEO		1.48×10^{-3}		4.54×10^{-11}	1.89×10^{-3}	6.04×10^{7}

Table 9-3. SET Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	48	4.50×10^{-4}	$3.07 x 10^{-8}$	1.38×10^{-11}	5.77×10^{-4}	1.98×10^{8}
GEO		1.48×10^{-3}		4.54×10^{-11}	1.89×10^{-3}	6.04×10^{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 TPS7H6101-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 8.13 × 10^4 to 1.18 × 10^5 ions/cm^2/s and fluences of approximately 1x10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H6101-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.

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