

ABSTRACT

The purpose of this study is to characterize the Single-Event Effects (SEE) performance due to heavy-ion irradiation of the TPS7H3014-SEP. Heavy-ions with LET_{EFF} of $48 \text{ MeV}\cdot\text{cm}^2/\text{mg}$ were used to irradiate production devices. Flux of $\approx 10^5 \text{ ions/cm}^2\cdot\text{s}$ and fluence of $\approx 10^7 \text{ ions/cm}^2$ per run were used for the characterization. The results demonstrate the TPS7H3014-SEP is SEL-free and SEB/SEGR-free at $T = 125^\circ\text{C}$ and $T = 25^\circ\text{C}$, respectively. The TPS7H3014-SEP was also tested for SET at $T = 25^\circ\text{C}$, results demonstrate the device is SET and SEFI free.

Table of Contents

1 Introduction	3
2 Single-Event Effects (SEE)	4
3 Device and Test Board Information	5
4 Irradiation Facility and Setup	8
5 Depth, Range, and LET_{EFF} Calculation	10
6 Test Setup and Procedures	11
7 Destructive Single-Event Effects (DSEE)	13
7.1 Single-Event Latch-Up (SEL) Results.....	13
7.2 Single-Event Burnout (SEB) and Single-Event Gate Rupture (SEGR) Results.....	15
8 Single-Event Transients (SET)	17
9 Event Rate Calculations	18
10 Summary	19
A References	19
B Revision History	19

List of Figures

Figure 3-1. Photograph of Delidded TPS7H3014-SEP [Left] and Pinout Diagram [Right].....	5
Figure 3-2. TPS7H3014-SEP EVM Top View.....	6
Figure 3-3. TPS7H3014-SEP EVM Schematic for DSEE Testing.....	7
Figure 3-4. TPS7H3014-SEP EVM Schematic for SET Testing.....	7
Figure 4-1. TPS7H3014EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron.....	9
Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H3014-SEP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right].....	10
Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H3014-SEP.....	12
Figure 7-1. Current versus Time for I_{IN} : Run #1 of the TPS7H3014-SEP at $T = 125^\circ\text{C}$	14
Figure 7-2. Current versus Time for I_{IN} : SEB On Run #4.....	16
Figure 7-3. Current versus Time for I_{IN} : SEB Off Run #5.....	16

List of Tables

Table 1-1. Overview Information.....	3
Table 2-1. SEE Biasing Conditions.....	4
Table 5-1. Ion LET_{EFF} and Range in Silicon.....	10
Table 6-1. Details of Power Supplies Used for the Heavy-Ion Test Campaign of the TPS7H3014-SEP.....	11
Table 6-2. Summary of Oscilloscope and Conditions Used for the SEE Test Campaign of the TPS7H3014-SEP.....	11
Table 7-1. Summary of TPS7H3014-SEP SEL Test Condition and Results.....	13
Table 7-2. Summary of TPS7H3014-SEP SEB/SEGR Test Condition and Results.....	15
Table 8-1. Summary of TPS7H3014-SEP SET Test Condition and Results.....	17
Table 9-1. SEL Event Rate Calculations for Worst-Week LEO and GEO Orbits.....	18
Table 9-2. SEB/SEGR Event Rate Calculations for Worst-Week LEO and GEO Orbits.....	18
Table 9-3. SET (Waiting to Sequence DOWN) Event Rate Calculations for Worst-Week LEO and GEO Orbits.....	18

Table 9-4. SET (Waiting to Sequence UP) Event Rate Calculations for Worst-Week LEO and GEO Orbits.....18

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1 Introduction

The TPS7H3014-SEP is an integrated 3V to 14V, four channel radiation-hardness assured power-supply sequencer. The channel count can be incremented as needed for the application by connecting multiple ICs in a daisy-chain configuration. The device features sequence up and reverse sequence down control signals (UP and DOWN), SEQ-DONE and PWRGD flags to monitor the sequence and power status of the monitored power tree. Other features for the device include:

- A $599\text{mV} \pm 1\%$ threshold voltage
- $24\mu\text{A} \pm 3\%$ hysteresis current
- Common programmable (268 μs to 23.37ms) delay timer
 - Valid during sequence up and down
- Time-to-regulation programmable timer (264 μs to 23.63ms) to track rising voltage on SENSE_x
 - Valid only during sequence up
- Open drain FAULT detection pin to monitor internally generated faults

The device is offered in a 24-pin plastic (TSSOP) package. General device information and test conditions are listed in [Table 1-1](#). For more detailed technical specifications, user-guides, and application notes please go to [TPS7H3014-SEP product page](#).

Table 1-1. Overview Information

DESCRIPTION ⁽¹⁾	DEVICE INFORMATION
TI Part Number	TPS7H3014-SEP
Orderable Number	TPS7H3014MPWTSEP
Device Function	4-channel sequencer
Technology	LBC7 (Linear BiCMOS 7)
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/nucleon) And Facility for Rare Isotope Beams, K500 Cyclotron (KSEE), Michigan State University (19.5 MeV/nucleon)
Heavy Ion Fluence per Run	1.00×10^7 ions/cm ²
Irradiation Temperature	25°C (for SEB/SEGR testing), 25°C (for SET testing), and 125°C (for SEL testing)

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2 Single-Event Effects (SEE)

The primary concern for the TPS7H3014-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 TPS7H3014-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. During the testing of the TPS7H3014-SEP, a total of five units were exposed under worst-case bias conditions for SEL. The TPS7H3014-SEP did not exhibit any SEL with heavy-ions with $LET_{EFF} = 48 \text{ MeV}\cdot\text{cm}^2/\text{mg}$ at flux of $\approx 10^5 \text{ ions/cm}^2\cdot\text{s}$, fluence of $\approx 10^7 \text{ ions/cm}^2$, and a die temperature of 125°C .

The TPS7H3014-SEP was evaluated for SEB/SEGR at a maximum voltage of 14V (V_{IN}) in the waiting to sequence up (all outputs low) and waiting to sequence down (all outputs high) states. Because it has been shown that the MOSFET susceptibility to burnout decrement with temperature [5], the device was evaluated while operating under room temperatures. The device was tested with no external thermal control device. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H3014-SP is SEB/SEGR-free up to $LET_{EFF} = 48 \text{ MeV}\cdot\text{cm}^2/\text{mg}$ at a flux of $\approx 10^5 \text{ ions/cm}^2\cdot\text{s}$, fluence of $\approx 10^7 \text{ ions/cm}^2$, and a die temperature of $\approx 25^\circ\text{C}$.

The TPS7H3014-SEP was tested under nominal input conditions for SET. During the testing of three devices, not a single transient was recorded, showing that the TPS7H3014-SEP is both transient free and SEFI free. To see more details please refer to [Section 8](#).

The forcing conditions for the different DSEE and SET testing are shown in [Table 2-1](#).

Table 2-1. SEE Biasing Conditions

DSEE TYPE	VIN (V)	VPULL_UP (V)	VUP (V)	T _J (°C)	FLUX (ions/cm ² ·s)	FLUENCE (ions/cm ²)
SEL	14	7	3.3	125	10 ⁵ /run	10 ⁷ /run
SEB/SEGR	14	7	[0,3.3]	25		
SET	5	3.3	[0,1]	25		

3 Device and Test Board Information

The TPS7H3014-SEP is packaged in a 24-pin TSSOP plastic package as shown in [Figure 3-1](#). The TPS7H3014-SEP evaluation module was used to evaluate the performance and characteristics of the TPS7H3014-SEP under heavy ion radiation. The TPS7H3014EVM (Evaluation Module) is shown in [Figure 3-2](#). The actual EVM BOM was modified from the original (or default) to set the EN_x to SENSE_x resistor divider to the correct values to attain the desired overdrive voltage on SENSE_x. Two different configurations were used during the heavy-ions test campaign, the details are provided on [Figure 3-3](#) and [Figure 3-4](#).

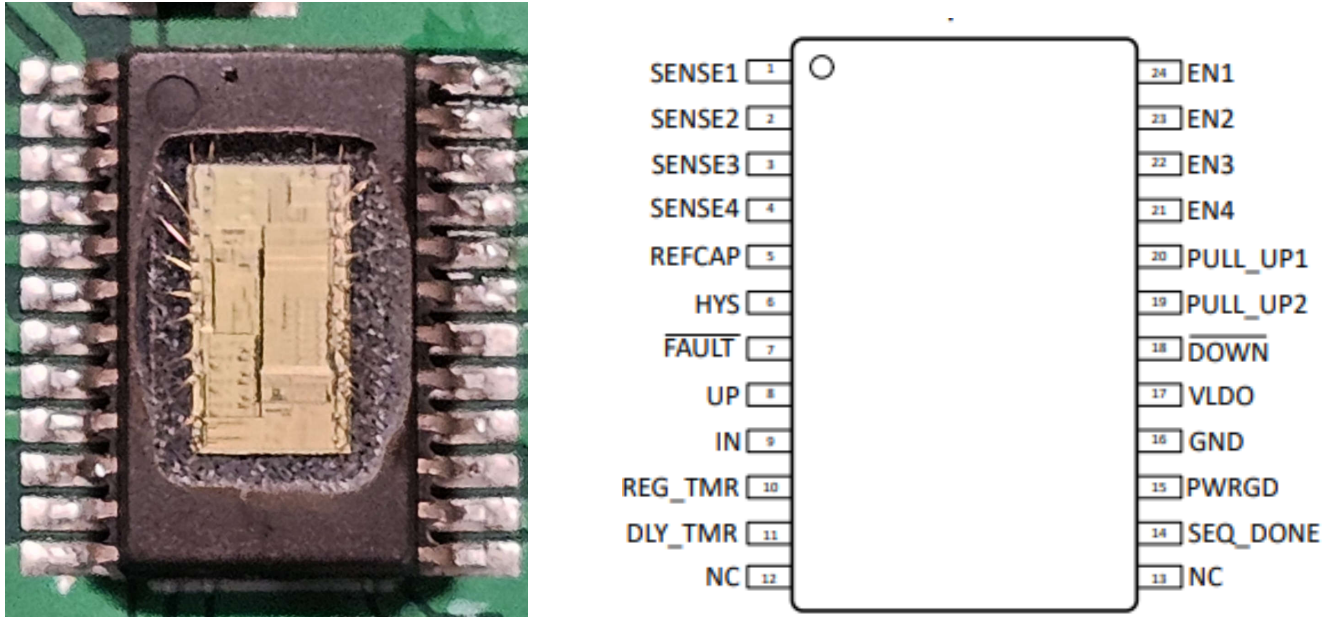


Figure 3-1. Photograph of Delidded TPS7H3014-SEP [Left] and Pinout Diagram [Right]

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

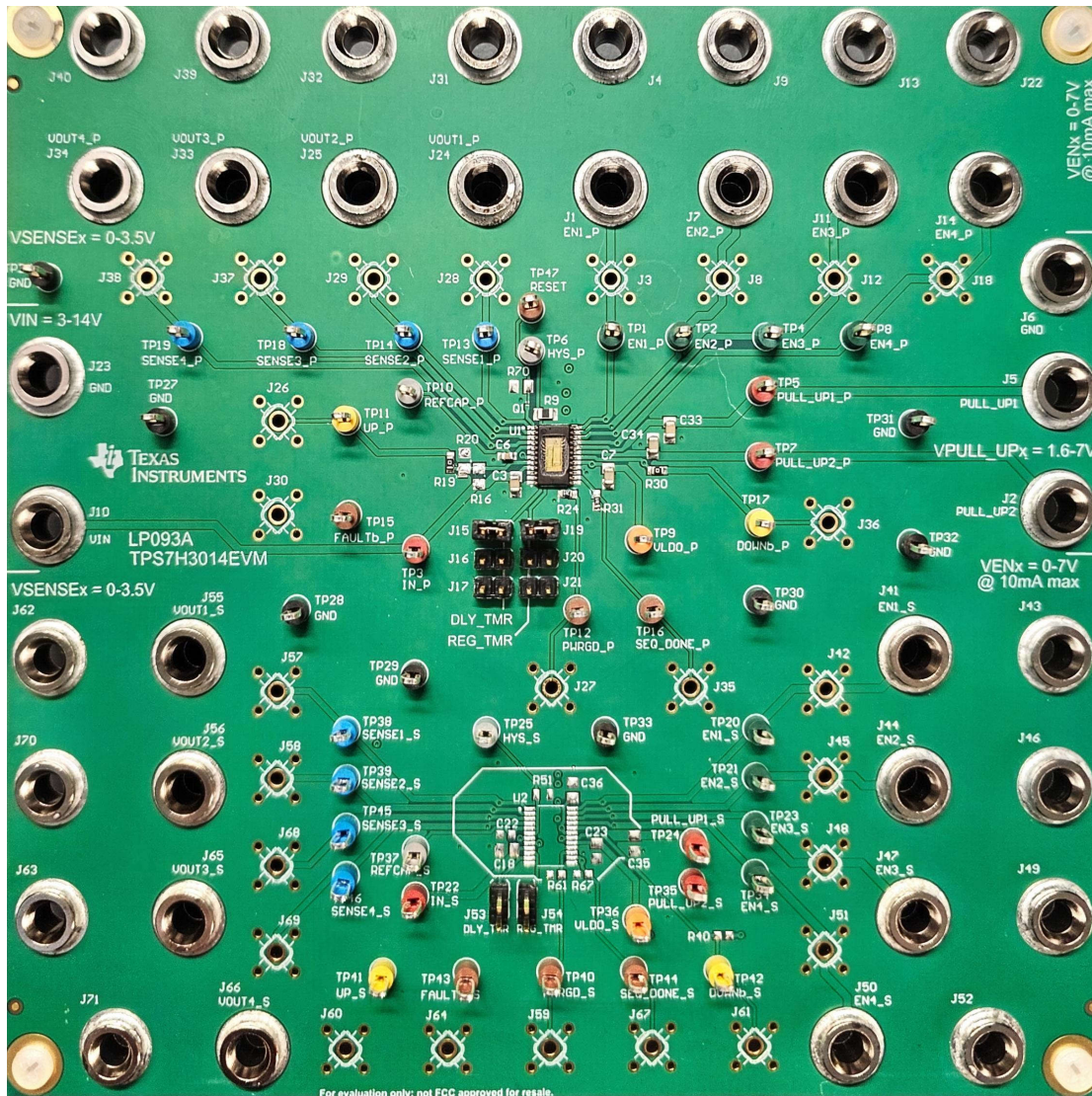


Figure 3-2. TPS7H3014-SEP EVM Top View

Primary

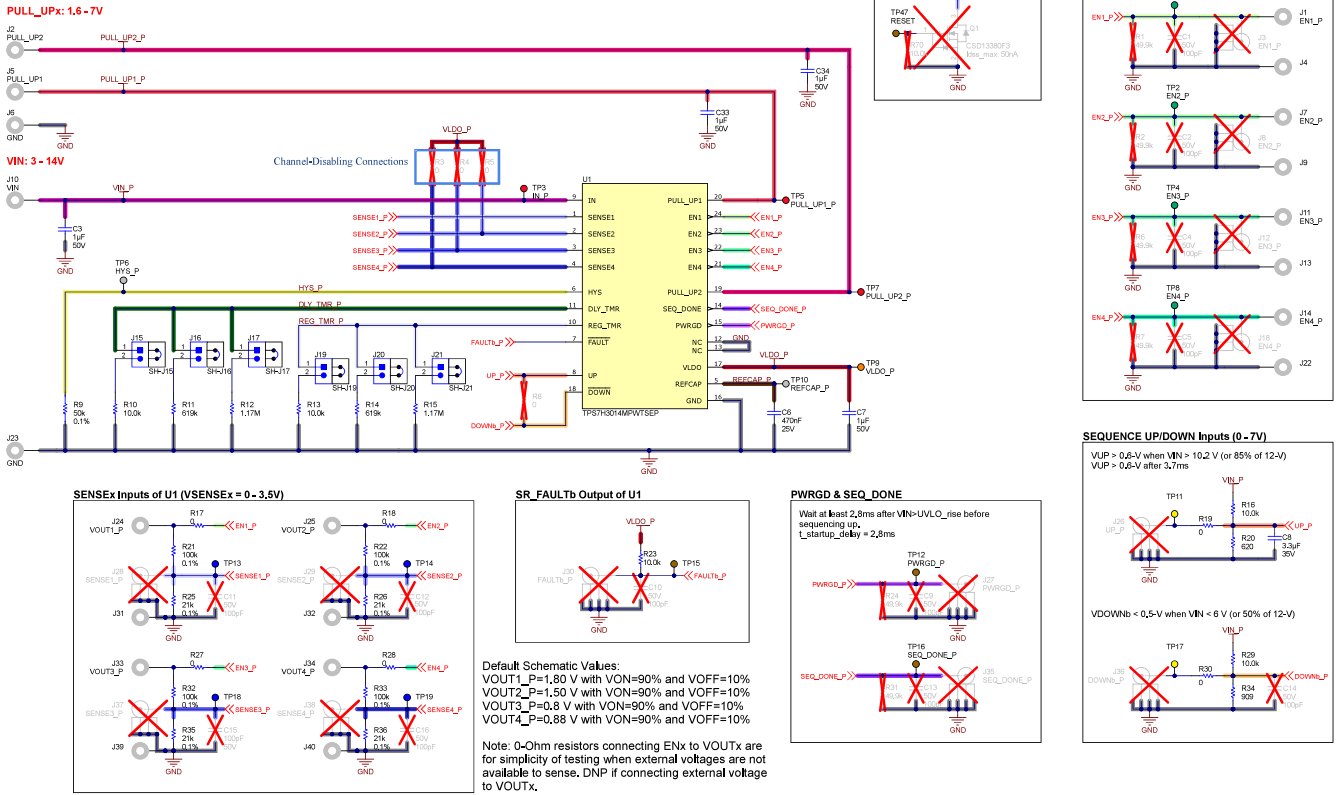


Figure 3-3. TPS7H3014-SEP EVM Schematic for DSEE Testing

Primary

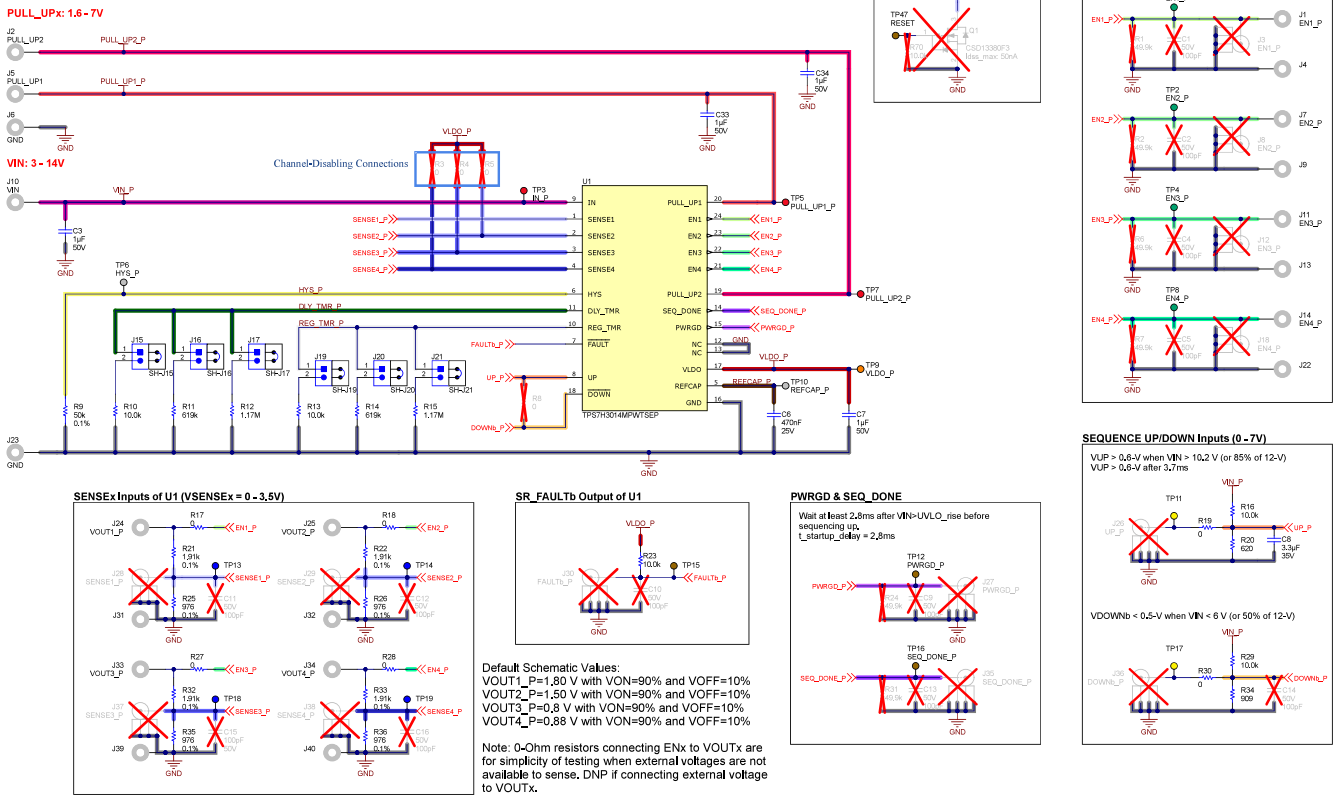


Figure 3-4. TPS7H3014-SEP EVM Schematic for SET Testing

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 9.92×10^4 to 1.50×10^5 ions/cm² ·s was used to provide heavy-ion fluences of 1.00×10^7 ions/cm². The TAMU facility uses a beam port that has a 1mil 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 7.46×10^4 to 1.15×10^5 ions/cm² ·s was used to provide heavy-ion fluences of 1.00×10^7 ions/cm². 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, there were 2 ions used, ¹⁰⁹Ag (TAMU) and ¹⁰⁹Ag (KSEE). Both ions were used to obtain LET_{EFF} of 48MeV·cm²/mg. The total kinetic energies for each of the ions were:

- ¹⁰⁹Ag (TAMU) = 1.635GeV (15MeV/nucleon)
 - Ion uniformity for these experiments was between 95% and 97%
- ¹⁰⁹Ag (KSEE) = 2.125GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was 91%

Figure 4-1 shows the TPS7H3014EVM in front of the beam line at the TAMU facility.

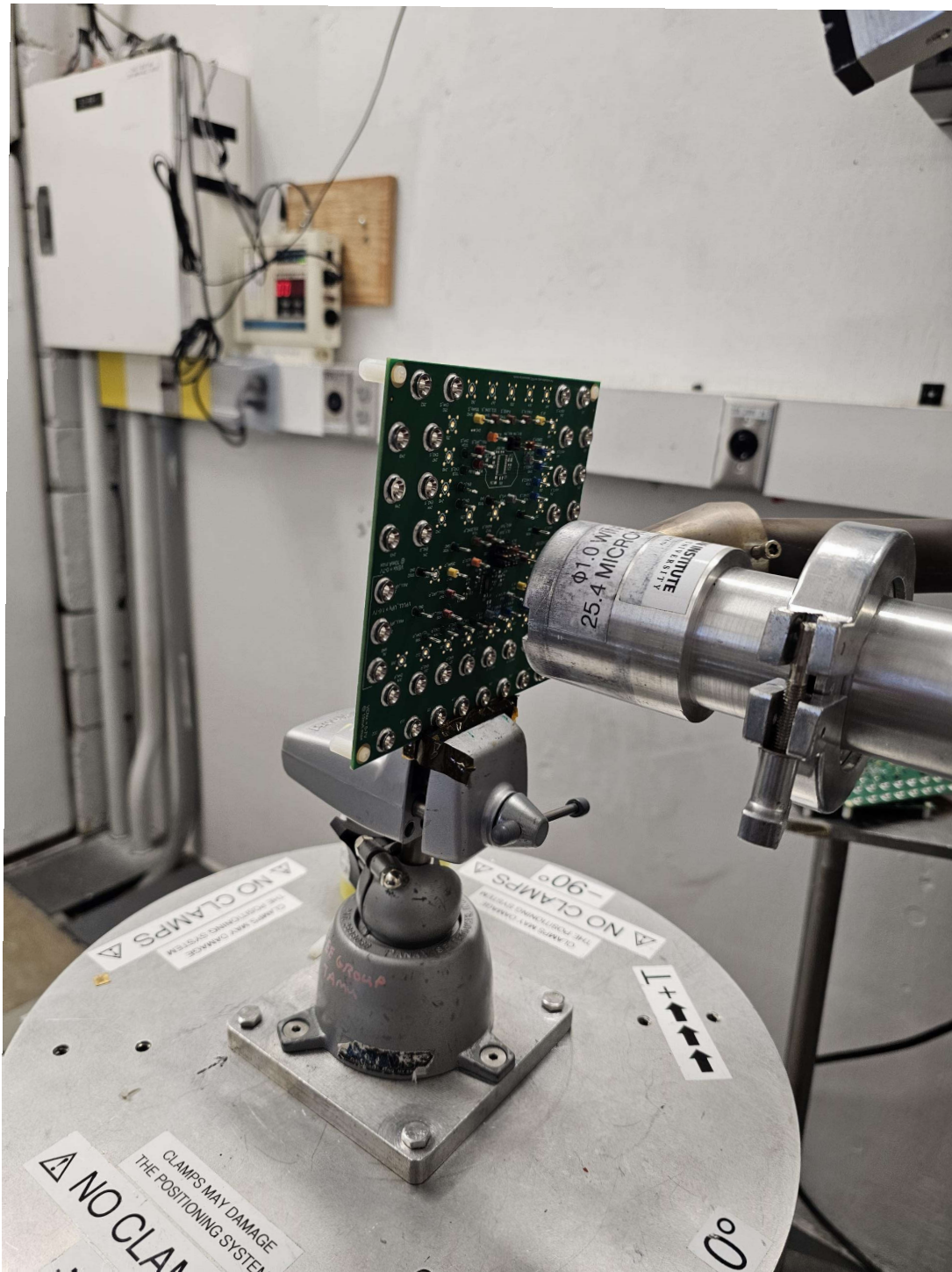


Figure 4-1. TPS7H3014EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 Depth, Range, and LET_{EFF} Calculation

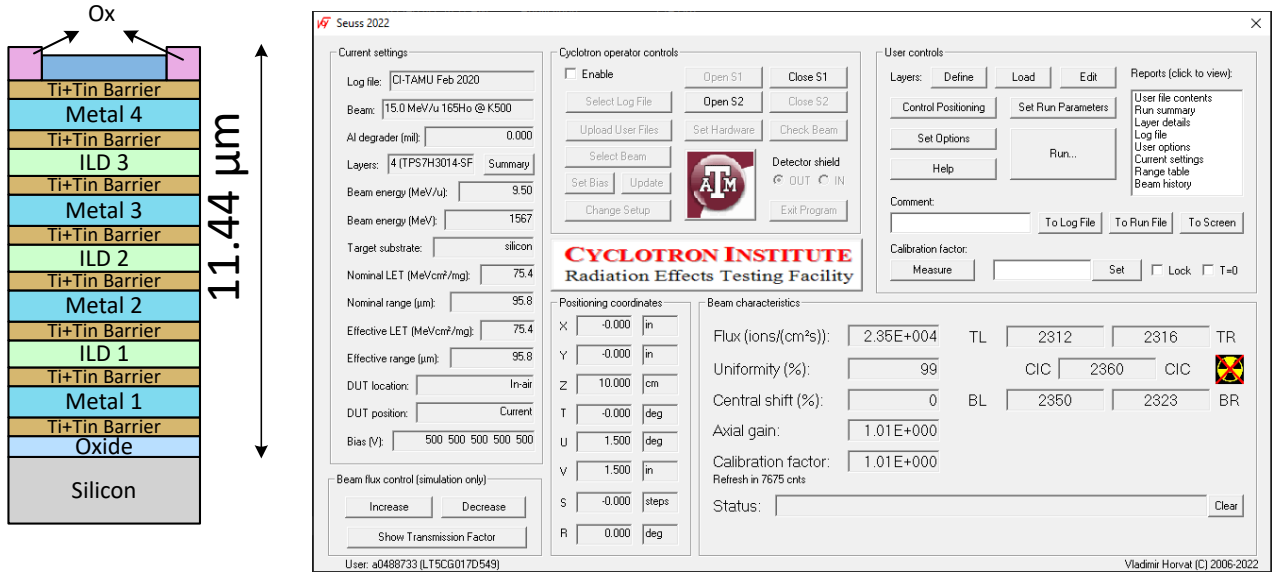


Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H3014-SEP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right]

The TPS7H3014-SEP is fabricated in the TI Linear BiCMOS 250nm process with a back-end-of-line (BEOL) stack consisting of four levels of standard thickness aluminum. The total stack height from the surface of the passivation to the silicon surface is 11.44μm 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 TPS7H3014-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 the 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	48	97.2
KSEE	19.5	¹⁰⁹ Ag	-	-	5	3-mil PEN	60	0	49.3	85.9

6 Test Setup and Procedures

There were four input supplies used to provide power to the TPS7H3014-SEP. The voltage values and the model of the used equipment per the SEE test type is presented in [Table 6-1](#).

Table 6-1. Details of Power Supplies Used for the Heavy-Ion Test Campaign of the TPS7H3014-SEP

VOLTAGE NAME	VOLTAGE (V)	SEE TEST TYPE	POWER SUPPLY MODEL
VIN	14	SEL, SEB/SEGR	N6766A
VPULL_UP1	7		PXle-4139
VPULL_UP2	7		
VUP	0, 3.3		
VIN	5	SET	N6766A
VPULL_UP1	3.3		PXle-4139
VPULL_UP2	3.3		
VUP	0, 1		

As discussed in [Section 3](#) the TPS7H3014-SEP was tested (or evaluated) under heavy-ions using three unique configurations.

- For DSEE the device was tested under the configuration shown in [Figure 3-3](#). We refer to this configuration as the loopback. In loopback mode EN_x is connected to SENSE_x via a resistor divider for automatic sequence up and down. EN_x was tied to SENSE_x using a resistor divider with R_{TOP} = 100kΩ and R_{BOTTOM} = 21kΩ. Under this configuration the overdrive The overdrive is referring to the difference between the steady-state voltage when the hysteresis current is active and the internal V_{TH_SENSE_x} reference voltage (599mV typically). For example, for an overdrive voltage of 1V the steady-state voltage is 1.599V when the I_{HYS_SENSE_x} is active. voltage is 1V (typically).
- For SET the device was tested under the configuration shown in [Figure 3-4](#). This testing was completed in the loopback configuration. EN_x was tied to SENSE_x using a resistor divider with R_{TOP} = 1.91kΩ and R_{BOTTOM} = 976Ω. Under this configuration the overdrive voltage is ±20mV (typically). The device was tested under:
 - Waiting to Sequence UP State (with -20mV).
 - Waiting to Sequence DOWN State (with +20mV).

Transients were monitored on EN1, EN4, and FAULT. The equipment used and the trigger details are summarized in [Table 6-2](#). The device was tested for transients under the Waiting to Sequence UP and Waiting to Sequence DOWN states. This was done to ensure the device will not activate/deactivate any downstream device (typically a POL) connected to it.

Table 6-2. Summary of Oscilloscope and Conditions Used for the SEE Test Campaign of the TPS7H3014-SEP

SIGNAL NAME	EQUIPMENT USED TO MONITOR SIGNAL	TRIGGER TYPE	TRIGGER VALUE WHEN SIGNAL WAS HIGH (%)	TRIGGER VALUE WHEN SIGNAL WAS LOW (V)
EN1	PXle-5172	Falling, edge Rising, edge	-20 (from nominal)	0.66, 0.36
EN4	PXle-5172	Falling, edge Rising, edge	-20 (from nominal)	0.66, 0.36
FAULT	PXle-5172	Falling, edge	-20 (from nominal)	0.66, 0.36

[Figure 6-1](#) shows a block diagram of the setup used for SEE testing of the TPS7H3014-SEP.

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to ensure that the test system was stable under all bias and load conditions prior to being taken to the test facilities. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H3014-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 20% edge 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. Neither, a single transient was capture by the oscilloscope measuring the outputs indicating the device is SET-free.

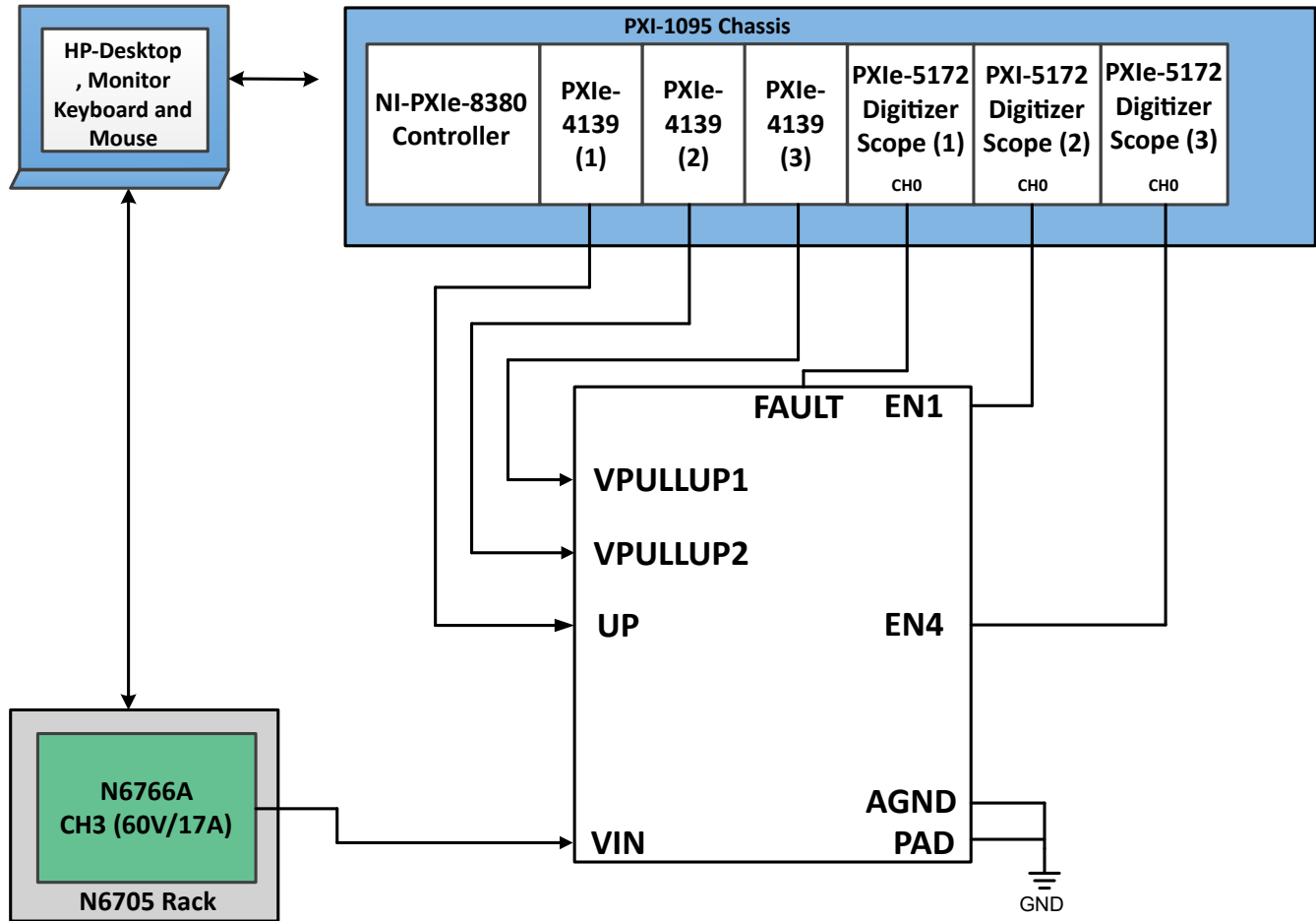


Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H3014-SEP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-Up (SEL) Results

During SEL characterization, the device was heated using a closed-loop PID controlled heat gun [MISTRAL 6 System (120V, 2400W)]. The DUT temperature was monitored prior to being irradiated with a FLIR IR-camera to ensure the junction temperature. The species used for SEL testing was ^{109}Ag at both facilities. Incident angle was used which achieved an LET_{EFF} of 48 $\text{MeV}\cdot\text{cm}^2/\text{mg}$ at TAMU and 49.3 $\text{MeV}\cdot\text{cm}^2/\text{mg}$ at KSEE.

Five devices were tested under the loopback mode (for more details in loopback mode refer to [footnote 1](#)). In the loopback mode (used for DSEE) the overdrive voltage was selected to be 1V. This was done to avoid interpreting a transient as a functional interrupt. All devices were tested in the Waiting to Sequence DOWN *state*. Maximum recommend voltages were used for V_{IN} , $V_{\text{PULL_UPX}}$ and V_{UP} . For more configuration information please refer to [Table 6-1](#).

Not a single functional interrupt was observed, nor was there any high current event on any of the power supplies of the TPS7H3014-SEP. A total of five units were tested under the same conditions and configuration. This indicates the TPS7H3014-SEP is SEL-free. The results for five runs across five devices are shown in [Table 7-1](#). A typical V_{IN} current versus time plot during a SEL run is shown in [Figure 7-1](#).

Table 7-1. Summary of TPS7H3014-SEP SEL Test Condition and Results

RUN #	UNIT #	FACILITY	ION	LET_{EFF} ($\text{MeV}\cdot\text{cm}^2/\text{mg}$)	FLUX (ions· $\text{cm}^2/\text{mg}\cdot\text{s}$)	FLUENCE (ions· cm^2/mg)	SEL (NUMBER OF EVENTS)
1	1	TAMU	^{109}Ag	48	1.18×10^5	1.00×10^7	0
2	2	TAMU	^{109}Ag	48	1.21×10^5	1.00×10^7	0
3	3	TAMU	^{109}Ag	48	1.43×10^5	1.00×10^7	0
14	6	KSEE	^{109}Ag	49.3	1.10×10^5	1.00×10^7	0
15	7	KSEE	^{109}Ag	49.3	7.46×10^4	1.00×10^7	0

Using the MFTF method described in [Single-Event Effects \(SEE\) Confidence Interval Calculations application report](#) and combining (or summing) the fluence of the five runs at 125°C (5×10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{\text{SEL}} \leq 7.38 \times 10^{-8} \text{ cm}^2/\text{device for } \text{LET}_{\text{EFF}} = 48 \text{ MeV}\cdot\text{cm}^2/\text{mg and } T = 125^\circ\text{C}.$$

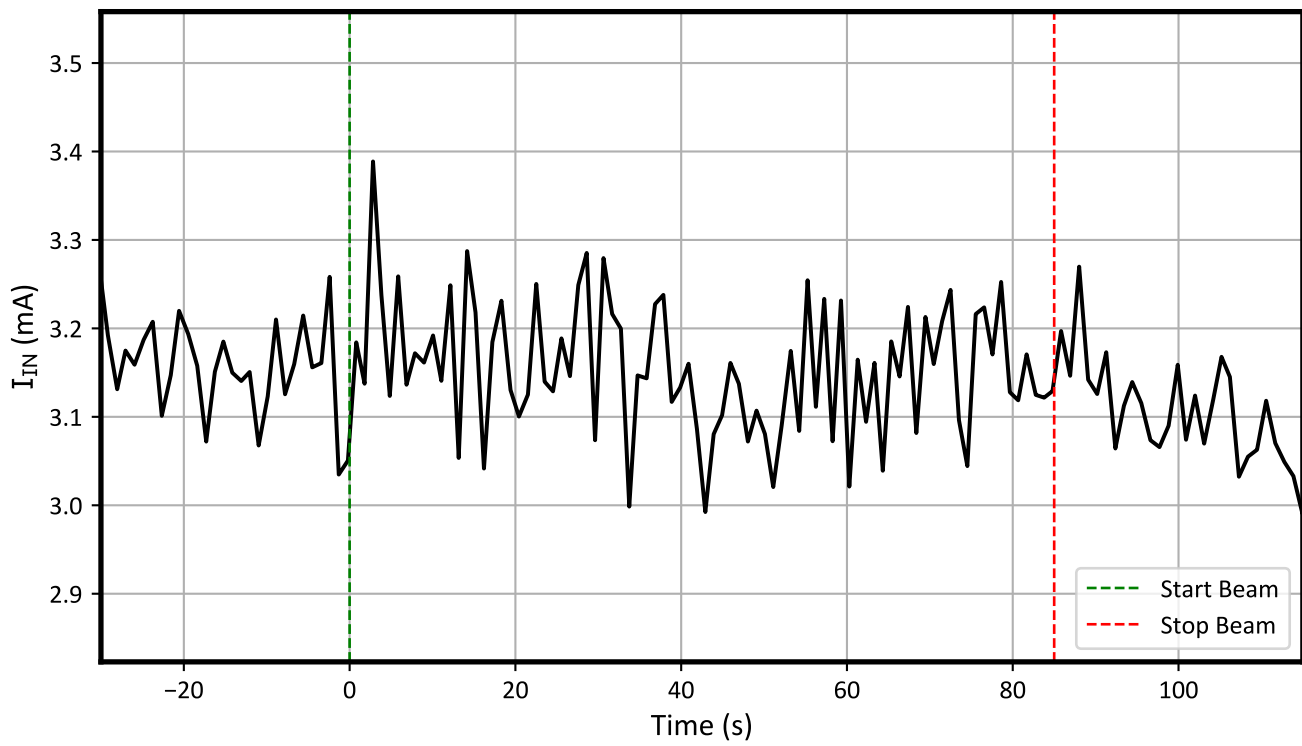


Figure 7-1. Current versus Time for I_{IN} : Run #1 of the TPS7H3014-SEP at $T = 125^{\circ}\text{C}$

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

During SEB/SEGR testing, the device was tested at room temperature. The same test conditions, in terms of biasing and voltage levels, apply for SEB/SEGR as was used during the SEL testing. In the case of the SEB/SEGR the device was tested in the following state machine states:

- Waiting to Sequence UP
 - All outputs are low ($EN_X = \text{LOW}$, $SEQ_DONE = \text{LOW}$, and $PWRGD = \text{LOW}$)
 - The device is waiting for a rising edge in UP to start the sequence up.
 - $VUP = 0V$ (only difference from the SEL biasing)
- Waiting to Sequence DOWN
 - All outputs are high ($EN_X = \text{HIGH}$, $SEQ_DONE = \text{HIGH}$, and $PWRGD = \text{HIGH}$)
 - The device is waiting for a falling edge on DOWN to start a sequence down.

For more configuration information, please refer to [Table 6-1](#).

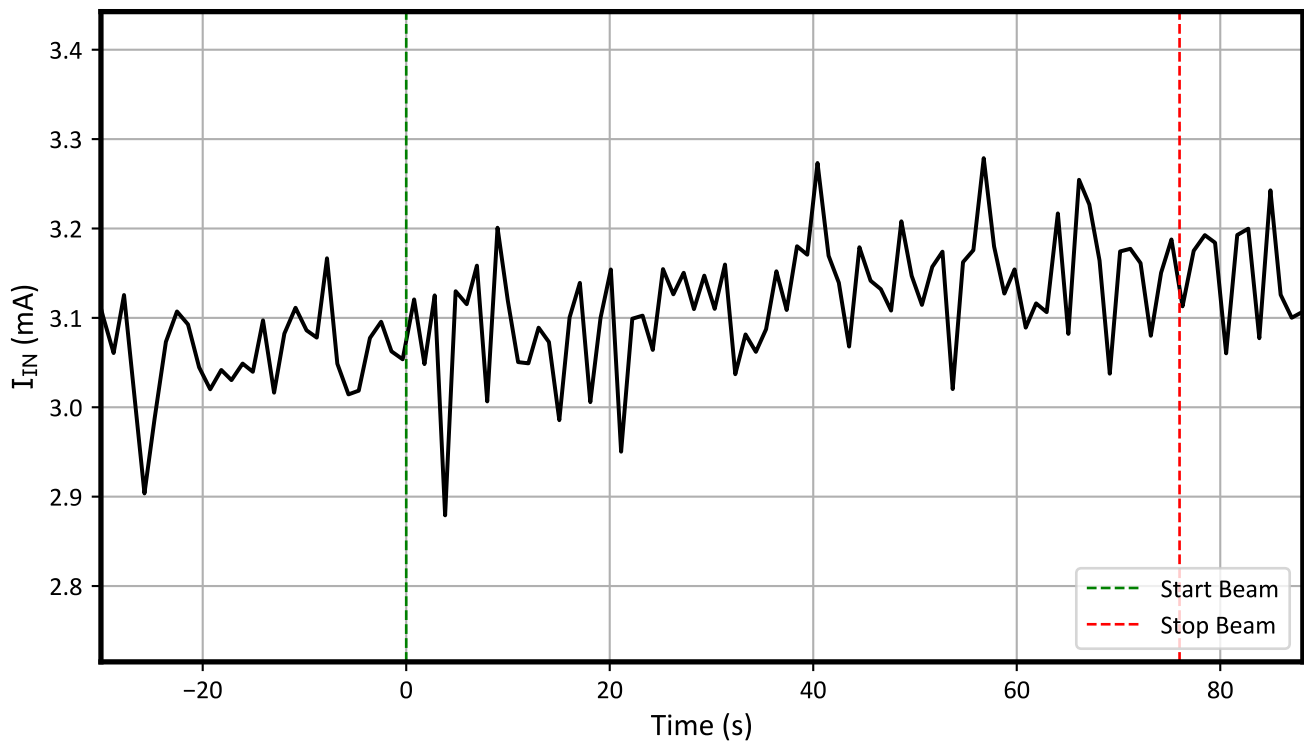
The results for ten runs across five devices for SEB_X are shown in [Table 7-2](#). During the testing of the 5 production devices and 10 SEB/SEGR runs, there were no SEB/SEGR events observed, indicating the TPS7H3014-SEP is SEB/SEGR free at 48 MeV·cm²/mg. Typical V_{IN} current vs time plots for SEB/SEGR on and off runs are shown in [Figure 7-2](#) and [Figure 7-3](#).

Table 7-2. Summary of TPS7H3014-SEP SEB/SEGR Test Condition and Results

RUN #	UNIT #	FACILITY	ION	LET _{EFF} (MeV·cm ² /mg)	FLUX (ions·cm ² / mg·s)	FLUENCE (ions·cm ² /mg)	ON/OFF STATUS	SEB EVENT?
4	1	TAMU	¹⁰⁹ Ag	48	9.92×10^4	1.00×10^7	On	No
5	1	TAMU	¹⁰⁹ Ag	48	1.23×10^5	1.00×10^7	Off	No
6	2	TAMU	¹⁰⁹ Ag	48	1.33×10^5	1.00×10^7	On	No
7	2	TAMU	¹⁰⁹ Ag	48	1.21×10^5	1.00×10^7	Off	No
8	3	TAMU	¹⁰⁹ Ag	48	1.39×10^5	1.00×10^7	On	No
9	3	TAMU	¹⁰⁹ Ag	48	1.45×10^5	1.00×10^7	Off	No
16	6	KSEE	¹⁰⁹ Ag	49.3	1.15×10^5	1.00×10^7	On	No
17	6	KSEE	¹⁰⁹ Ag	49.3	1.12×10^5	1.00×10^7	Off	No
18	7	KSEE	¹⁰⁹ Ag	49.3	1.03×10^5	1.00×10^7	On	No
19	7	KSEE	¹⁰⁹ Ag	49.3	1.09×10^5	1.00×10^7	Off	No

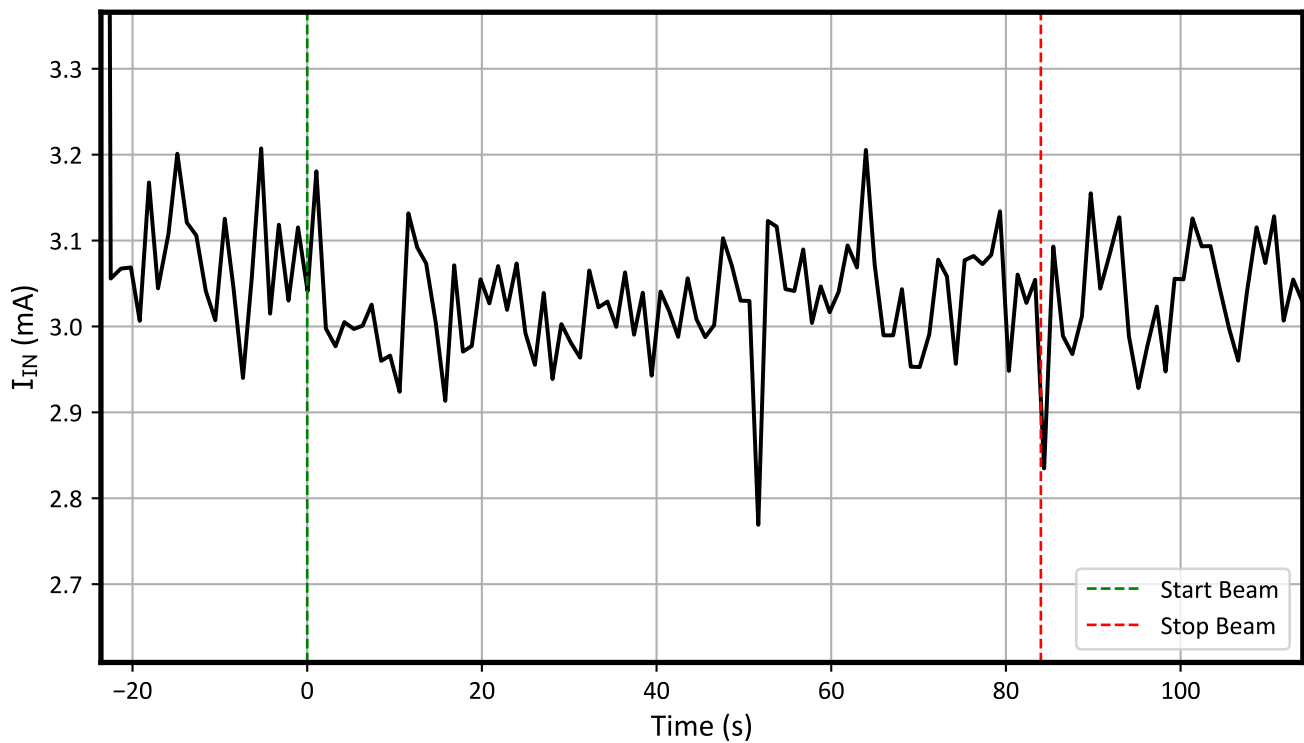
Using the MFTF method described in [Single-Event Effects \(SEE\) Confidence Interval Calculations application report](#), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{SEB} \leq 3.69 \times 10^{-8} \text{ cm}^2/\text{device for LET}_{EFF} = 48 \text{ MeV} \cdot \text{cm}^2/\text{mg and } T = 25^\circ\text{C}.$$



On refers to the Waiting to Sequence $\overline{\text{DOWN}}$ state.

Figure 7-2. Current versus Time for I_{IN} : SEB On Run #4



Off refers to the Waiting to Sequence UP state.

Figure 7-3. Current versus Time for I_{IN} : SEB Off Run #5

8 Single-Event Transients (SET)

The primary focus of SETs were heavy-ion-induced transient upsets on EN1, EN4, or FAULT. SET testing was done at room temperature using ^{109}Ag heavy-ions which produced a LET_{EFF} of $48 \text{ MeV}\cdot\text{cm}^2/\text{mg}$. The output signals were monitored by three NI PXIe-5172 scope cards. The PXIe-5172s were triggered with an edge-negative at -20% below the high voltage when in waiting to Sequence DOWN **state**. During the testing when the state machine was in the waiting to Sequence UP **state**, the trigger was set to 0.66V or 0.36V with an edge-positive trigger.

The PXIe-5172 sample rate was set to 100MS/s with a record length of 100k points (or samples). Two devices were tested under the loopback mode (for more details in loopback mode refer to [footnote 1](#)). In the loopback mode (used for SET) the overdrive voltage was selected to be $\pm 20\text{mV}$ (typically). The device was tested under the following conditions.

1. Waiting to Sequence UP State (with -20mV).
2. Waiting to Sequence DOWN State (with $+20\text{mV}$).

The device was tested under a typical voltage for IN (5V) and PULL_UP χ (3.3V). Under these configurations not a single transient was recorded on EN1, EN4, or FAULT. This demonstrates the TPS7H3014-SEP is SET and SEFI free. The SET test conditions and results for three units are shown in [Table 8-1](#).

Table 8-1. Summary of TPS7H3014-SP SET Test Condition and Results

RUN #	UNIT #	FACILITY	ION	LET_{EFF} ($\text{MeV}\cdot\text{cm}^2/\text{mg}$)	FLUX ($\text{ions}\cdot\text{cm}^2/\text{mg}\cdot\text{s}$)	FLUENCE ($\text{ions}\cdot\text{cm}^2/\text{mg}$)	WAITING TO SEQUENC E STATE	PXIe-5172 EN1 (# OF TRANSIEN TS)	PXIe-5172 EN4 (# OF TRANSIEN TS)	PXIe-5172 FAULT (# OF TRANSIEN TS)
10	4	TAMU	^{109}Ag	48	1.47×10^5	1.00×10^7	DOWN	0	0	0
11	4	TAMU	^{109}Ag	48	1.48×10^5	1.00×10^7	UP	0	0	0
12	5	TAMU	^{109}Ag	48	1.48×10^5	1.00×10^7	DOWN	0	0	0
13	5	TAMU	^{109}Ag	48	1.50×10^5	1.00×10^7	UP	0	0	0

9 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations and simplified SEE cross-sections according to methods described in [Heavy Ion Orbital Environment Single-Event Effects Estimations application report](#). We assume a minimum shielding configuration of 100 mils (2.54mm) 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, SEB/SEGR, and SET, the event rate calculation for the SEL, SEB/SEGR, and SET are shown in [Table 9-1](#), [Table 9-2](#), and [Table 9-2](#), respectively. **It is important to 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	7.38 × 10 ⁻⁸	3.32 × 10 ⁻¹¹	1.38 × 10 ⁻³	8.25 × 10 ⁷
GEO		1.48 × 10 ⁻³		1.09 × 10 ⁻¹⁰	4.54 × 10 ⁻³	2.52 × 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	3.69 × 10 ⁻⁸	1.66 × 10 ⁻¹¹	6.92 × 10 ⁻⁴	1.65 × 10 ⁸
GEO		1.48 × 10 ⁻³		5.45 × 10 ⁻¹¹	2.27 × 10 ⁻³	5.07 × 10 ⁷

Table 9-3. SET (Waiting to Sequence DOWN) 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	1.84 × 10 ⁻⁷	8.30 × 10 ⁻¹¹	3.46 × 10 ⁻³	3.30 × 10 ⁷
GEO		1.48 × 10 ⁻³		2.72 × 10 ⁻¹⁰	1.13 × 10 ⁻²	1.01 × 10 ⁷

Table 9-4. SET (Waiting to Sequence UP) 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	1.84 × 10 ⁻⁷	8.30 × 10 ⁻¹¹	3.46 × 10 ⁻³	3.30 × 10 ⁷
GEO		1.48 × 10 ⁻³		2.72 × 10 ⁻¹⁰	1.13 × 10 ⁻²	1.01 × 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 TPS7H3014-SEP. Heavy-ions with $LET_{EFF} = 48 \text{ MeV}\cdot\text{cm}^2/\text{mg}$ were used for the SEE characterization campaign. Flux of $\approx 10^5 \text{ ions/cm}^2\cdot\text{s}$ and fluences of $\approx 10^7 \text{ ions/cm}^2$ per run were used for the characterization. The SEE results demonstrated that the TPS7H3014-SEP is free of destructive SEL and SEB/SEGR. The device also shown to be SET and SEFI free at $LET_{EFF} = 48 \text{ MeV}\cdot\text{cm}^2/\text{mg}$ and across the full electrical specifications. CREME96-based worst-week event-rate calculations for LEO (ISS) and GEO orbits for the DSEE and SET are presented for reference.

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12 Revision History

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

Changes from Revision * (July 2025) to Revision A (August 2025)	Page
• Added facility information and test data for Michigan State University (MSU) Facility for Rare Isotope Beams' (FRIB) KSEE line.....	11

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