Radiation Report

Single-Event Effects (SEE) Radiation Report of the TXGS441-SEP

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TXGS441-SEP. Heavy-ions with LET_{EFF} of 47MeV×cm^2/mg were used to irradiate 4 production devices. Flux of 1.00 × 10^5 ions/cm^2/s and fluence of 1.00 × 10^7 ions/cm^2 per run were used for the characterization. The results demonstrated that the TXGS441-SEP is SEL-free up to 47MeV×cm^2/mg at T = 125°C. SET transients performance for output voltage excursions ≥ |3%| for dynamic signals and ≥ |5%| for static signals from the nominal voltage are presented and discussed.

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1 Introduction

The TXGS441-SEP is a ±40V, fixed direction, nongalvanic based voltage and ground-level translator that can support both logic-level shifting between 1.71V to 5.5V and ground-level shifting up to ±40V. Compared to traditional level shifters, the TXGS441-SEP family can solve the challenges of voltage translation across different ground levels.

The device is offered in a 14-pin DYY (SOT-23-THN) 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	TXGS441-SEP
Orderable Part Number	TXGS441MDYYTSEP
VID/SMD Number	V62/25663-01XE
Device Function	Radiation Tolerant 4-bit, ±40V Ground-Level Translator
Technology	LBC9 (Linear BiCMOS 9)
Exposure Facility	Facility for Rare Isotope 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 SET testing), and 125°C (for SEL testing)

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2 Single-Event Effects (SEE)

The primary event of interest for the TXGS441-SEP is the robustness against the destructive single-event effects (DSEE): single-event latch-up (SEL).

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 TXGS441-SEP was tested for SEL at the maximum recommended operating conditions of 5.5V supply and 40V GND shift. During testing of the 3 devices, the TXGS441-SEP did not exhibit any SEL with heavy-ions with LET_{EFF} = 47MeV×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 TXGS441-SEP was characterized for SET at flux of 1.00 × 10^5 ions/cm^2/s , fluence of 1.00 × 10^7 ions/cm^2 and room temperature. The device was characterized at V_{CCA}, V_{CCB} of (1.71V, 1.71V), (1.71V, 5.5V), (5.5V, 1.71V), and (5.5V, 5.5V) respectively. V_{GS} was set to 40V in all runs. Heavy-ions with LET_{EFF} of 47MeV×cm^2/mg were used to characterize the transient performance. To see the SET results of the TXGS441-SEP, please refer to Single-Event Transients (SET) Results.

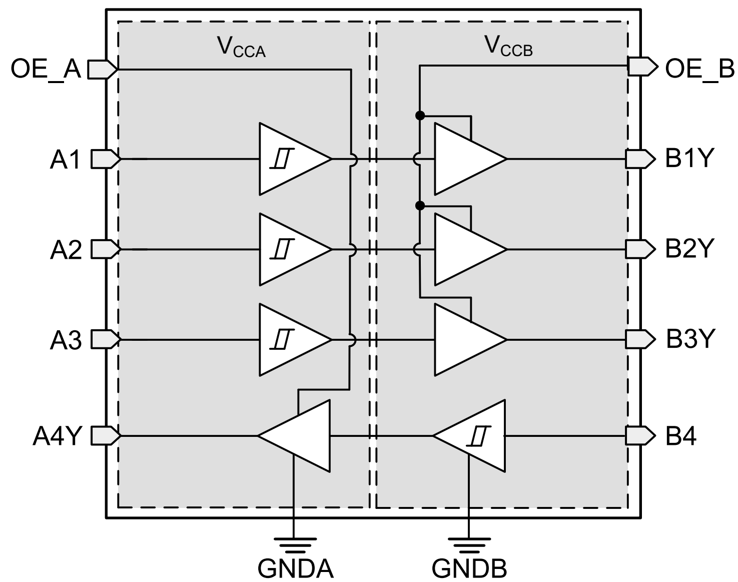

Figure 2-1. Photograph of TXGS441-SEP Functional Block Diagram

3 Device and Test Board Information

The TXGS441-SEP is packaged in a 14-pin DYY (SOT-23-THN) plastic package as shown in Figure 3-1. Figure 3-3 shows the EVM that was used to evaluate the performance and characteristics of the TXGS441-SEP under heavy ion radiation. The TXGS441-SEP pinout is shown in Figure 3-2. The bias diagrams used for SEL testing are shown in Figure 3-4, Figure 3-5, and Figure 3-6. The bias diagrams used for SET testing are shown in is shown in Figure 3-7, Figure 3-8, Figure 3-9, and Figure 3-10.

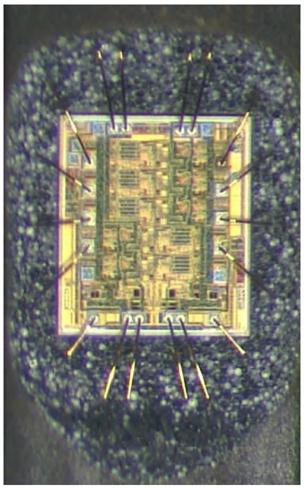

Figure 3-1. Photograph of Decapped TXGS441-SEP

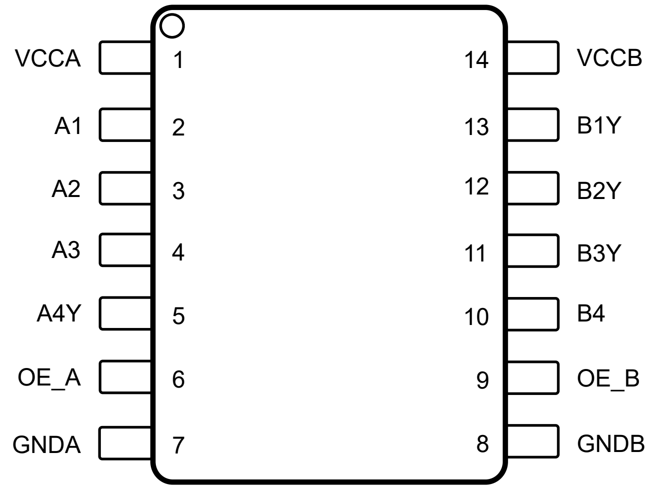

Figure 3-2. TXGS441-SEP Pinout

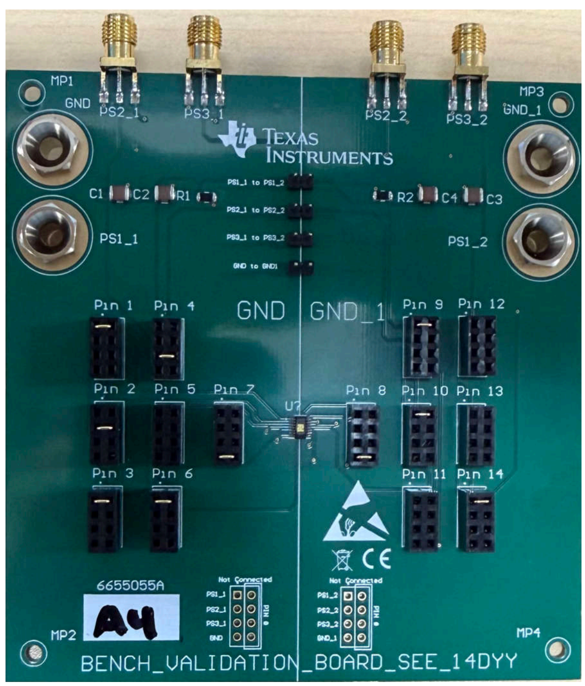

Figure 3-3. TXGS441-SEP EVM Top View

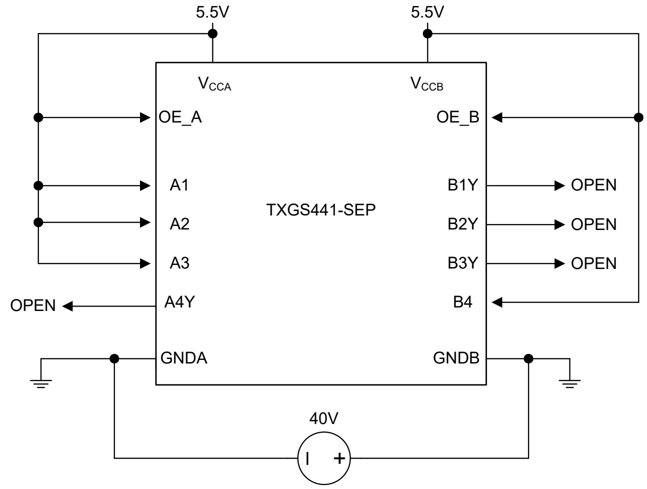

Figure 3-4. TXGS441-SEP SEL Bias #1

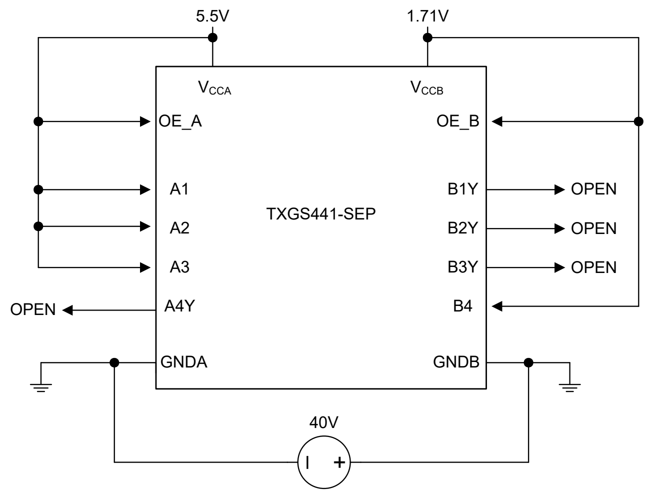

Figure 3-5. TXGS441-SEP SEL Bias #2

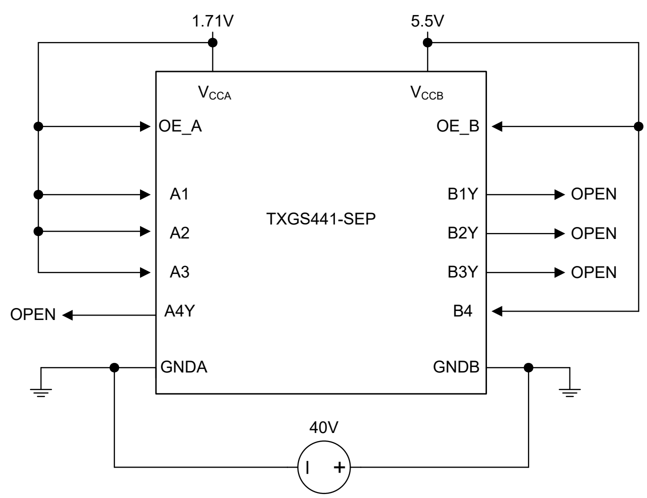

Figure 3-6. TXGS441-SEP SEL Bias #3

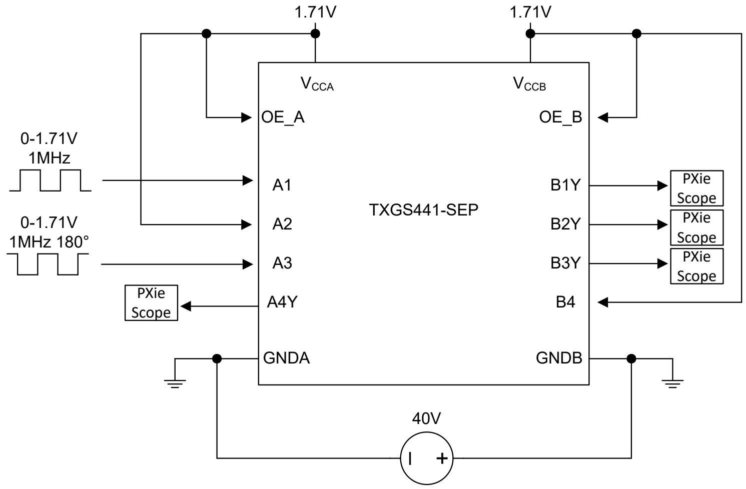

Figure 3-7. TXGS441-SEP SET Bias #1

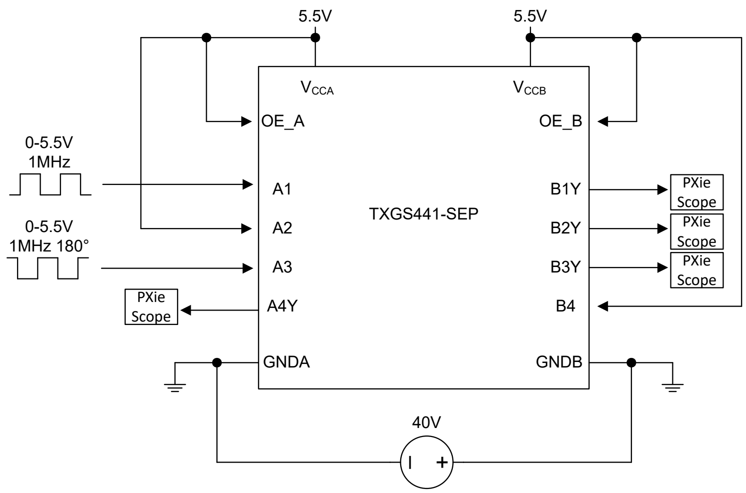

Figure 3-8. TXGS441-SEP SET Bias #2

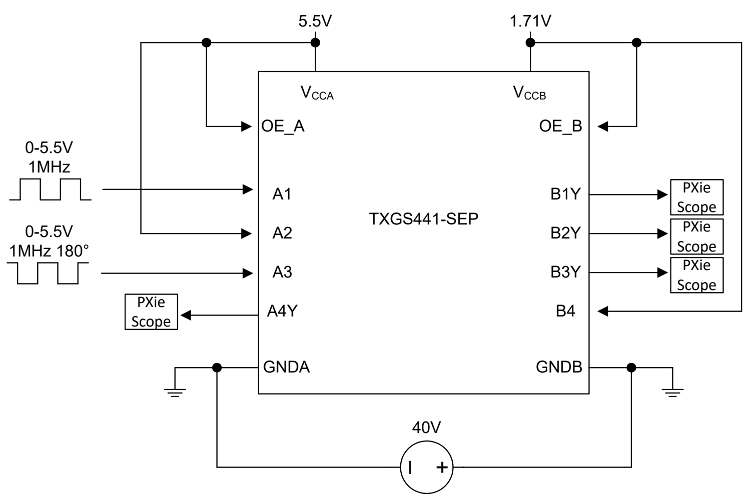

Figure 3-9. TXGS441-SEP SET Bias #3

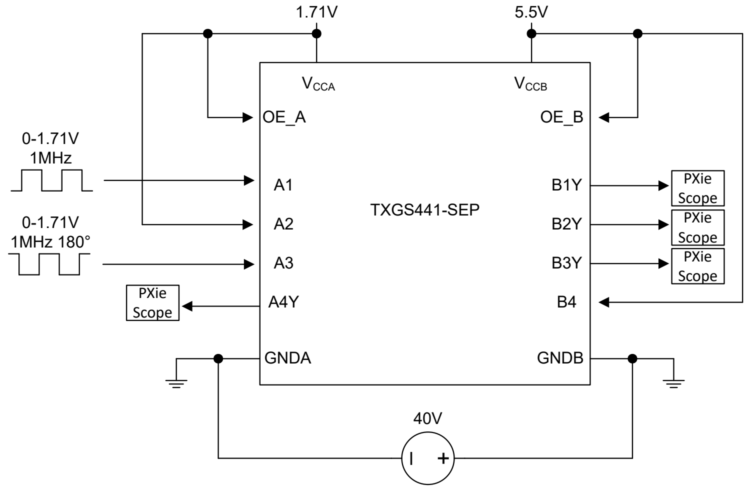

Figure 3-10. TXGS441-SEP SET Bias #4

4 Irradiation Facility and Setup

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

- 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 1.00×10^5 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 between 50mm for all runs.

For the experiments conducted on this report, there was one ion used ^{109}Ag. ^{109}Ag was used to obtain LET_{EFF} of 47MeV×cm^2/mg. The total kinetic energies for each of the ions were:

- ^{109}Ag = 19.5MeV/nucleon
  - Ion uniformity for these experiments was between 91% and 92%

Table 4-1. Ion LET_{EFF} and Range in Silicon

Facility	Beam Energy (MeV/nucleon)	Ion Type	Beam Port Window	Air Gap (mm)	Angle of Incidence	LET_{EFF} (MeV×cm^2/mg)
KSEE	19.5	^{109}Ag	3-mil PEN	50	0	47

Figure 4-1 shows the TXGS441-SEP SEE test board in front of the beam line at the MSU KSEE facility.

Figure 4-1. TXGS441-SEP SEE Test Board in Front of the Heavy-Ion Beam Exit Port at the Facility for Rare Isotope Beams (FRIB)

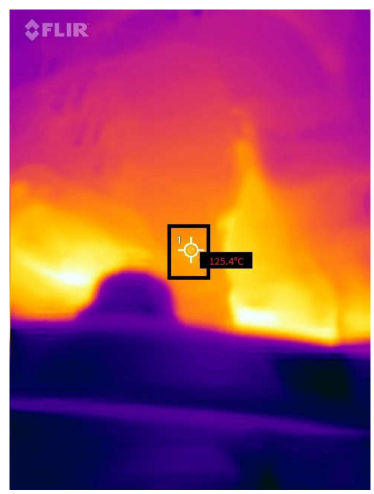

Figure 4-2. TXGS441-SEP SEE Test Board Through Beam Line Camera at the Facility for Rare Isotope Beams (FRIB)

5 Test Setup and Procedures

There were three input supplies used to power the TXGS441-SEP which provided V_{CCA} , V_{CCB}, and V_{GS}. The V_{CCA} for the device was provided by a National Instruments NI PXIe-4137 and alternated voltages from 1.71V and 5.5V. The V_{CCB} for the device was provided by NI PXIe-4139 and alternated voltages from 1.71V and 5.5V. The last input supply, V_{GS}, was provided by NI PXIe-4137 and remained 40V for all SEL tests. For all SET runs, NI PXIe-5433 was utilized from 0-1.71 to 0-5.5V at 1MHz on inputs A1 and A3.

The primary signals monitored on the SEE test board were $V_{B1Y,}$ $V_{B2Y,}$ $V_{B3Y, and}$ V_{A4Y} and this was done using four instruments. The first was a NI PXIe-5110 Scope card which was set to trigger on a 3% width based on the nominal value of V_{B1Y}. The second was a NI PXIe-5172 Scope card with a 5% voltage level window trigger based on its measured value of V_{B2Y}. The third was a NI PXIe-5110 Scope card with a 3% width trigger based on its measured value of V_{B3Y}. The fourth was a NI PXIe-5172 Scope card with a 5% voltage level window trigger based on its measured value of $V_{A4Y.}$ All SET testing used these conditions.

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.

Equipment Settings and Parameters Used During the SEE Testing of the TXGS441-SEP shows the connections, limits, and compliance values used during the testing.

Table 5-1. Equipment Settings and Parameters Used During the SEE Testing of the TXGS441-SEP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{CCA}	NI-PXIe 4137 (Slot 2)	±200V, ±3A	100µA	1.71V to 5.5V
V_{CCB}	NI-PXIe 4139 (Slot 4)	±60V, ±10A	10mA	1.71V to 5.5V
V_{GS}	NI-PXIe 4137 (Slot 3)	±200V, ±3A	10mA	40V
Func Gen	NI-PXIe 5433(Slot 11)	±12V, 80MHz	NA	0-5.5V, 1MHz
V_{B1Y}	NI-PXIe 5110(Slot 6)	±20V, 1 GS/s	NA	—
V_{B2Y}	PXIe-5172 (Slot 3)	±40V, 250 MS/s	NA	—
V_{B3Y}	PXIe-5110 (Slot 7)	±20V, 1 GS/s	NA	—
V_{A4Y}	PXIe-5172 (Slot 5)	±40V, 250 MS/s	NA	—

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 Facility for Rare Isotope Beams (FRIB). During the heavy-ion testing, the LabVIEW control program powered up the TXGS441-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% width trigger on the toggling outputs and a 5% voltage level trigger on the static outputs, 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 events occurred during any of the tests.

6 Destructive Single-Event Effects (DSEE)

6.1 Single-Event Latch-up (SEL) Results

During the SEL testing the device was heated to 125°C by using a Closed-Loop PID controlled heat gun (MISTRAL 6 System [120V, 2400W]) (KSEE). The die temperature was verified using a standalone FLIR thermal camera prior to exposure to heavy ions at KSEE.

The species used for SEL testing was ^{109}Ag at 19.5MeV/nucleon. ^{109}Ag Flux of approximately 1.00 × 10^5 ions/cm^2/s and a fluence of approximately 1.00 × 10^7 ions/cm^2 per run was used with one run at a fluence of 1.50 × 10^7 ions/cm^2. Run duration to achieve this fluence was approximately two minutes. The three devices were powered up and exposed to the heavy-ions using the range of voltages as specified by Section 3 which produces as output voltage of 5.5V. No SEL events were observed during all 10 runs, indicating that the TXGS441-SEP is SEL-free up to 47MeV×cm^2/mg.Table 6-1 shows the SEL test conditions and results. Figure 6-1 shows a plot of the current versus time for run.

Table 6-1. Summary of TXGS441-SEP SEL Test Condition and Results

Run #	Unit #	Facility	Ion	LET_{EFF} (MeV × cm^2/mg)	Flux (ions/cm^2/s)	Fluence (ions/cm^2)	V_{CCA} (V)	V_{CCB} (V)	V_{GS} (V)	SEL (# Events)
1	1	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	5.5	5.5	40	0
2	1	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	5.5	1.71	40	0
3	1	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	1.71	5.5	40	0
4	2	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	1.71	5.5	40	0
5	2	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	5.5	1.71	40	0
6	2	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	5.5	5.5	40	0
7	3	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	5.5	5.5	40	0
8	3	KSEE	^{109}Ag	47	1.00 × 10^5	1.50 × 10^7	5.5	5.5	40	0
9	3	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	5.5	1.71	40	0
10	3	KSEE	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	1.71	5.5	40	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of all runs at 125°C per each bias. Bias scheme 1 saw zero SEL events and had a total fluence of 4.5×10^7 ions/cm^2. Bias scheme 2 and 3 saw zero SEL events and had a total fluence of 3×10^7 ions/cm^2. The upper-bound cross-section (using a 95% confidence level) is calculated as:

Bias 1: $\sigma_{SEL} \leq 2.05\times10^{-8}$ cm^2/device for LET_{EFF} = 47MeV×cm^2/mg and T = 125°C.

Bias 2 and 3: $\sigma_{SEL} \leq 4.10\times10^{-8}$ cm^2/device for LET_{EFF} = 47MeV×cm^2/mg and T = 125°C.

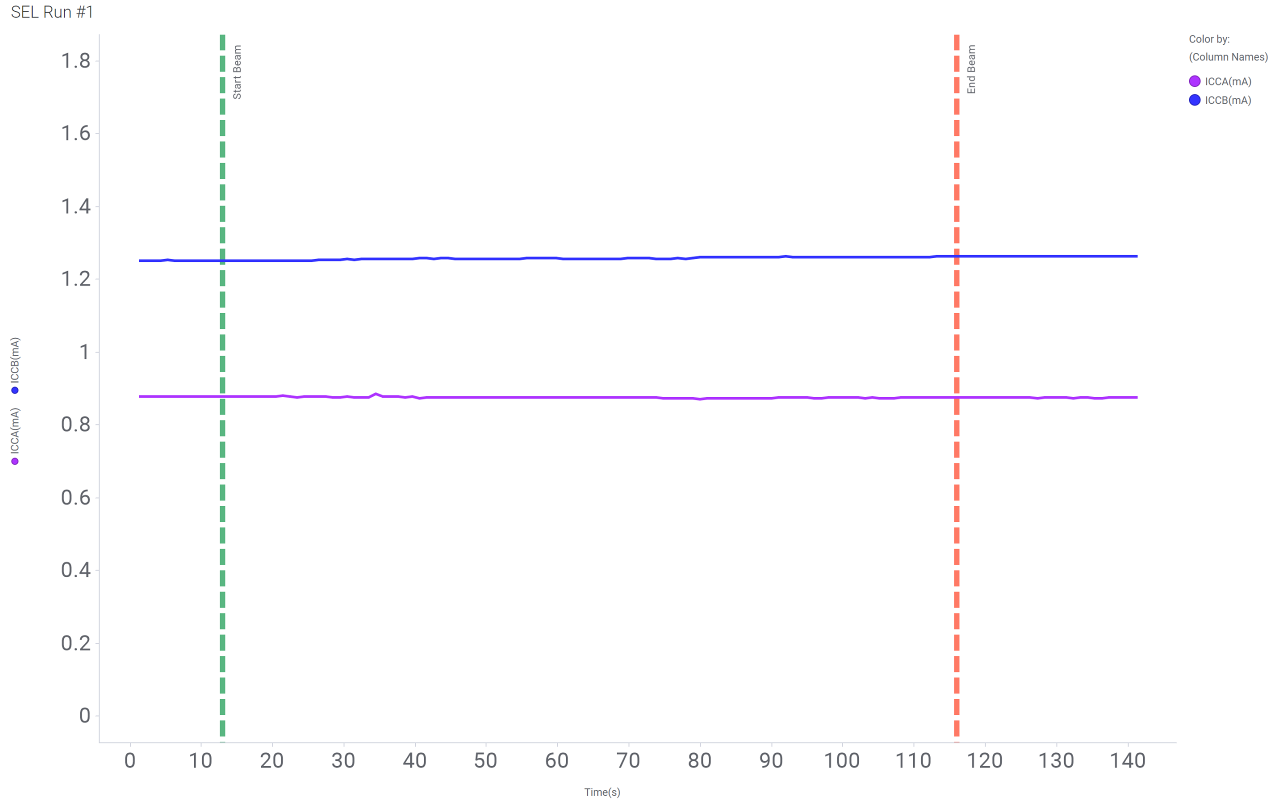

Figure 6-1. Current(mA) versus Time(s) for Run #1(SEL) of the TXGS441-SEP at T = 125°C

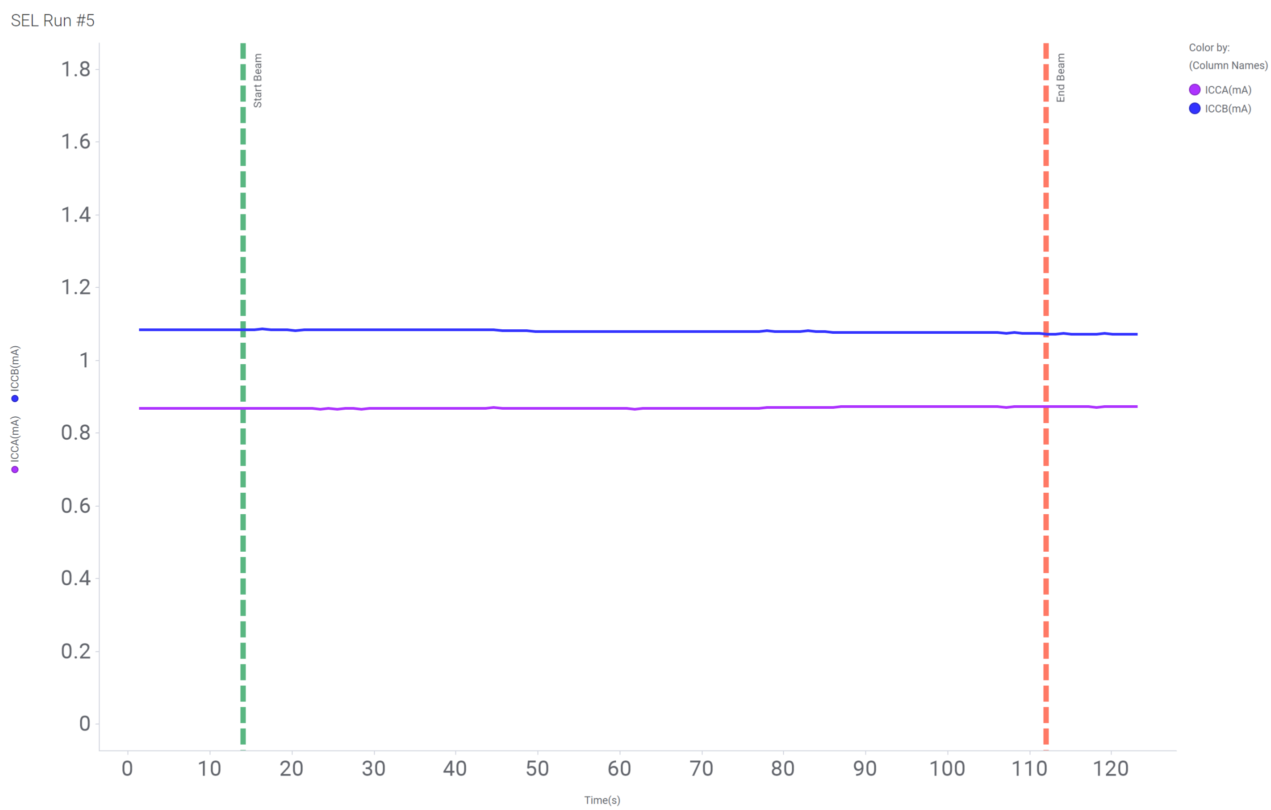

Figure 6-2. Current(mA) versus Time(s) for Run #5 (SEL) of the TXGS441-SEP at T = 125°C

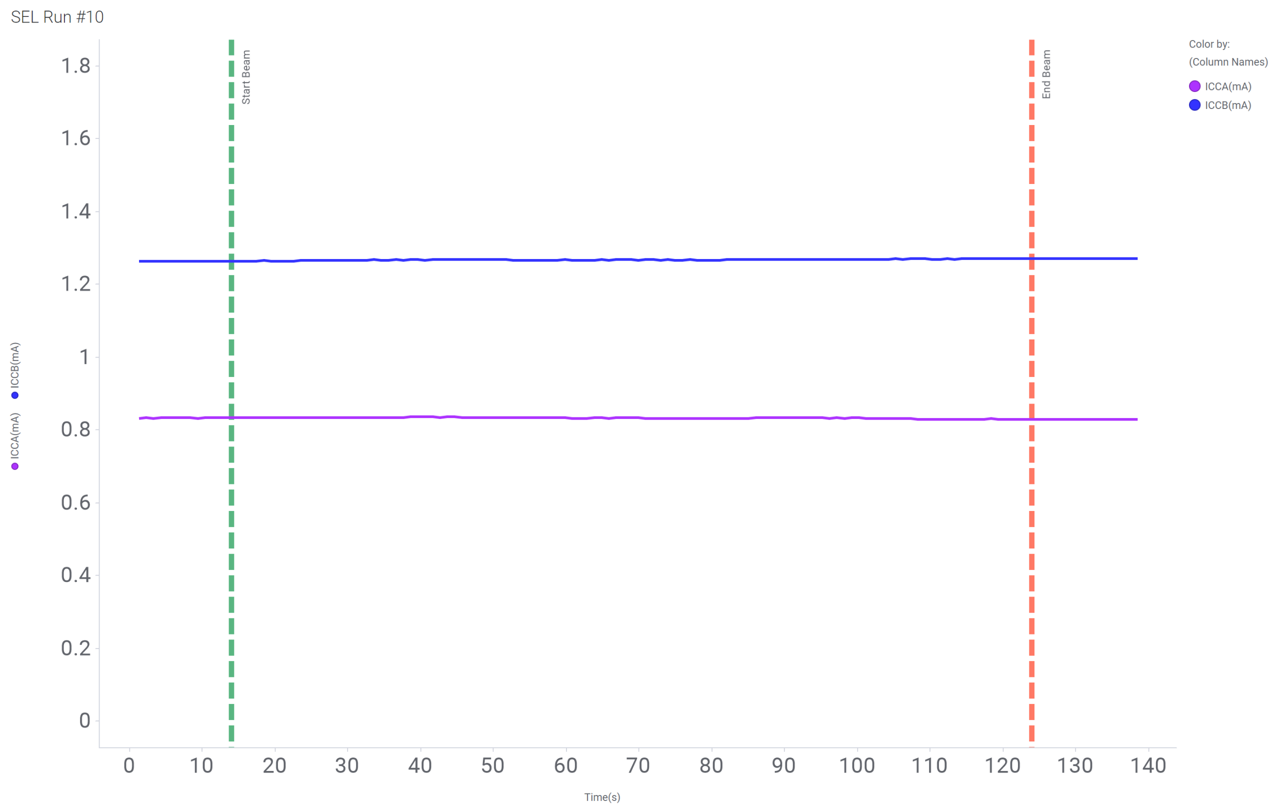

Figure 6-3. Current(mA) versus Time(s) for Run #10(SEL) of the TXGS441-SEP at T = 125°C

7 Single-Event Transients (SET) Results

SETs are defined as heavy-ion induced transients upsets on the V_{B1Y}, V_{B2Y}, V_{B3Y}, and V_{A4Y} of the TXGS441-SEP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for SET testing was ^{109}Ag at 19.5 MeV/nucleon (for more details refer to). Ag for a LET_{EFF} of 47MeV×cm^2/mg, for more details refer to . Flux of 1.00×10^5 ions/cm^2/s and a fluence of 1.00×10^7 ions/cm^2, per run were used for the SET characterization discussed on this chapter.

Waveform size, sample rate, trigger type, value, and signal for all scopes used is presented on Table 7-1.

Only one Signal was used as a trigger source at a time, this table presents 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.

Table 7-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
NI-PXIe 5110 (Slot 6)	V_{B1Y}	Width	± 3%	2k	100MS/s
NI-PXIe 5172 (Slot 3)	V_{B2Y}	Voltage Level Window	± 5%	2k	100MS/s
NI-PXIe 5110 (Slot 7)	V_{B3Y}	Width	± 3%	2k	100MS/s
NI-PXIe 5172 (Slot 5)	V_{A4Y}	Voltage Level Window	± 5%	2k	100MS/s

For the V_{CCA} = 1.71V and V_{CCB} = 1.71V configuration, V_{CCA} = 1.71V and V_{CCB} = 5.5V configuration, and V_{CCA} = 5.5V and V_{CCB} = 5.5V configuration, one unit was characterized at 47MeV× ^{109}Ag was used to achieve LET_{EFF} = 47MeV. NI-PXIe-5172 scopes were used to monitor the V_{B2Y} and V_{A4Y} signals of the TXGS441-SEP with V_{B2Y} triggering off a 5% voltage level window and V_{A4Y} triggering a 5% voltage level window. NI-PXIe-5110 scopes were used to monitor the V_{B1Y} and V_{B3Y} signals of the TXGS441-SEP with V_{B1Y} triggering off a 3% width and V_{B3Y} triggering a 3% width.Table 7-2 summarizes the results for the 1 unit tested. As the summary of results shows, the onset for the TXGS441-SEP occurs at an LET_{EFF} of 47MeV.

Worst case transients are shown below. A few different types of transients are observed:

Dynamic Signal Transients:

- Low Glitch: Signal glitches on a high output. Example shown in Figure 7-1. This example shows the maximum observed duration glitch with a duration of 0.25µs.
- Low Glitch: Signal glitches on a high output. Example shown in Figure 7-1. This example shows the maximum observed duration glitch with a duration of 0.25µs.
- High Glitch: Signal glitched on a low output. Example shown in Figure 7-2. This example shows the maximum observed duration glitch with a duration of 0.24µs.
- Stuck Low: Signal fails to toggle to high state for more than one clock cycle. Example shown in Figure 7-3. This example shows the maximum observed duration glitch with a duration of 9.67µs.
- Stuck High: Signal fails to toggle to low state for more than one clock cycle. Example shown in Figure 7-4. This example shows the maximum observed duration glitch with a duration of 3.81µs.

Static Signal Transients:

- V_{B2Y} Worst SET: Static high signal went low. Example shown in Figure 7-5. This example shows the maximum observed duration glitch with a duration of 9.86µs.
- V_{A4Y} Worst SET: Static high signal went low. Example shown in Figure 7-10. This example shows the maximum observed duration glitch with a duration of 10.63µs.

Table 7-2. Summary of TXGS441-SEP SET Test Condition and Results

Bias	Run #	Unit #	Facility	Ion	LET_{EFF} (MeV×cm^2/mg)	Flux (ions/cm^2/s)	Fluence (ions/cm^2)	# Triggers V_{B1Y}	# Triggers V_{B2Y}	# Triggers V_{B3Y}	# Triggers V_{A4Y}
1	11	4	FRIB	^{109}Ag	47	1.00×10^5	1.00×10^7	42	38	28	41
4	12	4	FRIB	^{109}Ag	47	1.00×10^5	1.00×10^7	17	26	18	36
3	13	4	FRIB	^{109}Ag	47	1.00×10^5	1.00×10^7	40	33	33	17

Table 7-2. Summary of TXGS441-SEP SET Test Condition and Results (continued)

Bias	Run #	Unit #	Facility	Ion	LET_{EFF} (MeV×cm²/mg)	Flux (ions/cm²/s)	Fluence (ions/cm²)	# Triggers V_{B1Y}	# Triggers V_{B2Y}	# Triggers V_{B3Y}	# Triggers V_{A4Y}
2	14	4	FRIB	^{109}Ag	47	1.00×10^5	1.00×10^7	21	23	26	27

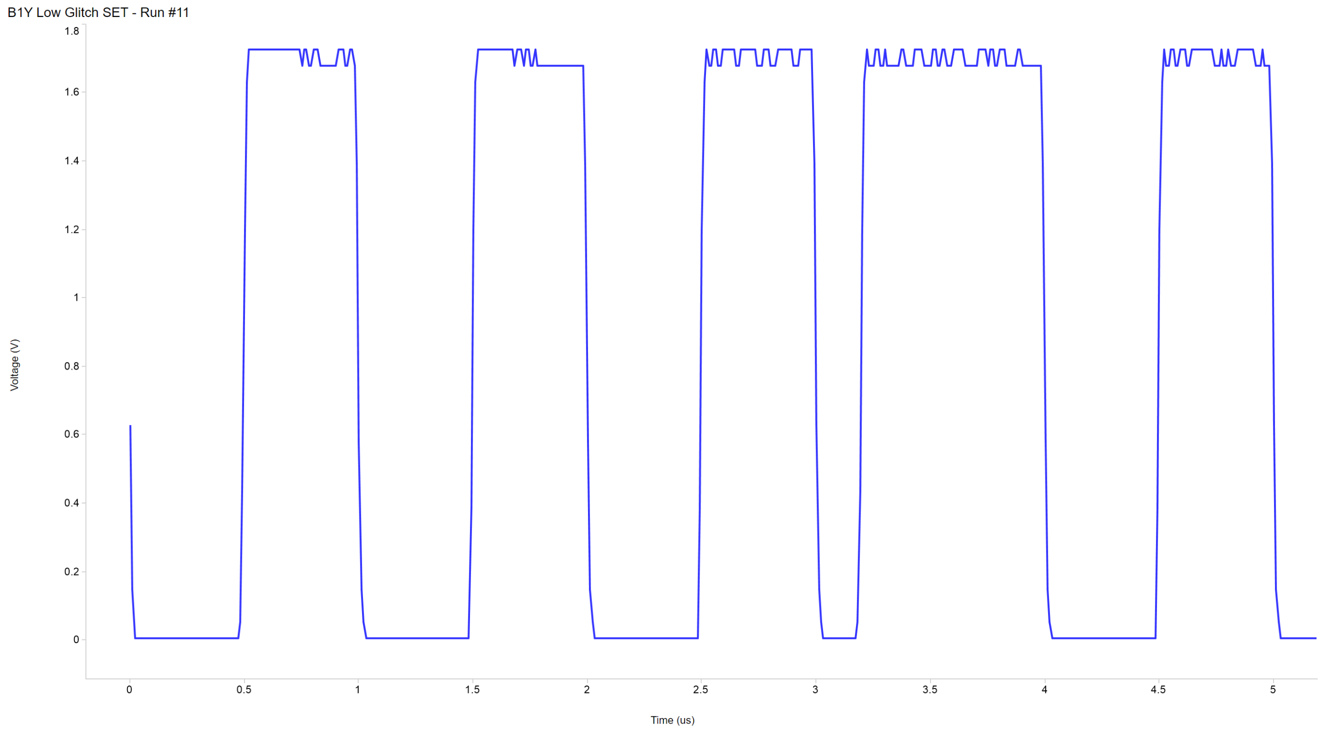

Figure 7-1. V_{B1Y} Low Glitch SET (Run #11, Bias 1)

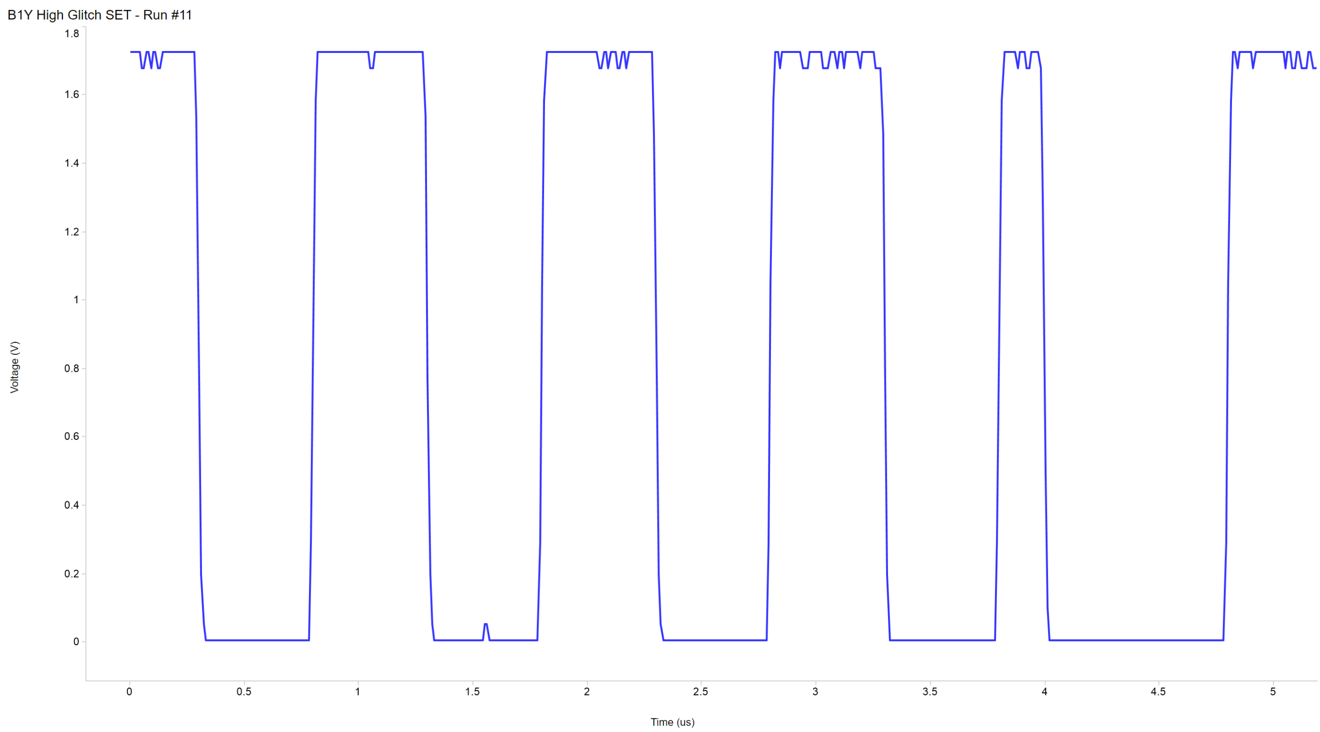

Figure 7-2. V_{B1Y} High Glitch SET (Run #11, Bias 1)

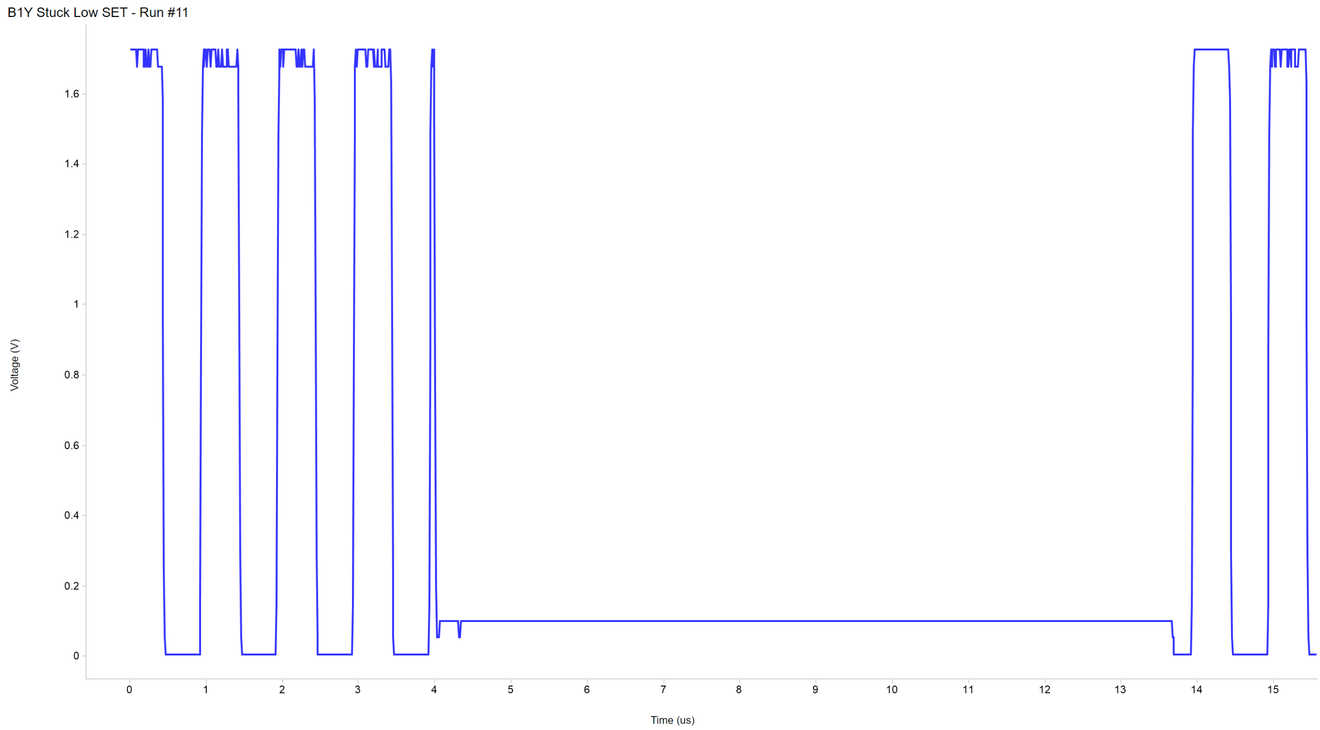

Figure 7-3. V_{B1Y} Stuck Low SET (Run #11, Bias 1)

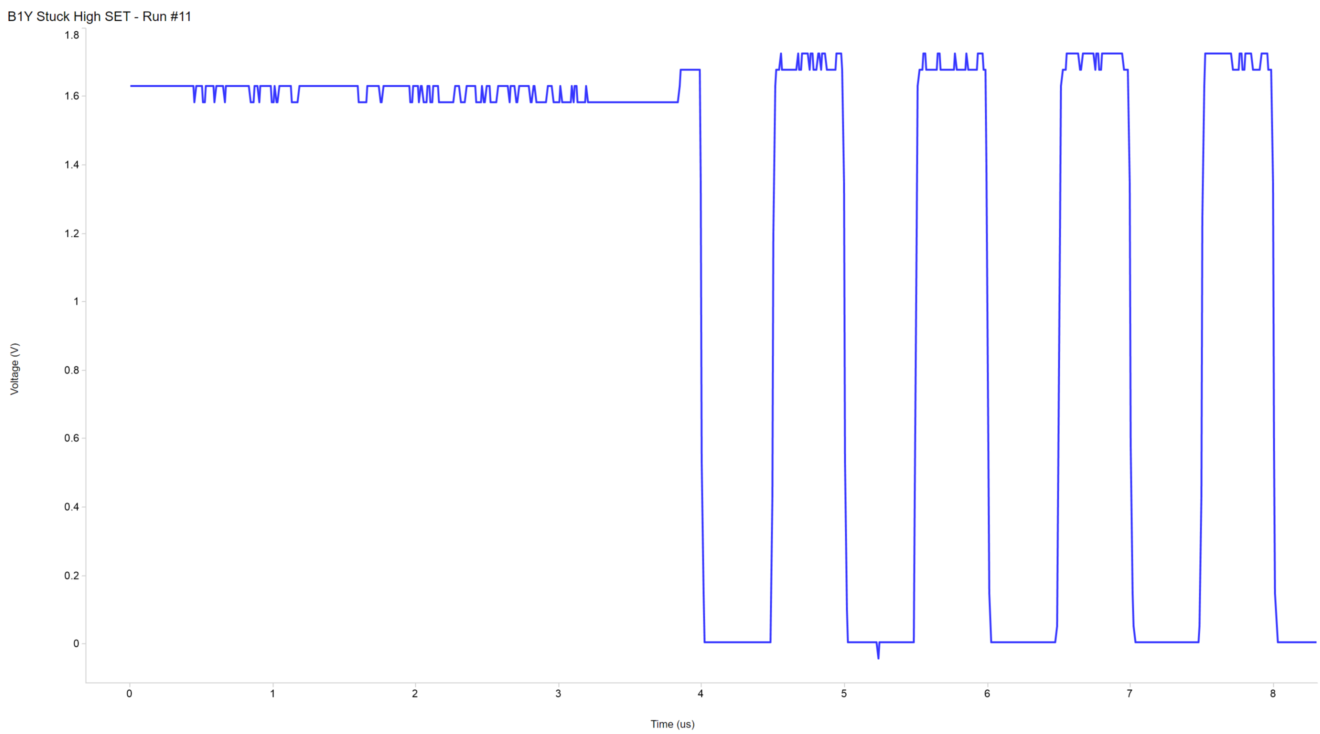

Figure 7-4. V_{B1Y} Stuck High SET (Run #11, Bias 1)

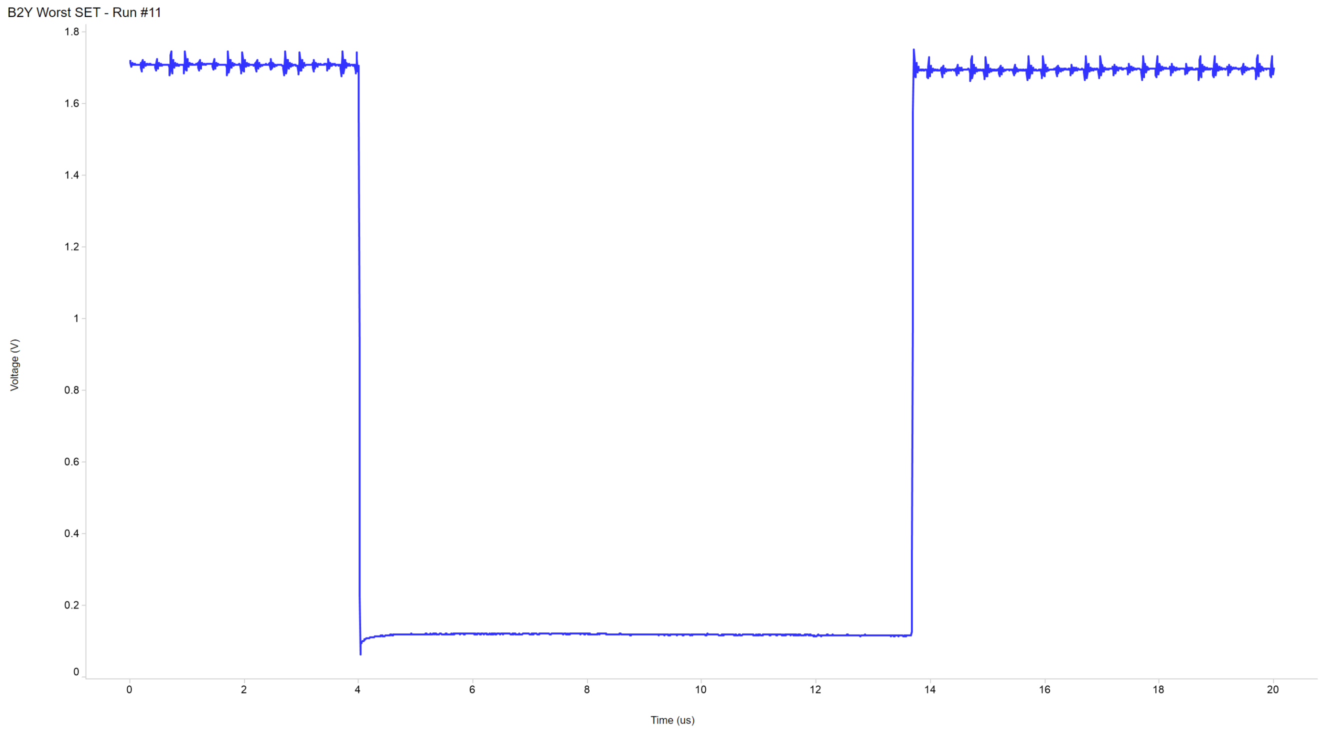

Figure 7-5. V_{B2Y} Worst SET (Run #11, Bias 1)

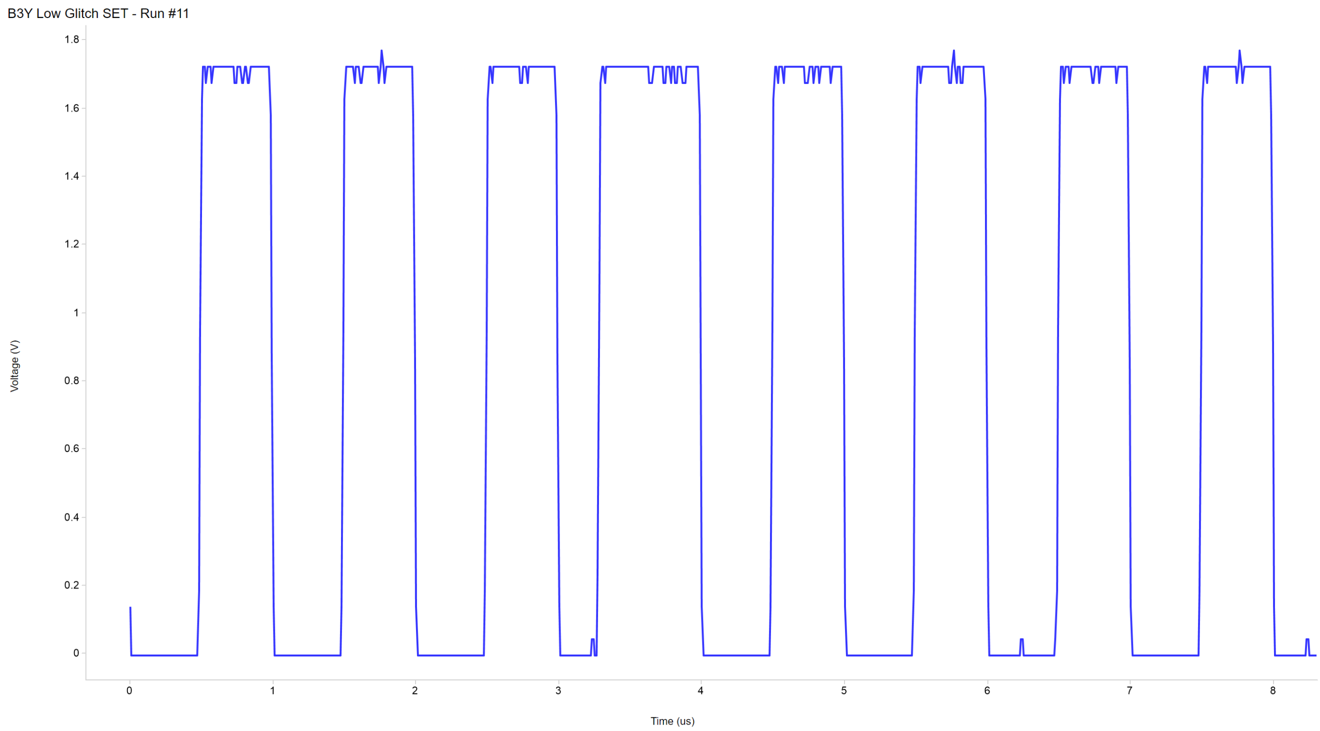

Figure 7-6. V_{B3Y} Low Glitch SET (Run #11, Bias 1)

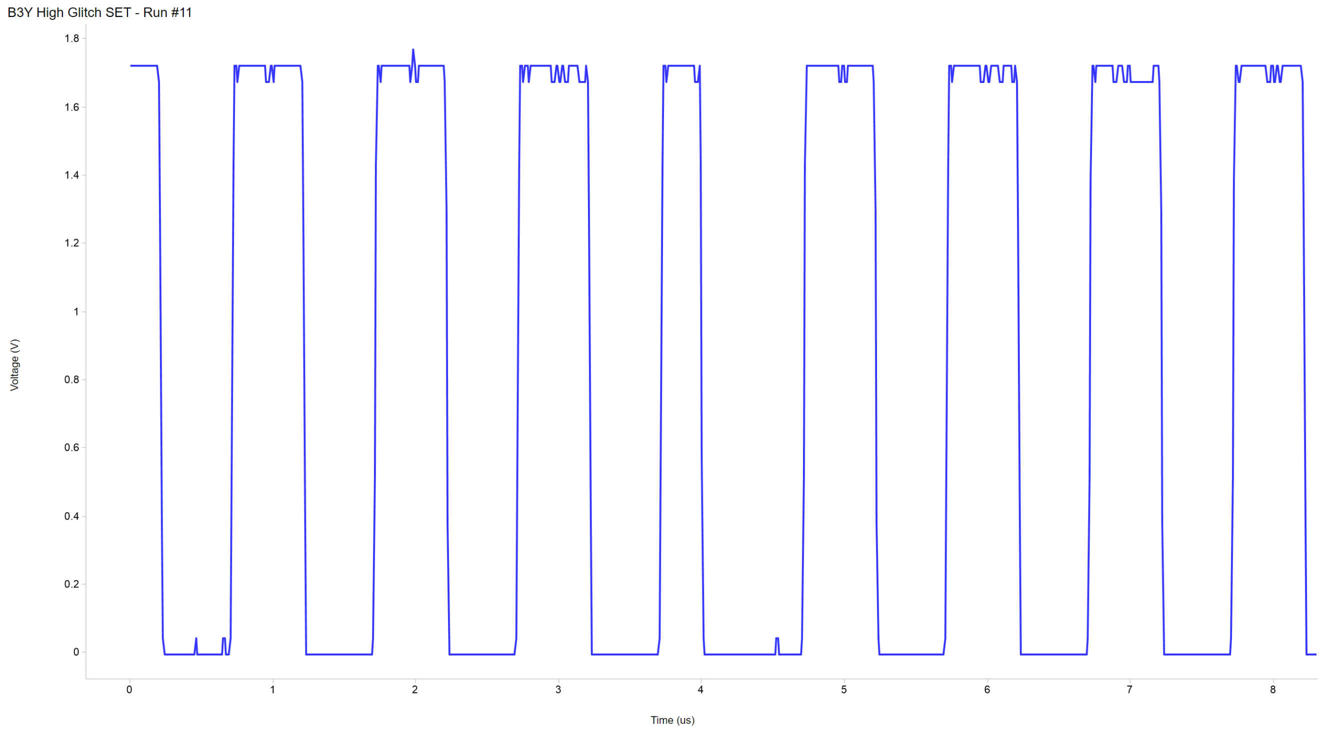

Figure 7-7. V_{B3Y} High Glitch SET (Run #11, Bias 1)

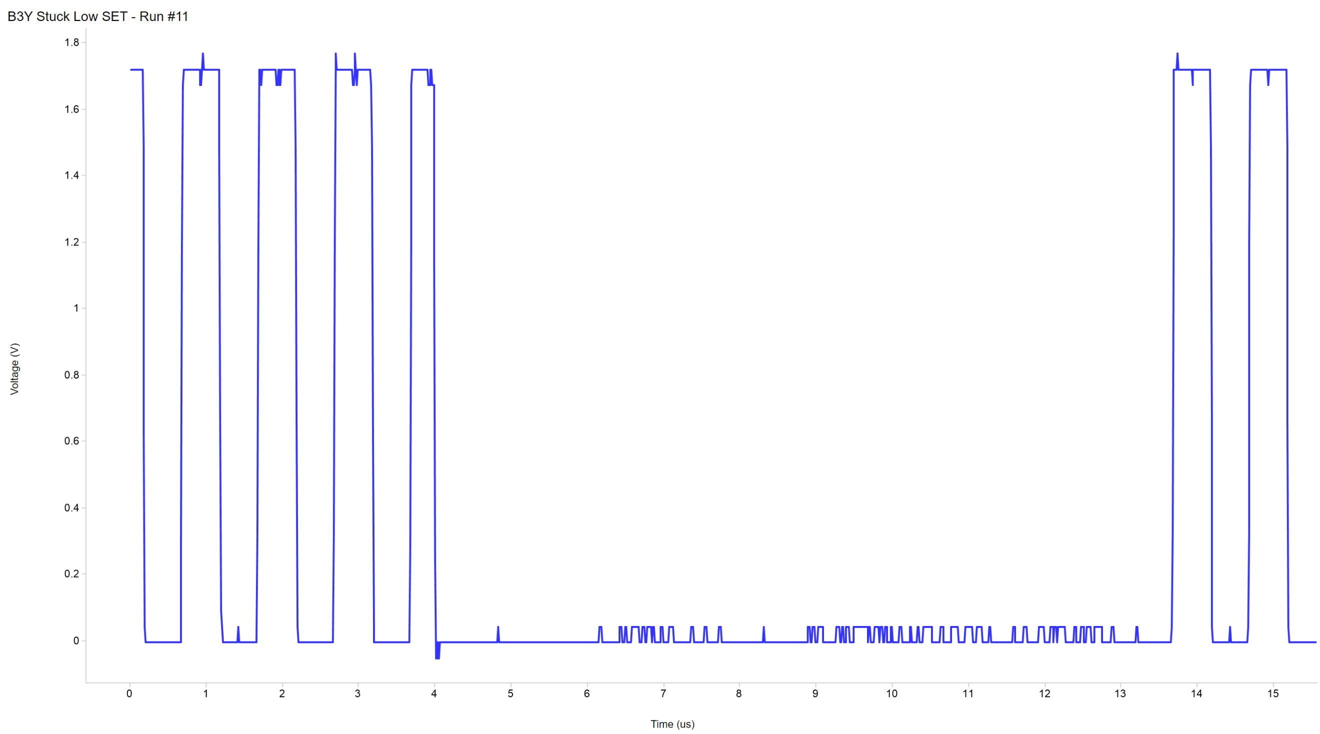

Figure 7-8. V_{B3Y} Stuck Low SET (Run #11, Bias 1)

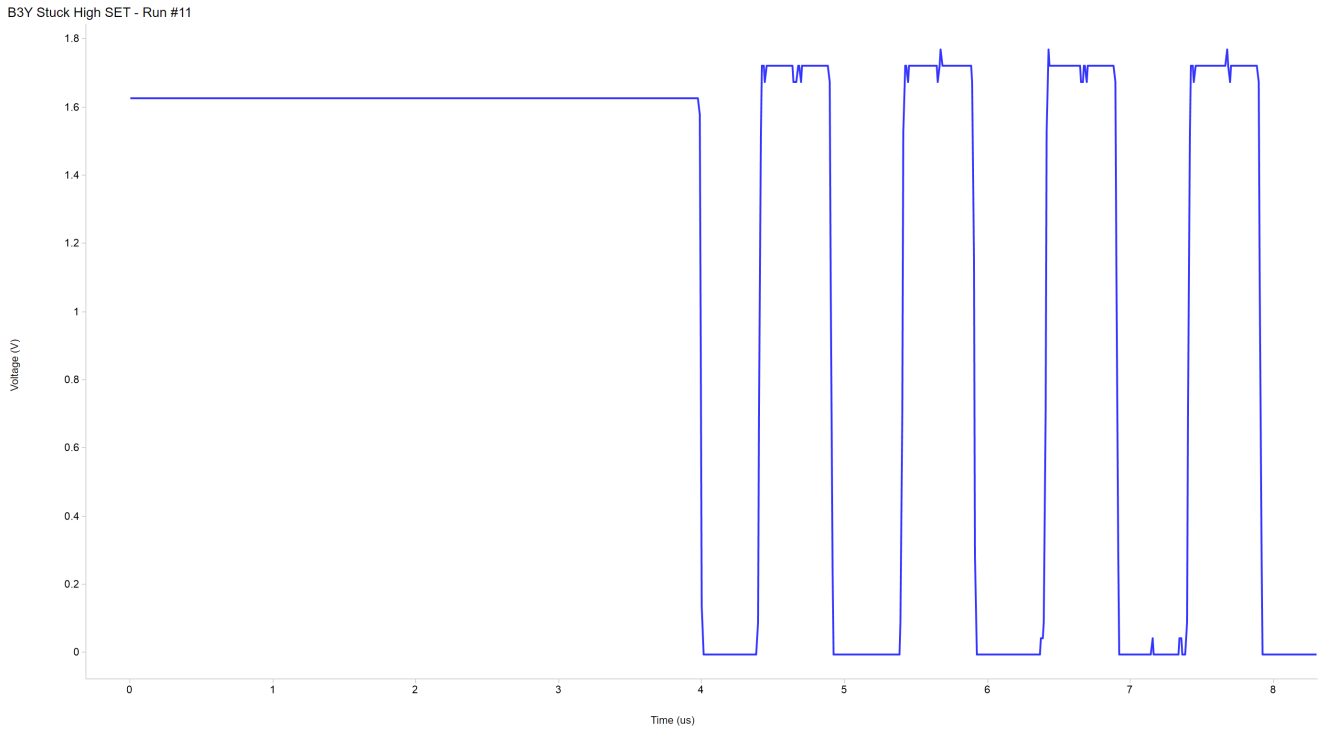

Figure 7-9. V_{B3Y} Stuck High SET (Run #11, Bias 1)

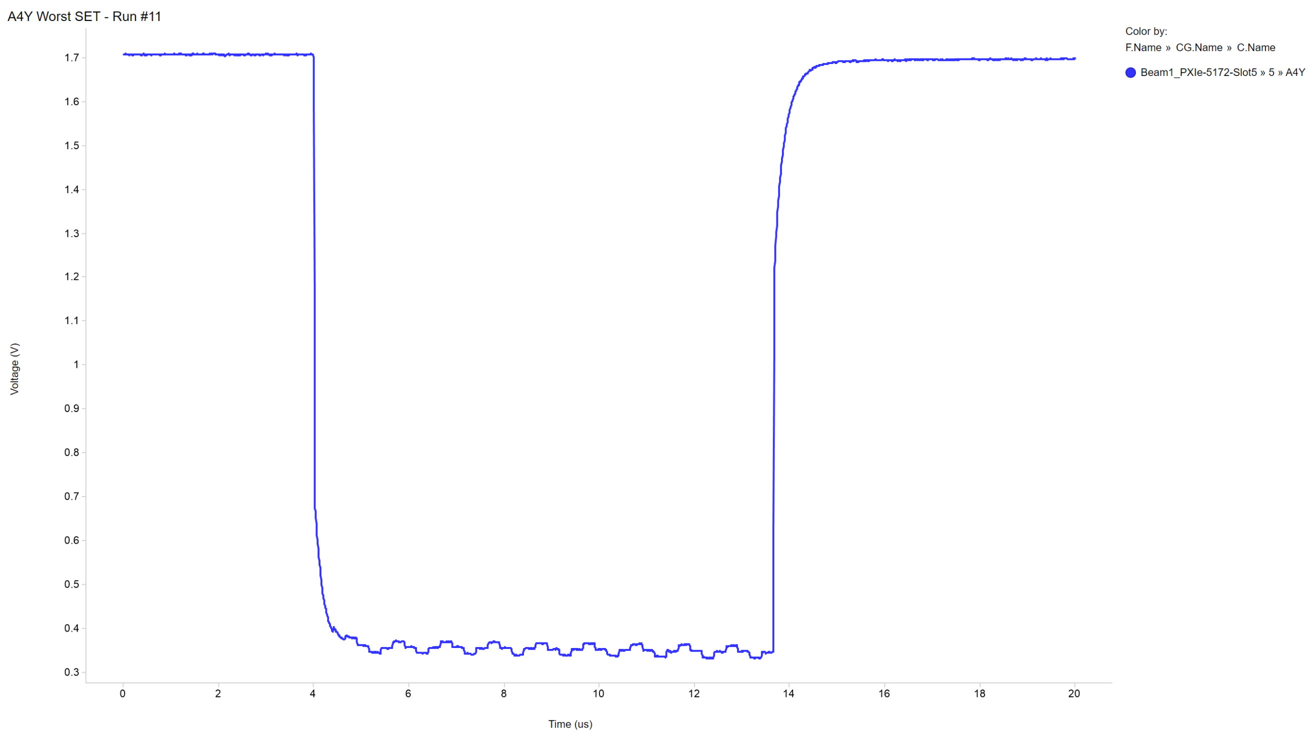

Figure 7-10. V_{A4Y} Worst SET (Run #11, Bias 1)

Table 7-3. TXGS441-SEP SET Cross-Sections

Signal	Fluence (ions/cm^2)	Bias #1: Transients (#)	Bias #2: Transients (#)	Bias #3: Transients (#)	Bias #4: Transients (#)	Bias #1: Upper-Bound Cross-Section (cm^2)	Bias #2: Upper-Bound Cross-Section (cm^2)	Bias #3: Upper-Bound Cross-Section (cm^2)	Bias #4: Upper-Bound Cross-Section (cm^2)
B1Y	1.00×10^7	42	21	40	17	5.68×10^{-6}	3.21×10^{-6}	5.45×10^{-6}	2.72×10^{-6}
B2Y	1.00×10^7	38	23	33	26	5.22×10^{-6}	3.45×10^{-6}	4.63×10^{-6}	3.81×10^{-6}
B3Y	1.00×10^7	28	26	33	18	4.05×10^{-6}	3.81×10^{-6}	4.63×10^{-6}	2.84×10^{-6}
A4Y	1.00×10^7	41	27	17	36	5.56×10^{-6}	3.93×10^{-6}	2.72×10^{-6}	4.98×10^{-6}

8 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, the event rate calculation for the SEL is shown on Table 8-1 respectively. Note that this number is for reference since no SEL events were observed.

Table 8-1 uses fluence of 3 x 10^7 ions/cm^2 from bias 2 and 3:

Table 8-1. 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	3.83×10^{-4}	3.69×10^{-8}	1.41×10^{-11}	5.88×10^{-4}	4.74×10^{8}
GEO		1.24×10^{-3}		4.58×10^{-11}	1.91×10^{-3}	1.68×10^{8}

9 Summary

The purpose of this study was to characterize the effect of heavy-ion irradiation on the single-event effect (SEE) performance of the TXGS441-SEP ±40V, fixed direction, nongalvanic based voltage and ground-level translator. Heavy-ions with LET_{EFF} = 47MeV×cm^2/mg were used for the SEE characterization campaign. Flux of ≈10^5 ions/cm^2/s and fluences of ≈10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TXGS441-SEP is free of destructive SEL and across the full electrical specifications. Transients at LET_{EFF} = 47MeV×cm^2/mg on $V_{B1Y,}$ $V_{B2Y,}$ $V_{B3Y,}$ $V_{A4Y,}$ are presented and discussed. CREME96-based worst-week event-rate calculations for LEO(ISS) and GEO orbits for the SEL are presented for reference.

10 References

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