

Single-Event Effects (SEE) Radiation Report of the THVD9491-SP



Abstract

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the THVD9491-SP. Heavy-ions with LET_{EFF} of $75\text{MeV} \times \text{cm}^2/\text{mg}$ were used to irradiate 4 production devices. Flux of 1.00×10^4 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 THVD9491-SP is SEL-free up to $75\text{MeV} \times \text{cm}^2/\text{mg}$ at $T = 125^\circ\text{C}$. SET transients performance for output voltage excursions $\geq 3\%$ from the nominal voltage are presented and discussed.

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1 Introduction

The THVD9491-SP is a full duplex RS-422/RS-485 transceiver using a 1.65V to 5.5V logic supply for data and enable logic signals, and a 3V to 5.5V bus side supply. The devices have slew rate select feature that enables the devices to be used at two maximum speeds based on the SLR pin setting

This device features integrated IEC ESD protection, eliminating the need for external system level protection components. Symmetric $\pm 12\text{V}$ input common-mode range makes reliable data communication over longer cable run lengths and/or in the presence of large ground loop voltages. Enhanced 250mV receiver hysteresis provides high noise rejection. In addition, the receiver fail-safe feature makes sure of a logic high when the inputs are open or shorted together.

The device is offered in a 14-pin D SOIC 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	THVD9491-SP
Orderable Part Number	5962R2522201PXE
VID/SMD Number	5962R2522201PXE
Device Function	Radiation Hardened 3V to 5.5V RS-485 Transceiver with Flexible I/O Supply and IEC ESD Protection
Technology	LBC9 (Linear BiCMOS 9)
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/ 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 concern for the THVD9491-SP is the robustness against the destructive single-event effects (DSEE): single-event latch-up (SEL). In mixed technologies such as the BiCMOS process used on the THVD9491-SP, the CMOS circuitry introduces a potential for SEL susceptibility.

SEL can occur if excess current injection caused by the passage of an energetic ion is high enough to trigger the formation of a parasitic cross-coupled PNP and NPN bipolar structure (formed between the p-sub and n-well and n+ and p+ contacts). 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 THVD9491-SP was tested for SEL at the maximum recommended operating conditions of $V_{CC} = 5.5V$ and Bus Pin A = 12V. Output conditions were tested at R pin = 5.5V and Y pin = 5.5V. During testing of the 3 devices, the THVD9491-SP did not exhibit any SEL with heavy-ions with $LET_{EFF} = 75MeV \times cm^2 / mg$ at flux of approximately 10^4 ions/cm²/s, fluence of approximately 10^7 ions/cm², and a die temperature of 125°C.

The THVD9491-SP was characterized for SET at flux of 1.00×10^4 ions/cm²/s, fluences of 1.00×10^7 ions/cm², and room temperature. The device was characterized with two bias conditions. Bias condition 1 had V_{CC} at 3.3V, V_{IO} at 1.8V and Bus Pin A at 6V. Bias condition 2 had V_{CC} at 3.3V, V_{IO} at 1.8V and driver output pins (Y and Z) connected to receiver input pins (A and B) respectively. Heavy-ions with LET_{EFF} of $75MeV \times cm^2 / mg$ were used to characterize the transient performance. To see the SET results of the THVD9491-SP, please refer to [Single-Event Transients \(SET\)](#).

3 Device and Test Board Information

The THVD9491-SP is packaged in a 14-pin D SOIC Plastic package as shown in [Figure 3-2](#). The THVD9491-SP evaluation board was used to evaluate the performance and characteristics of the THVD9491-SP under heavy ion radiation. The THVD9491-SP Evaluation Board is shown in [Figure 3-3](#).

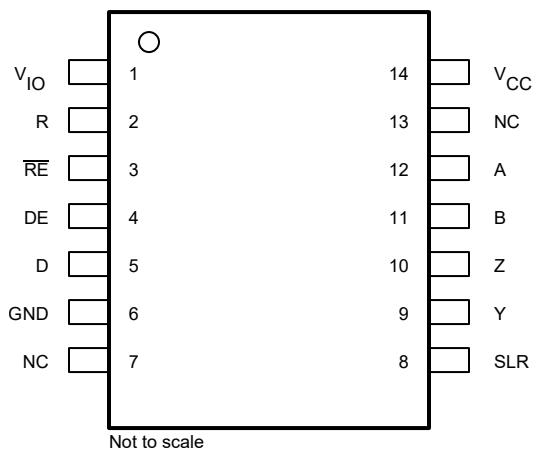


Figure 3-1. THVD9491-SP Pinout Diagram

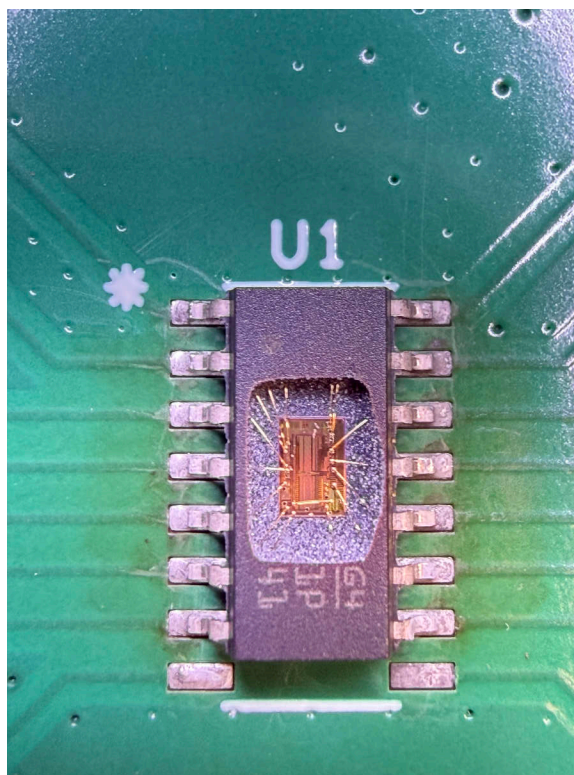


Figure 3-2. Photograph of Decapped THVD9491-SP

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

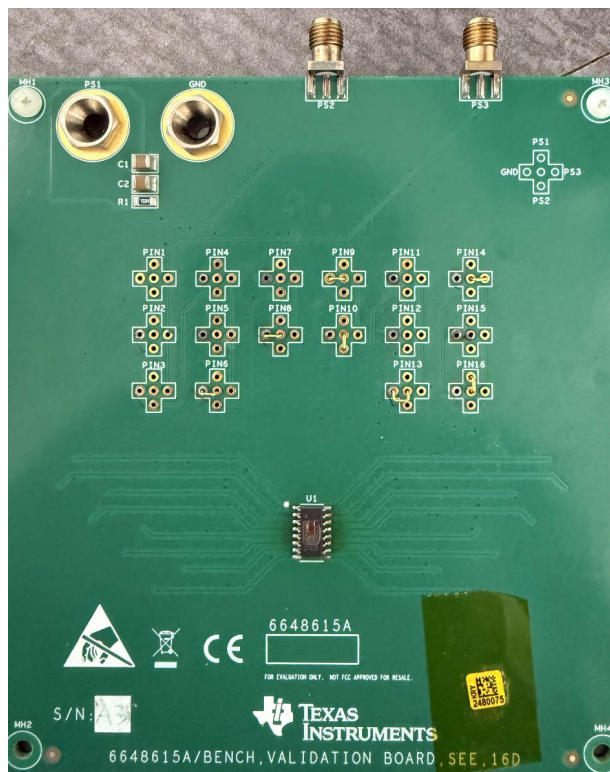


Figure 3-3. THVD9491-SP Evaluation Board Top View

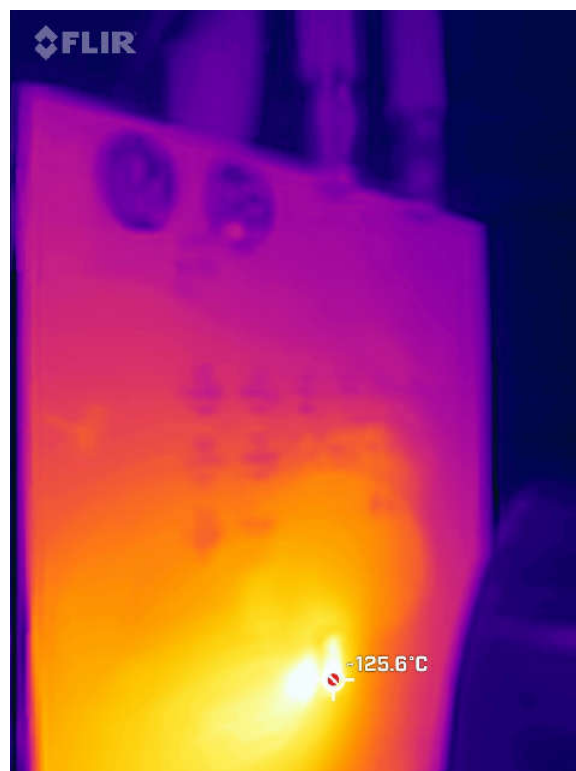


Figure 3-4. THVD9491-SP SEL Thermal Image

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 1in 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 1.00×10^4 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 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.

For the experiments conducted on this report, the ion used was ¹⁸¹Ta. ¹⁶⁵Ta was used to obtain LET_{EFF} of 75MeV × cm²/mg. The total kinetic energies for the ion was:

- ¹⁸¹Ta = 2.714GeV (15MeV/nucleon)
 - Ion uniformity for these experiments was between 95% and 96%

Figure 4-1 shows the THVD9491-SP Evaluation Board in front of the beam line at the TAMU facility.



Figure 4-1. THVD9491-SP Evaluation Board in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 Test Setup and Procedures

There were three input supplies used to power the THVD9491-SP which provided V_{CC} , V_{IO} and A. The V_{IO} for the device was provided through a National Instruments (NI) PXIe-4139 SMU from 1.8V for SET to 5.5V for SEL. The V_{CC} for the device was provided by a National Instruments (NI) PXIe-4139 SMU and ranged from 3.3V to 5.5V depending on the type of test. The last input supply was a National Instruments (NI) PXIe-4139 SMU and ranged from 6V for SET when applicable to 12V for SEL.

The primary signals monitored on the test board were R pin and Y pin (when driver output was not tied to receiver input) and this was done using two instruments. The first instrument was a NI PXIe-5172 Scope card, which was set to trigger on a 3% window based on the nominal value of R (on all tests). The first instrument was a NI PXIe-5172 Scope card, which was set to trigger on a 3% window based on the nominal value of Y (when applicable on SET and SEL).

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 through an MXI controller and NI PXIe-8381 remote control module.

[Equipment Settings and Parameters Used During the SEE Testing of the THVD9491-SP](#) 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 THVD9491-SP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{CC}	NI-PXIe 4139 (Slot# 3)	$\pm 60V$, 3A	3A	3.3V, 5.5V
V_{IO}	NI-PXIe 4139 (Slot# 4)	$\pm 60V$, 3A	3A	1.8V, 5.5V
A	NI-PXIe 4139 (Slot# 5)	$\pm 60V$, 3A	3A	6V, 12V
R	PXIe-5172 (1)	100MS/s	—	100MS/s
Y	PXIe-5172 (2)	100MS/s	—	100MS/s

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 facility. During the heavy-ion testing, the LabVIEW control program powered up the THVD9491-SP device and set the external sourcing and monitoring functions of the external equipment. After functionality and stability was confirmed, the beam shutter was opened to expose the device to the heavy-ion beam. The shutter remained open until the target fluence was achieved (determined by external detectors and counters). During irradiation, the NI scope cards continuously monitored the signals. When the output exceeded the pre-defined 3% window 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 events occurred during any of the tests.

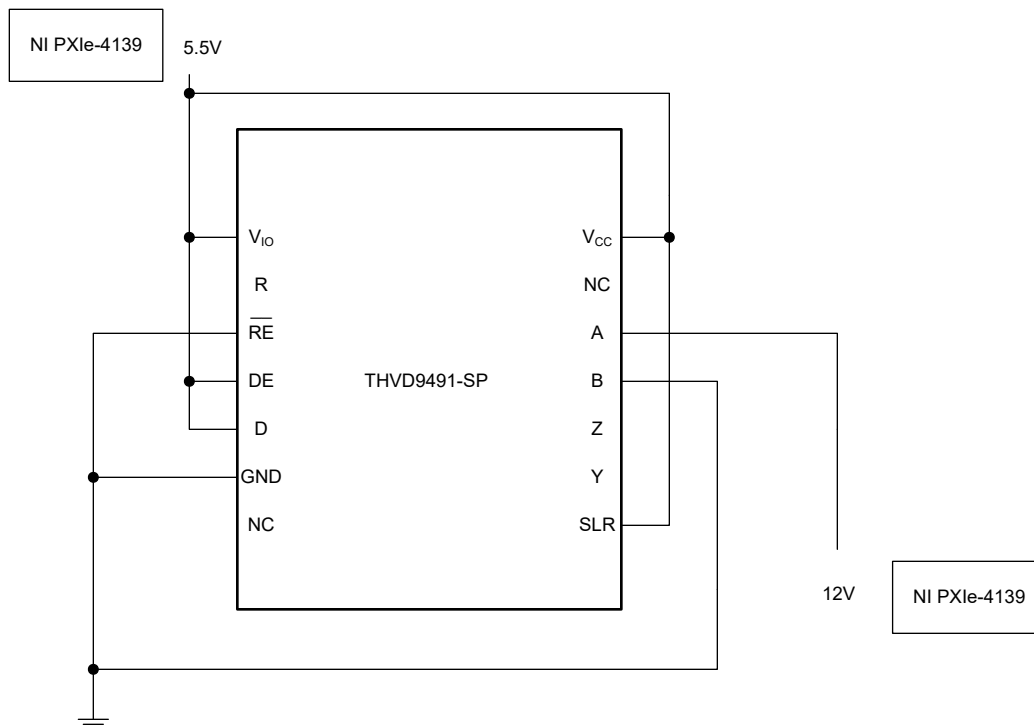


Figure 5-1. Block Diagram of the SEL Test Setup for the THVD9491-SP

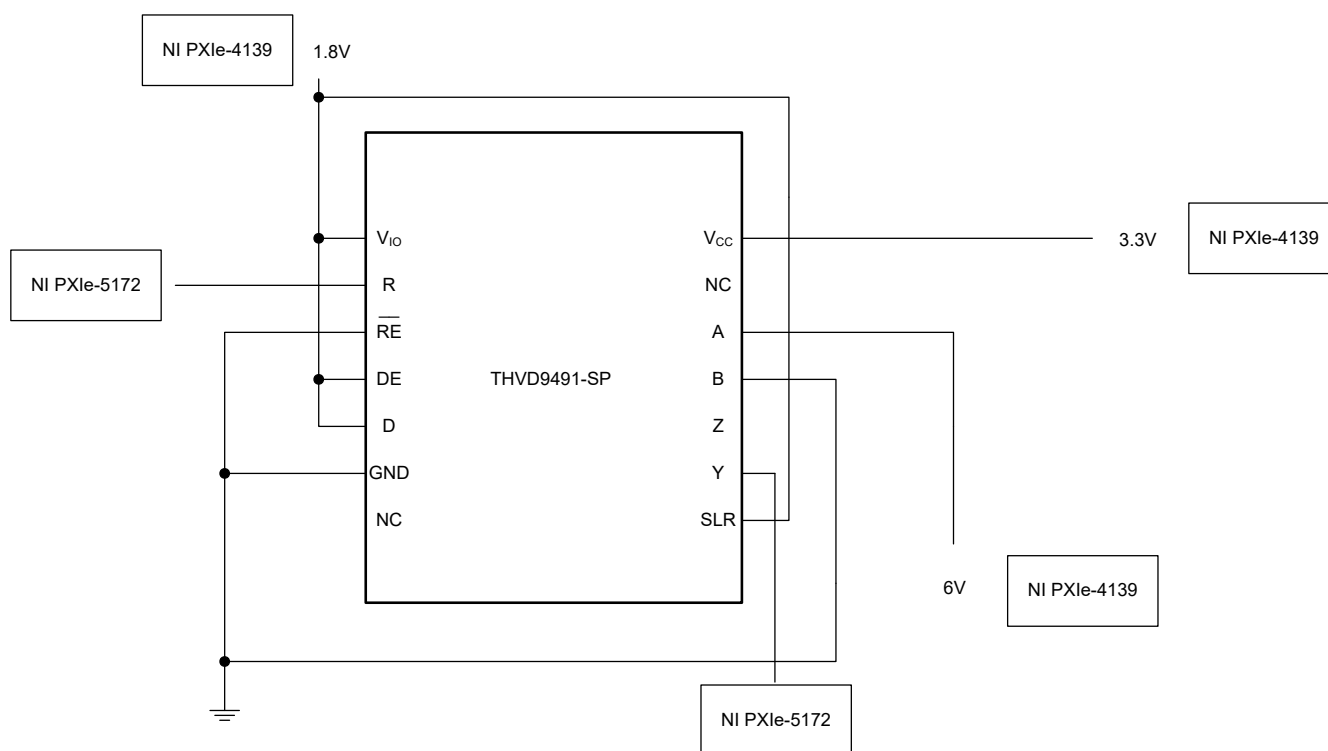


Figure 5-2. Block Diagram of the SET Test Setup for the THVD9491-SP

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]). 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 species used for SEL testing was ^{181}Ta at 15MeV/nucleon. Flux of approximately 10^4 ions/cm²/s and a fluence of approximately 10^7 ions/cm² per run was used. Run duration to achieve this fluence was approximately two minutes. The three devices were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 5.5V and a recommended output voltage of 3.3V. No SEL events were observed during all four runs, indicating that the THVD9491-SP is SEL-free up to 75MeV × cm²/mg. Table 6-1 shows the SEL test conditions and results. Figure 6-1 shows a plot of the current versus time for run #5.

Table 6-1. Summary of THVD9491-SP 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 _{CC} (V)	V _{IO} (V)	A (V)	I _{CC} (mA)	SEL (# Events)
1	1	TAMU	^{181}Ta	75	1.27×10^4	1×10^7	5.5	5.5	12	3.663	0
2	1	TAMU	^{181}Ta	75	1.11×10^4	1×10^7	5.5	5.5	12	3.656	0
3	2	TAMU	^{181}Ta	75	0.83×10^4	1×10^7	5.5	5.5	12	3.723	0
4	2	TAMU	^{181}Ta	75	1.02×10^4	1×10^7	5.5	5.5	12	3.727	0
5	3	TAMU	^{181}Ta	75	1.32×10^4	1×10^7	5.5	5.5	12	3.679	0
6	3	TAMU	^{181}Ta	75	1.18×10^4	1×10^7	5.5	5.5	12	3.671	0
7	3	TAMU	^{181}Ta	75	1.25×10^4	1.5×10^7	5.5	5.5	12	3.643	0

Using the MFTF method described in [Single-Event Effects \(SEE\) Confidence Interval Calculations application report](#) and combining (or summing) the fluences of the seven runs at 125°C (7.5×10^7 ions/cm²), the upper-bound cross section (using a 95% confidence level) is calculated as:

$$\sigma_{\text{SEL}} \leq 4.92 \times 10^{-8} \text{ cm}^2/\text{device for LET}_{\text{EFF}} = 75\text{MeV} \times \text{cm}^2/\text{mg and } T = 125^\circ\text{C}.$$

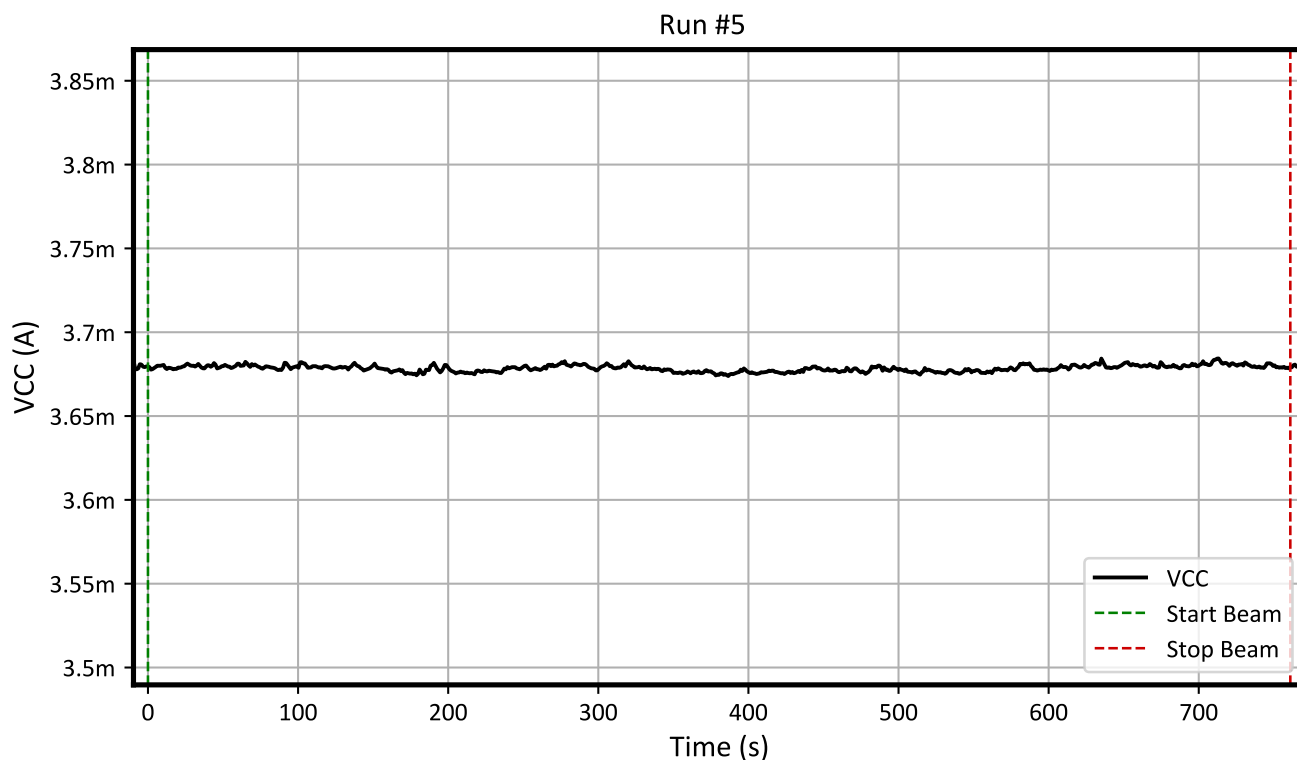


Figure 6-1. Current versus Time for Run #5 (SEL) of the THVD9491-SP at T = 125°C ($V_{OUT} = 5.5V$)

7 Single-Event Transients (SET)

SETs are defined as heavy-ion induced transients upsets on the R and Y output pins of the THVD9491-SP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for SET testing was ^{181}Ta at 15MeV/nucleon for a LET_{EFF} of 75MeV $\times$ cm²/mg. Flux of 10⁴ ions/cm²/s and a fluence of 10⁷ ions/cm², 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](#).

Table 7-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
PXIe-5172 (1)	R	Window	$\pm 3\%$	1k	100MS/s
PXIe-5172 (2)	Y	Window	$\pm 3\%$	1k	100MS/s

$V_{CC} = 3V$ and $V_A = 6V$

For the $V_{CC} = 3V$ and $V_A = 6V$ configuration, one unit was characterized at 75MeV. ^{181}Ta was used to achieve $\text{LET}_{\text{EFF}} = 75\text{MeV}$. Two PXIe-5172 scopes were used to monitor the R and Y outputs of the THVD9491-SP with both outputs triggering off a 3% window. [Table 7-2](#) summarizes the results for the unit tested.

The largest observed R Output transient is shown in [Figure 7-1](#), and the largest observed Y Output transient is shown in [Figure 7-1](#). [Figure 7-5](#) shows the largest positive spike transient observed in Y Output. The figure shows that although the signals go beyond the 3% window, they recover back to nominal and the device continues to operate properly. Histograms of all observed transients for run #8 are shown in [Figure 7-1](#) and [Figure 7-6](#).

Table 7-2. Summary of THVD9491-SP SET Test Condition and Results

Run #	Unit #	Facility	Ion	LET _{EFF} (MeV × cm ² /mg)	Flux (ions/cm ² /s)	Fluence (ions/cm ²)	R SET ≥ 3% (#)	Y SET ≥ 3% (#)
8	3	TAMU	¹⁸¹ Ta	75	1.28×10^4	1.00×10^7	908	438
9	3	TAMU	¹⁸¹ Ta	75	1.26×10^4	1.00×10^7	867	434

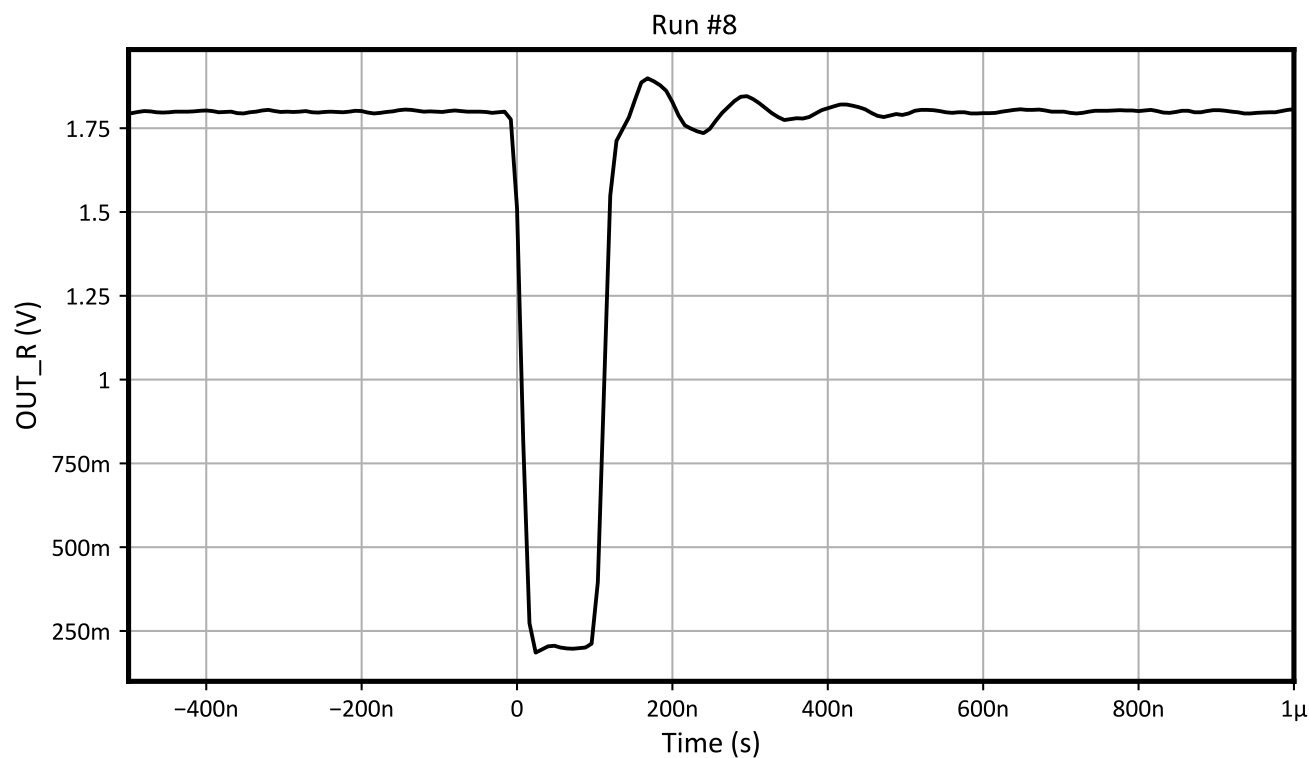


Figure 7-1. Largest Observed R Output Transient (Run #8)

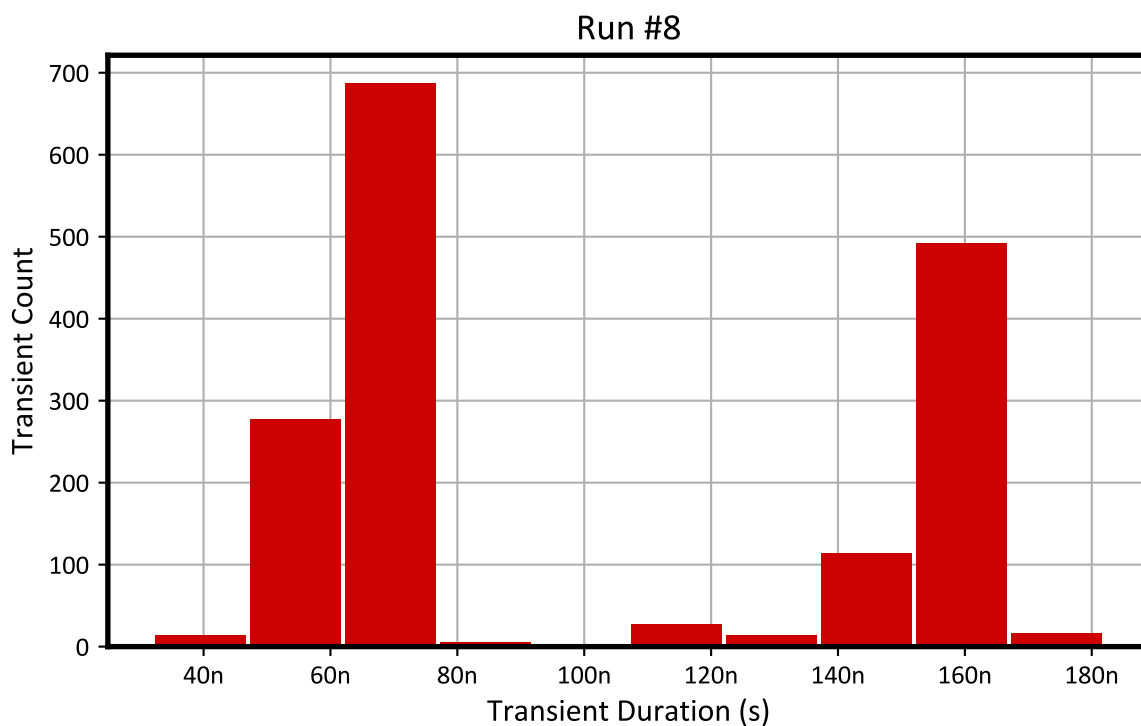


Figure 7-2. R Output Transient Duration Histogram (Run #8)

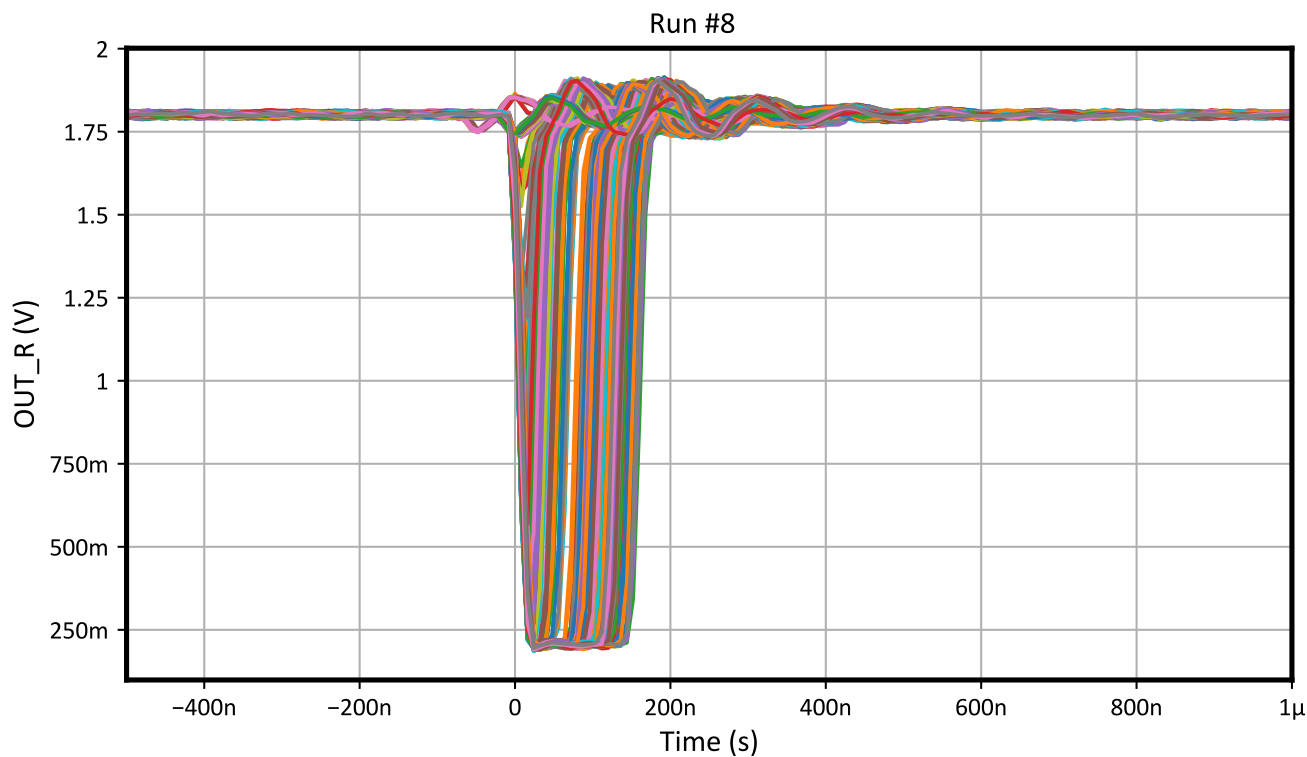


Figure 7-3. R Output All Transients (Run #8)

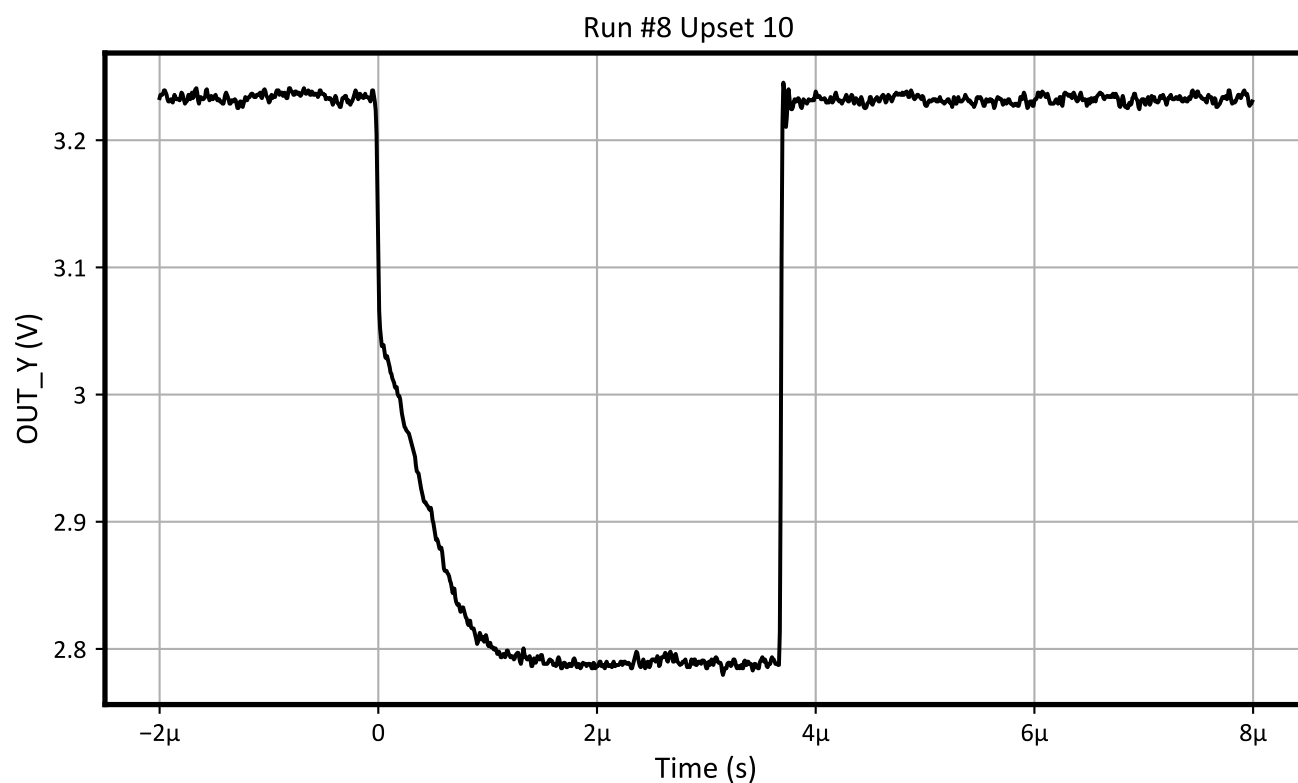


Figure 7-4. Y Output Longest Observed Transient (Run #8)

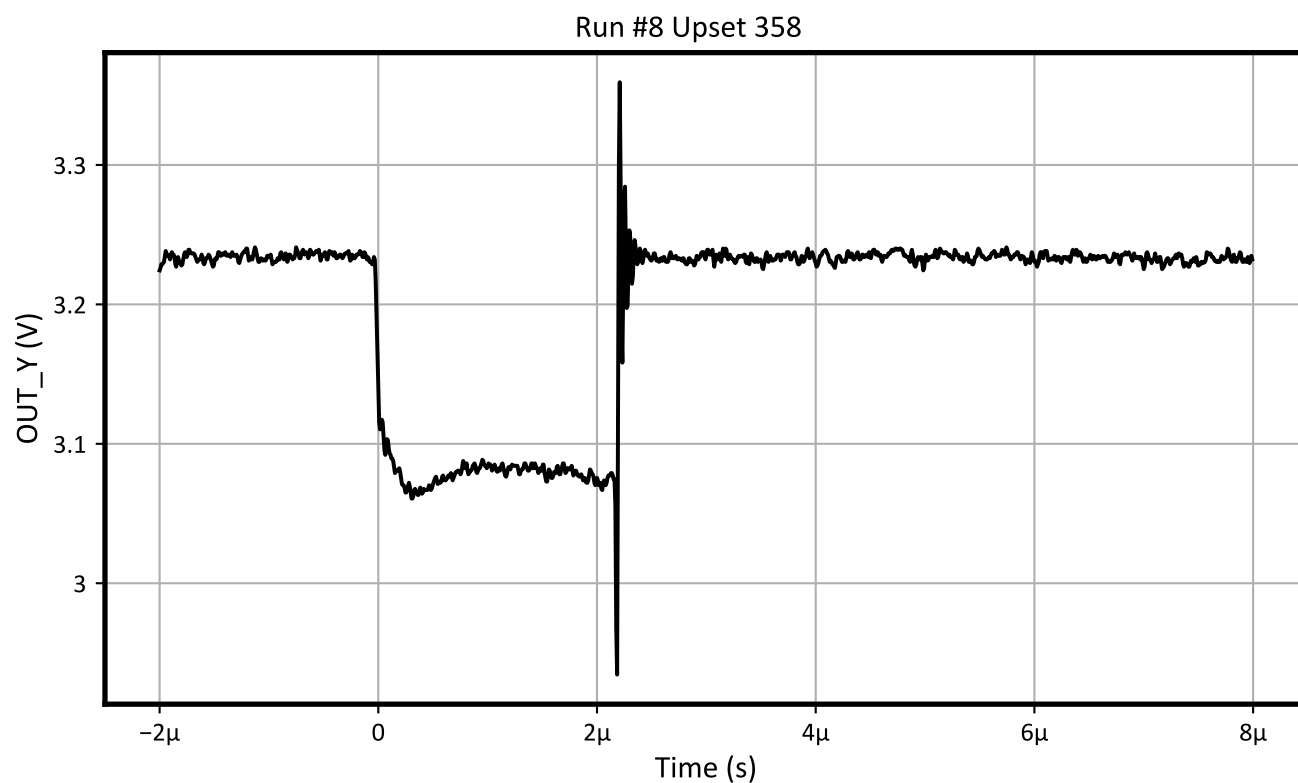


Figure 7-5. Y Output Largest Positive Spike Observed Transient (Run #8)

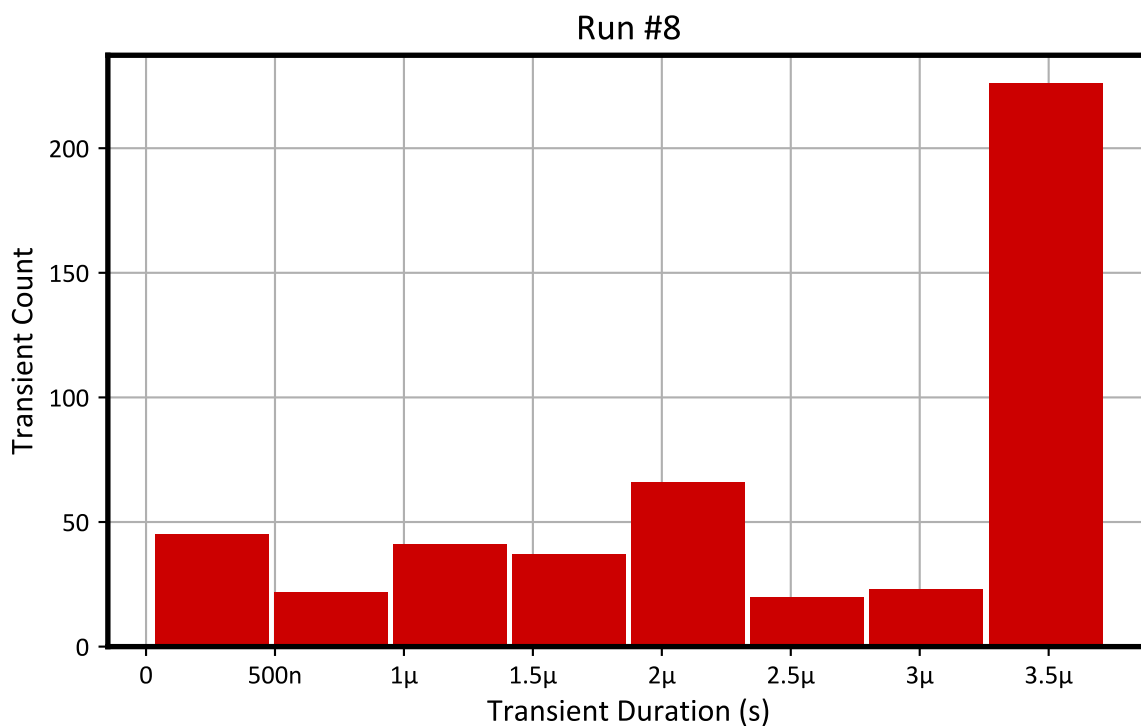


Figure 7-6. Y Output Transient Duration Histogram (Run #8)

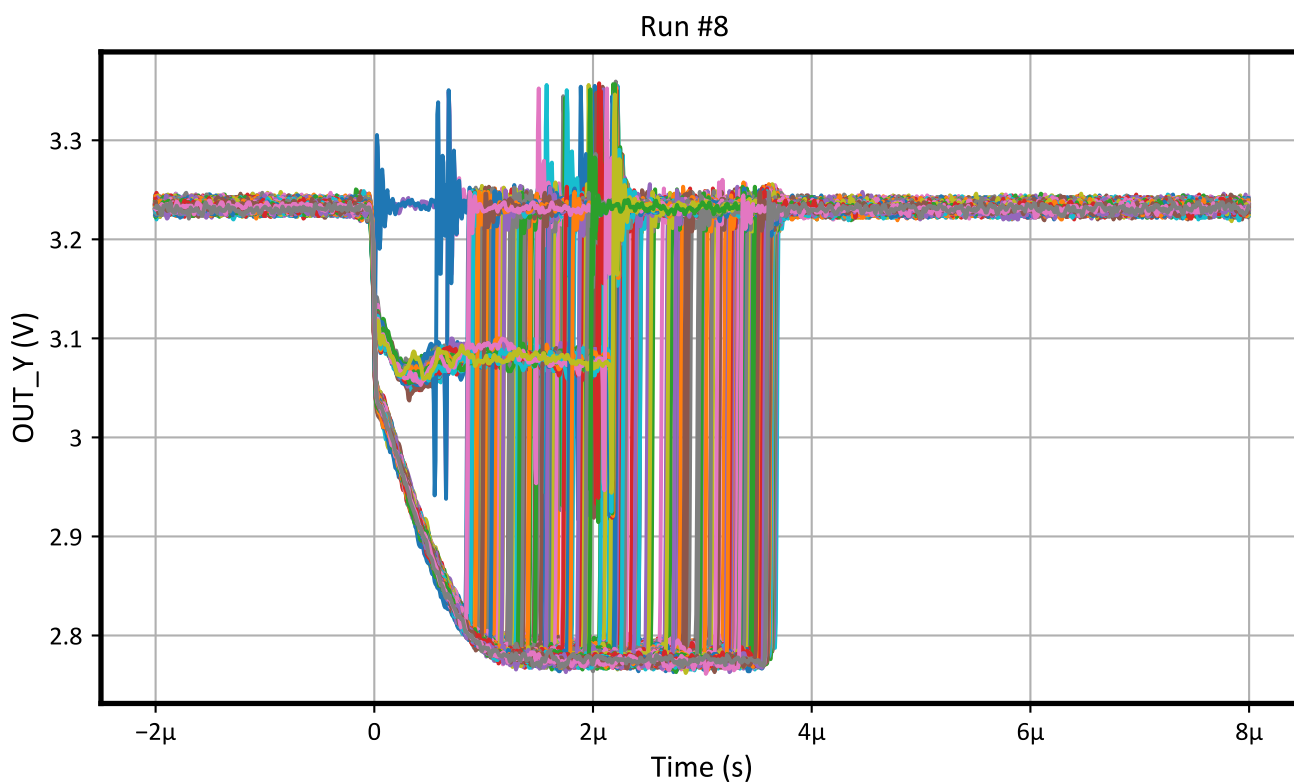


Figure 7-7. Y Output All Transients (Run #8)

Table 7-3. THVD9491-SP SET Cross-Sections

Signal	LET _{EFF} (MeV × cm ² /mg)	Fluence (ions/cm ²)	Transients (#)	Upper-Bound Cross Section (cm ²)
R	75	2×10^7	1775	9.3×10^{-5}
Y	75	2×10^7	872	4.66×10^{-5}

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 in [Table 8-1](#)

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)	σ _{SAT} (cm ²)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	75	6.26×10^{-5}	4.92×10^{-8}	3.08×10^{-12}	1.28×10^{-4}	8.9×10^8
GEO		1.77×10^{-4}		8.70×10^{-12}	3.62×10^{-4}	3.15×10^8

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 THVD9491-SP full duplex RS-422/RS-485 transceiver using a 1.65V to 5.5V logic supply. Heavy-ions with $LET_{EFF} = 75\text{MeV} \times \text{cm}^2/\text{mg}$ were used for the SEE characterization campaign. Flux of approximately 10^4 ions/cm²/s and fluence of approximately 10^7 ions/cm² per run were used for the characterization. The SEE results demonstrated that the THVD9491-SP is free of destructive SEL at $LET_{EFF} = 75\text{MeV} \times \text{cm}^2/\text{mg}$ and across the full electrical specifications. Transients at $LET_{EFF} = 75\text{MeV} \times \text{cm}^2/\text{mg}$ on R and Y outputs are presented and discussed. CREME96-based worst-week event-rate calculations for LEO(ISS) and GEO orbits for the DSEE are presented for reference.

10 References

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