Radiation Report

SN55LVRA4-SEP Single-Event Effects (SEE) Radiation Report

ABSTRACT

The purpose of this study is to characterize the single-event-effects (SEE) performance due to heavy-ion irradiation of the SN55LVRA4-SEP. SEE performance was verified at minimum (3V) and maximum (3.6V) operating conditions. Heavy-ions with an LET_{EFF} of 50MeV-cm^2/ mg (for SEL) and LET_{EFF} of 47MeV-cm^2/ mg (for SET) were used to irradiate five production devices with a fluence of 1 × 10^7 ions / cm^2. The results demonstrate that the SN55LVRA4-SEP is SEL-free up to LET_{EFF} = 50MeV-cm^2 / mg as 125°C. SET performance at minimum and maximum operating voltages saw excursions, as shown and discussed in this report.

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1 Overview

The SN55LVRA4-SEP is a radiation tolerant quad channel differential receiver that implements the electrical characteristics of low-voltage differential signaling (LVDS) with a 3.3V supply. The intended application and signaling technique of these devices is point-to-point baseband data transmission over controlled impedance media of approximately 100Ω.

For more information, see the SN55LVRA4-SEP product page.

Table 1-1. Overview Information

Description	Device Information
TI Part Number	SN55LVRA4-SEP
Orderable Part Number	SN55LVRA4MDTSEP
VID Number	V62/25606
Device Function	Radiation-tolerant, Quad channel differential receiver
Technology	LIN3B
Exposure Facility (SEL)	Facility for Rare Isotope Beams (FRIB) at Michigan State University – FRIB Single Event Effects (FSEE) Facility
Exposure Facility (SET)	K500 Cyclotron at Texas A&M University
Heavy Ion Fluence per Run	1×10^7 ions / cm^2
Irradiation Temperature	25°C (for SET testing) and 125°C (for SEL testing)

2 Single-Event Effects (SEE)

The primary single-event effect (SEE) event of interest in the SN55LVRA4-SEP is the destructive single-event latch-up. From a risk or impact perspective, the occurrence of an SEL is potentially the most destructive SEE event and the biggest concern for space applications. In mixed technologies such as the Linear Bi-CMOS (LIN3B) process used for SN55LVRA4-SEP, the CMOS circuitry introduces a potential 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-substrate 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 or until the device is destroyed by the high-current state. The process modifications applied for SEL-mitigation were sufficient, as the SN55LVRA4-SEP exhibited no SEL with heavy-ions up to an LET_{EFF} of 50MeV-cm^2 / mg at a fluence of 1 × 10^7 ions / cm^2 and a chip temperature of 125°C.

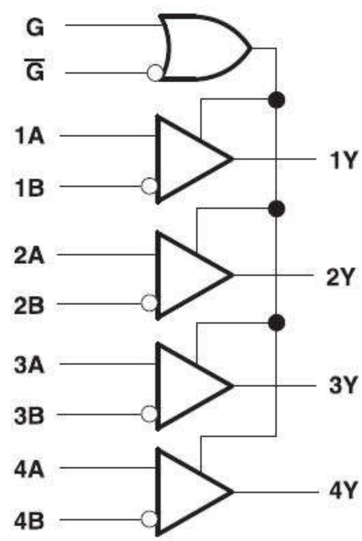

Figure 2-1. Functional Block Diagram of the SN55LVRA4-SEP

3 Test Device and Test Board Information

The SN55LVRA4-SEP is a packaged 16-pin, SOIC plastic package shown in the pinout diagram in Figure 3-1. Figure 3-2 shows the device with the package cap decapped to reveal the die for heavy ion testing. Figure 3-3 shows the evaluation board used for Single-Event Latch-up (SEL) testing. Figure 3-4 shows the evaluation board used for Single-Event Transient (SET) testing. Figure 3-5 shows the bias diagram used for Single-Event Latch-up (SEL) testing. Figure 3-6 shows the bias diagrams used for Single-Event Transient (SET) testing.

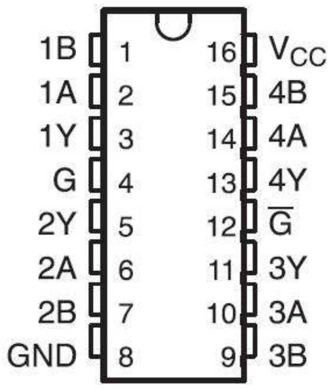

Figure 3-1. SN55LVRA4-SEP Pinout Diagram

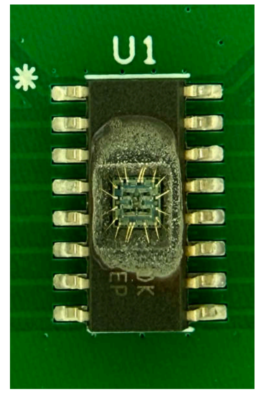

Figure 3-2. Photo of SN55LVRA4-SEP Package Decapped

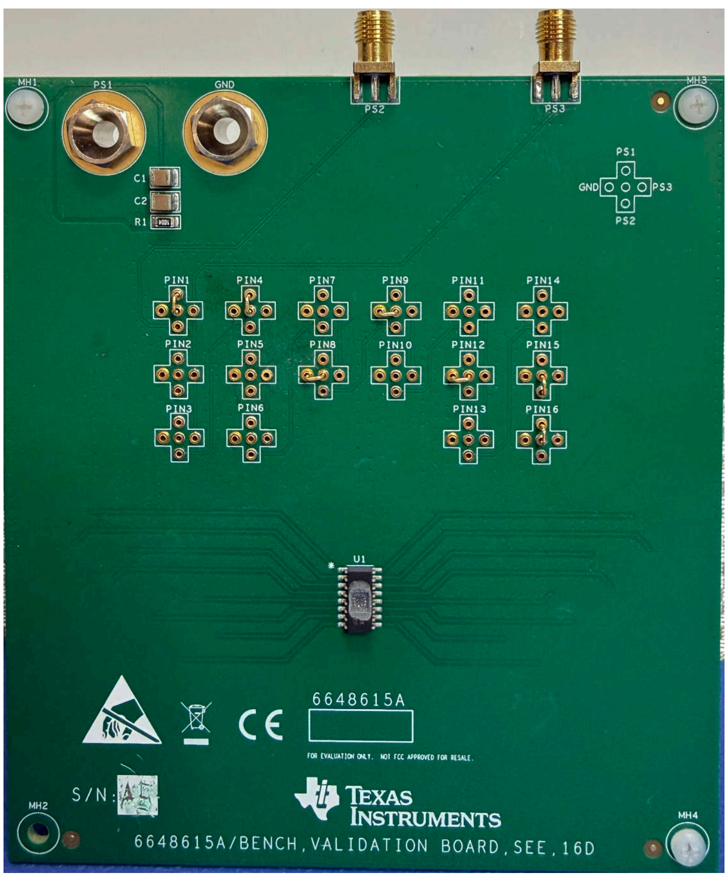

Figure 3-3. SN55LVRA4-SEP Evaluation Board (Top View) for SEL Testing

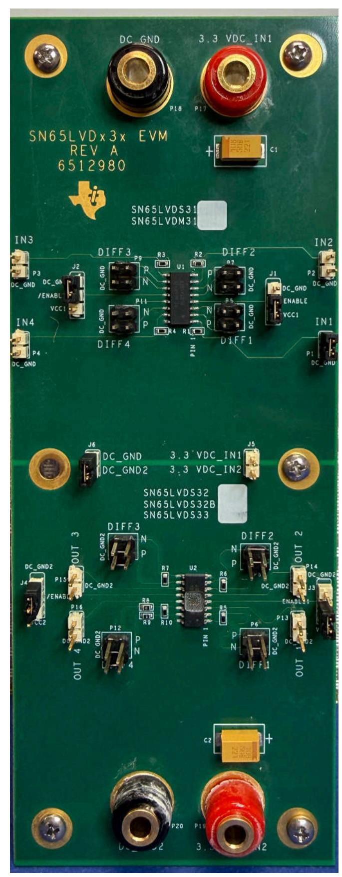

Figure 3-4. SN55LVRA4-SEP Evaluation Board (Top View) for SET Testing

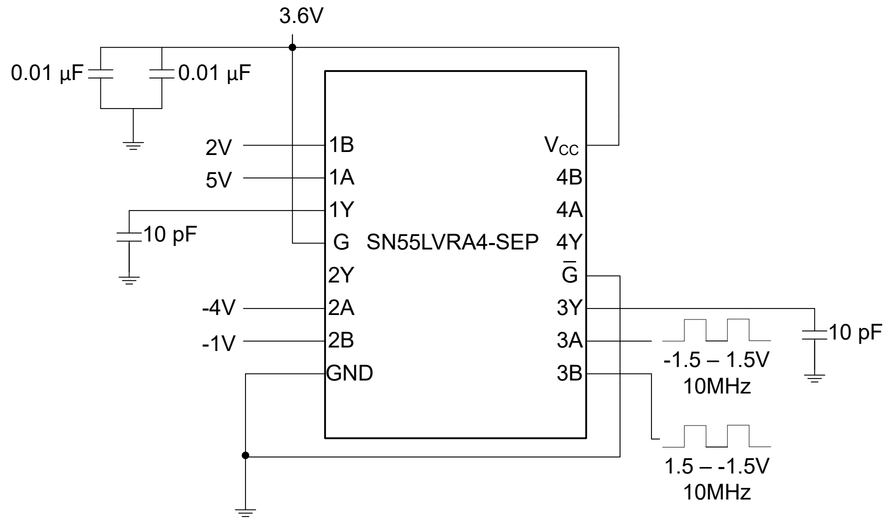

Figure 3-5. SN55LVRA4-SEP SEL Bias Diagram

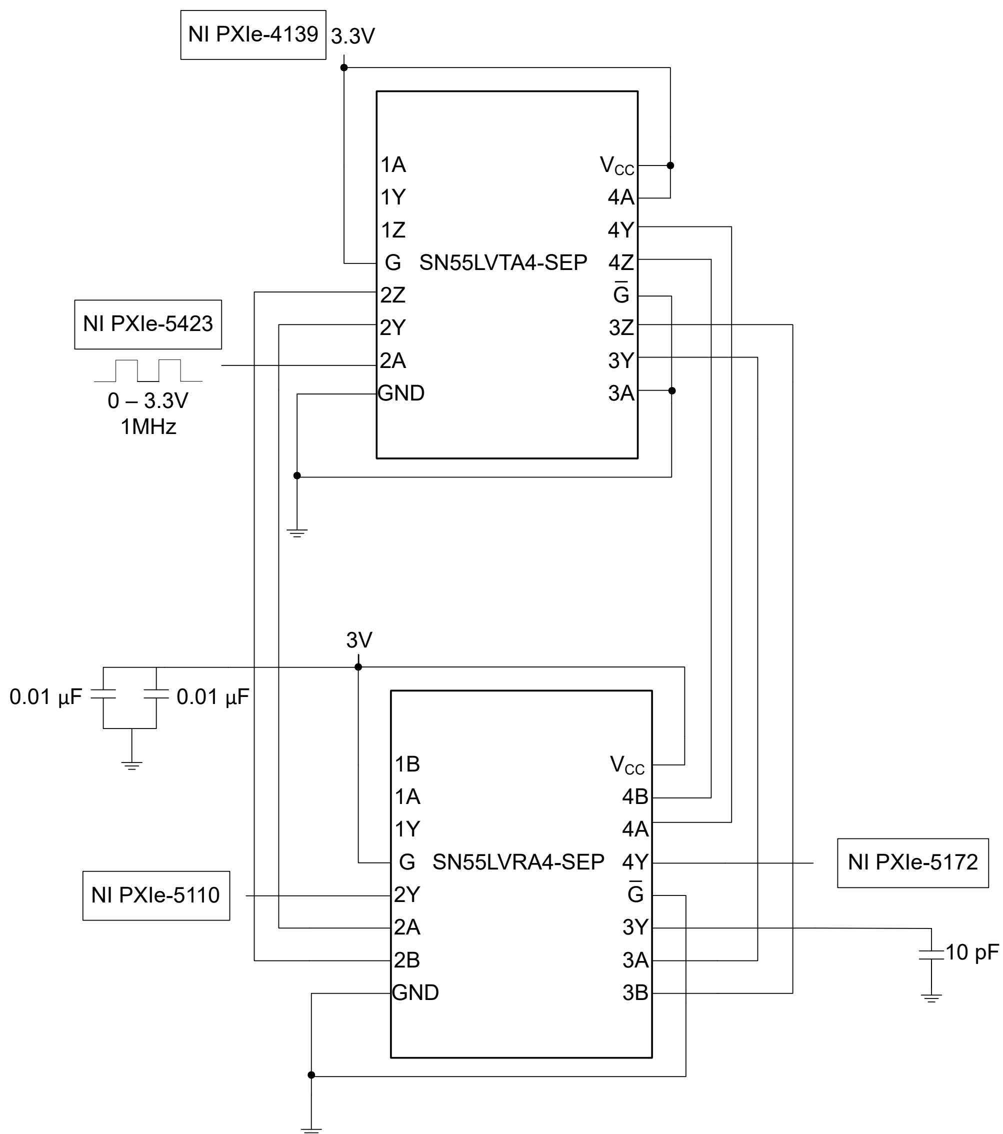

Figure 3-6. SN55LVRA4-SEP SET Bias Diagram

4 Irradiation Facility and Setup

The heavy ion species used for the SEL studies on this product were provided and delivered by the Facility for Rare Isotope Beams (FRIB) at Michigan State University (FRIB Single Event Effects (FSEE) Facility's linear accelerator.) The FSEE Facility has a dedicated beamline built on the FRIB linac infrastructure with a user experimental station at the end of the FSEE beamline. Ion beams are delivered with high uniformity over a 1-inch diameter exposure area using a thin vacuum window. For this study, ion flux of 1 × 10^5 ions / cm^2-s was used to provide heavy ion fluence of 1 × 10^7 ions / cm^2 using ^{129}Xe ion at a linac energy of 25 MeV / μ. Ion beam uniformity for all tests was 97.5%.

Figure 4-1 shows one of the four SN55LVRA4-SEP test boards used for experiments at the MSU facility. The in-air gap between the device and the ion beam port window was maintained at 70mm for all runs.

The heavy-ion species used for the SET studies on this product were provided and delivered by the TAMU Cyclotron Radiation Effects Facility using a 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 this study, ion flux of 10^5 ions / cm^2 * s were used to provide heavy-ion fluences of approximately 10^7 ions / cm^2 for SET testing. For the experiments conducted on this report, ^{109}Ag ions at angle of incidence of 0° for an LET_{EFF} of 47MeV × cm^2 / mg were used. The total kinetic energy of ^{109}Ag in the vacuum is 1.634GeV (15 MeV/nucleon). Ion uniformity for these experiments was between 93% and 97%.

Figure 4-2 shows the SN55LVRA4-SEP test board used for experiments at the TAMU facility. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.

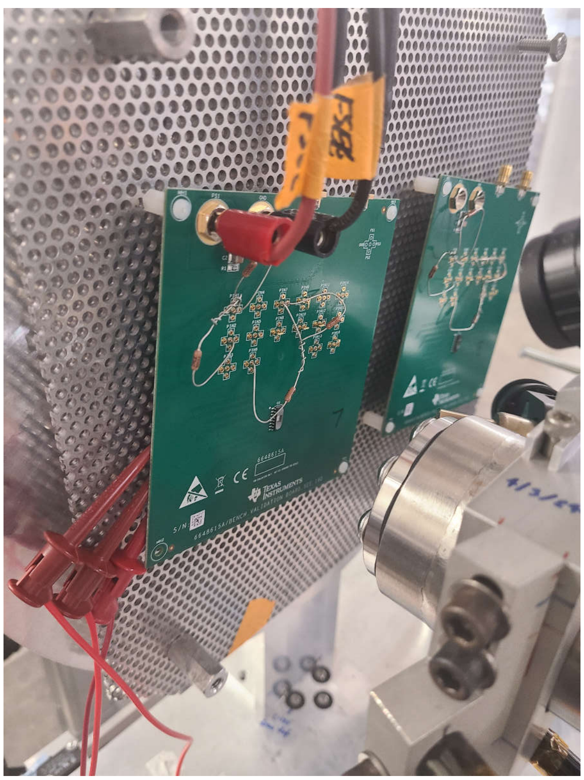

Figure 4-1. SN55LVRA4-SEP Evaluation Board at the MSU Facility

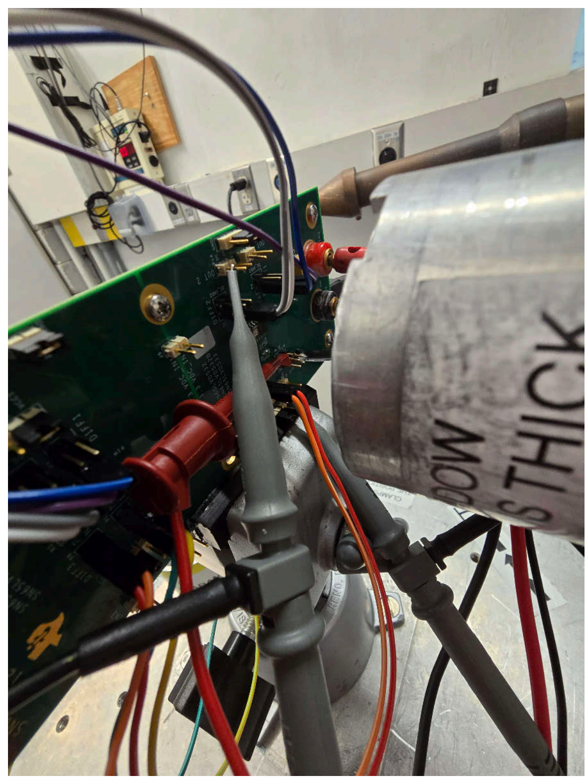

Figure 4-2. SN55LVRA4-SEP Evaluation Board at TAMU Facility

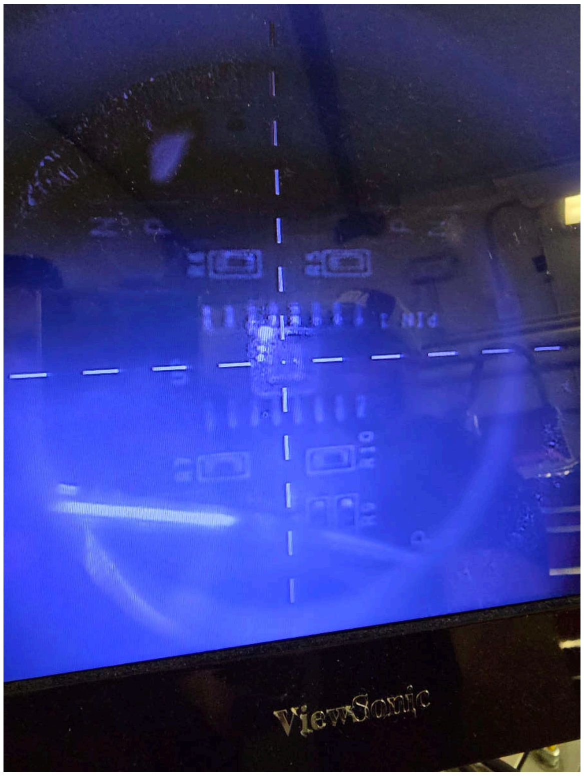

Figure 4-3. SN55LVRA4-SEP Beam Line Setup at TAMU Facility

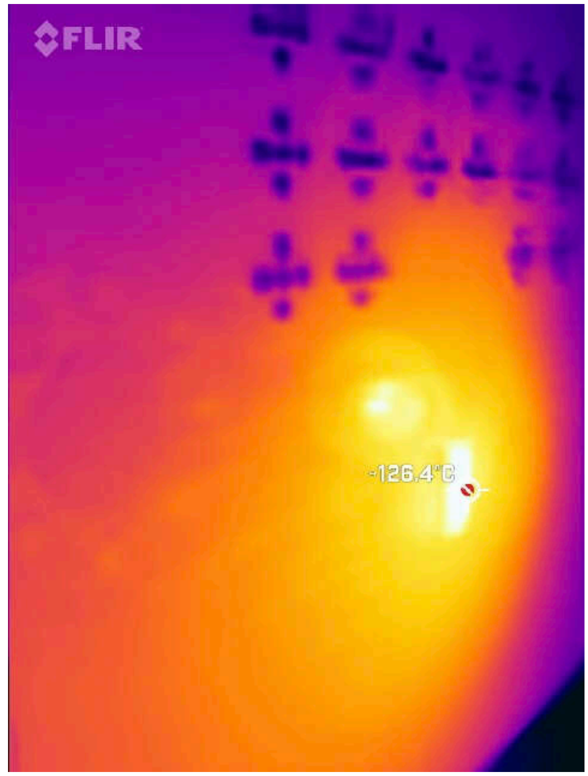

Figure 4-4. SN55LVRA4-SEP Thermal Image for SEL

5 Results

5.1 Single-Event Latch-up (SEL) Results

During SEL characterization, the device was heated using forced hot air, maintaining device temperature at 125°C. A FLIR (FLIR ONE Pro LT) thermal camera was used to validate die temperature to make sure the device was accurately heated (see Figure 4-4.) The species used for SEL testing was a Xenon (^{129}Xe) ion at 25MeV / μ with an angle-of-incidence of 0° for an LET_{EFF} of 50MeV-cm^2/ mg. A fluence of approximately 1 × 10^7 ions / cm^2 was used for each run.

The three devices were powered up and exposed to the heavy-ions using the maximum recommended supply voltage of 3.6V using a National Instruments™ PXI Chassis PXIe-4139 on VCC, 2V on input 1B, 5V on input 1A, -4V on input 2A, -1V input on 2B. A -1.5V to 1.5, 10MHz square wave on input 3A and a 180° phase shifted signal on input 3B using a National Instruments™ PXI Chassis PXIe-5423 function generator. The run duration to achieve this fluence was approximately 100 seconds. As listed in Table 5-1, no SEL events were observed during the eight runs, indicating that the SN55LVRA4-SEP is SEL-free. Figure 5-1, Figure 5-2, and Figure 5-3 show the plots of current versus time for runs one, five, and seven, respectively.

A single unit was tested with a fluence of 1.5E+07 using the same bias condition as above. No SEL events occurred on these runs either.

Table 5-1. Summary of SN55LVRA4-SEP SEL Test Conditions and Results

Run Number	Unit Number	Distance (mm)	Temperature (°C)	Ion	Angle	Flux (ions × cm^2 / mg)	Fluence (Number of ions)	LET_{EFF} (MeV × cm^2/mg)	Did an SEL Event Occur?
1	1	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
2	1	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
3	2	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
4	2	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
5	3	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
6	3	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
7	4	70	125	Xe	0°	1.00E+05	1.50E+07	50	No
8	4	70	125	Xe	0°	1.00E+05	1.50E+07	50	No

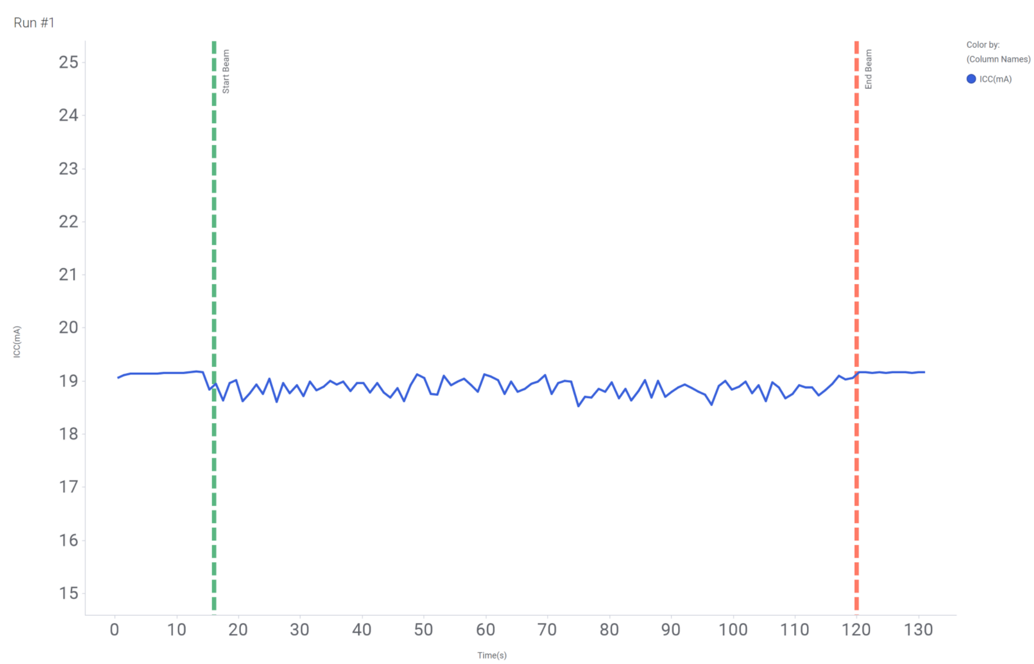

Figure 5-1. Current Versus Time for Run 1 of the SN55LVRA4-SEP at T = 125°C

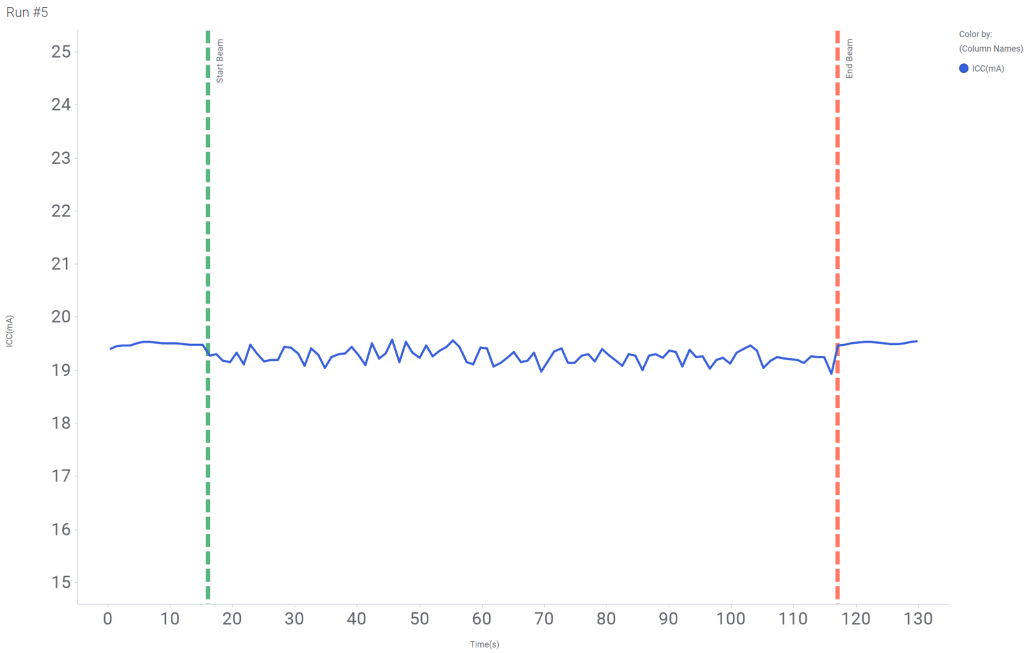

Figure 5-2. Current Versus Time for Run 5 of the SN55LVRA4-SEP at T = 125°C

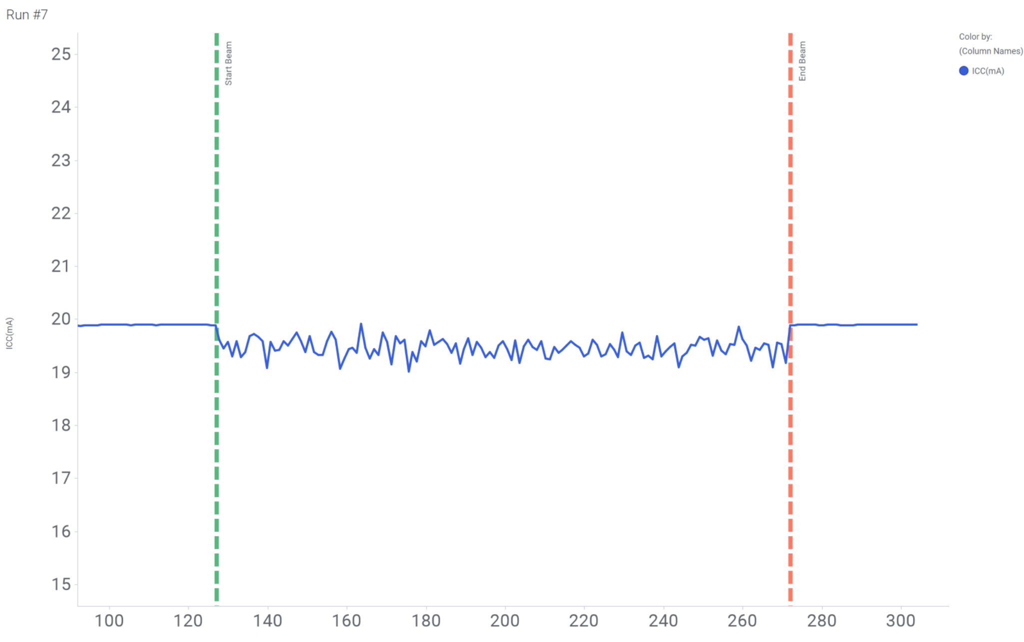

Figure 5-3. Current Versus Time for Run 7 of the SN55LVRA4-SEP at T = 125°C

No SEL events were observed, indicating that the SN55LVRA4-SEP is SEL-immune at LET_{EFF} = 50MeV-cm^2 / mg and T = 125°C. Using the MFTF method shown in Single-Event Effects (SEE) Confidence Internal Calculations , the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{SEL} \leq 6.15 \times 10^{-8} cm^2/\text{device for } LET_{EFF} = 50 \text{ MeV}\cdot cm^2/mg \text{ and } T = 125°C \quad (1)$$

5.2 Single-Event Transients (SET) Results

SETs are defined as heavy-ion-induced transient upsets on output pins 1Y and 4Z of the SN55LVRA4-SEP. SET testing was performed at room temperature (no external temperature control applied). The species used for the SET testing was ^{109}Ag for a LET_{EFF} = 47MeV × cm^2 / mg. Flux of approximately 10^5 ions / cm^2 × s and a fluence of approximately 10^7 ions / cm^2 were used for the SET runs.

Three units were tested across multiple input conditions to determine the worst-case setup for SETs. The unit was tested with V_{CC} of 3V. All combinations of VCC and scope trigger configurations showed no transient upsets, as listed in Table 5-2.

To capture SETs, one NI PXI-5110 scope card was used to continuously monitor the output voltage on pin 2Y, and one PXI-5172 scope card was used to continuously monitor the output voltage on pin 4Y. The scope monitoring the square wave output signal was configured to a rising edge window trigger of ±5%, while the scope monitoring the static output signal was configured to a rising edge voltage trigger of ±5%. The NI scopes were programmed to a sample rate of 100M samples per second (S/s) and recorded 1000 samples, with a 20% pretrigger reference, in case of an event (trigger). The setup was verified for each run to ensure no false triggers was captured before the beam was turned on. The ±5% threshold on the static and square wave outputs was determined to be the lowest threshold capable of not providing false triggers due to noise.

Under heavy-ions, the SN55LVRA4-SEP exhibited transients on both output, 2Y and 4Y. The number of transients on each run are listed in Table 5-2.

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

- Signal Transients:
  - Low Glitch: Signal glitches on a high output. Example shown in Figure 5-4. This example shows the maximum observed duration glitch with a duration of 0.04µs.
  - High Glitch: Signal glitched on a low output. Example shown in Figure 5-5. This example shows the maximum observed duration glitch with a duration of 0.04µs.
  - Stuck High: Signal fails to toggle to low state for one clock cycle. Example shown in Figure 5-6. This example shows the maximum observed duration glitch with a duration of 0.2µs.
  - Struck Low: Signal fails to toggle to high state for one clock cycle. Example shown in Figure 5-7. This example shows the maximum observed duration glitch with a duration of 0.2µs.

Table 5-2. Summary of SN55LVRA4-SEP SET Test Condition and Results

Run Number	Unit Number	Voltage Level	Ion	LET_{EFF} (MeV × cm^2/mg)	FLUX (ions × cm^2/ mg)	Fluence (Number ions)	Voltage Trigger	Window Trigger	SET Upsets (OUT4)	SET Upsets (OUT2)
9	5	3V	Ag	47	1.00E+05	1.00E+07	5%	20%	188	504
10	5	3V	Ag	47	1.00E+05	1.00E+07	5%	5%	164	554
11	5	3.3V	Ag	47	1.00E+05	1.00E+07	5%	5%	117	386

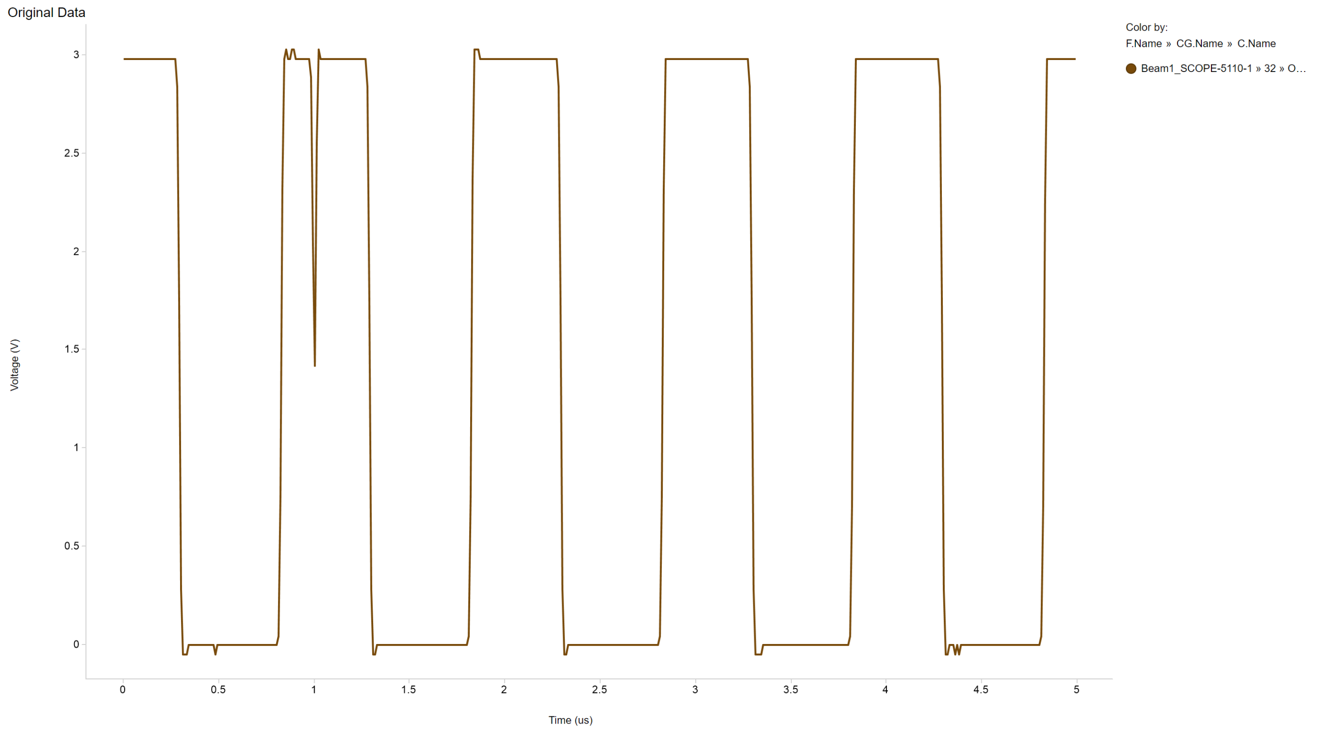

Figure 5-4. Single Event Transient on Dynamic Signal - Low Glitch

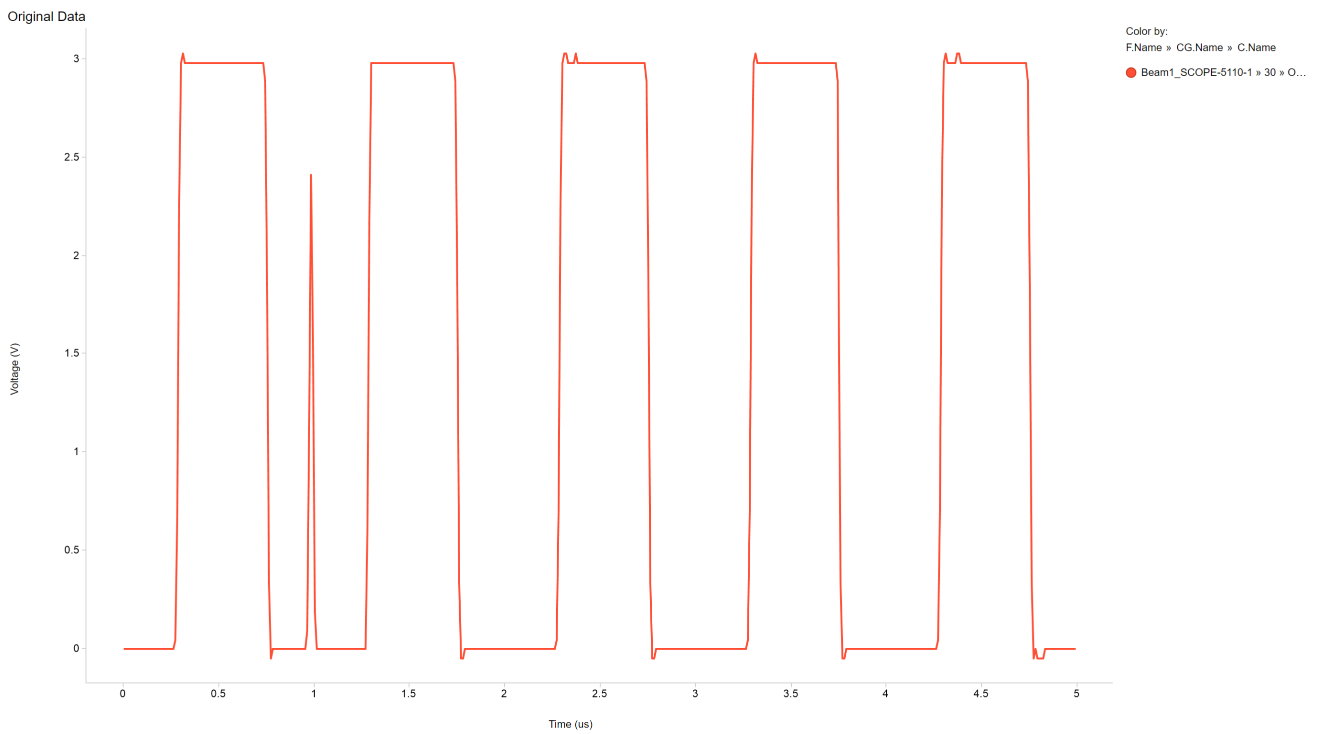

Figure 5-5. Single Event Transient on Dynamic Signal - High Glitch

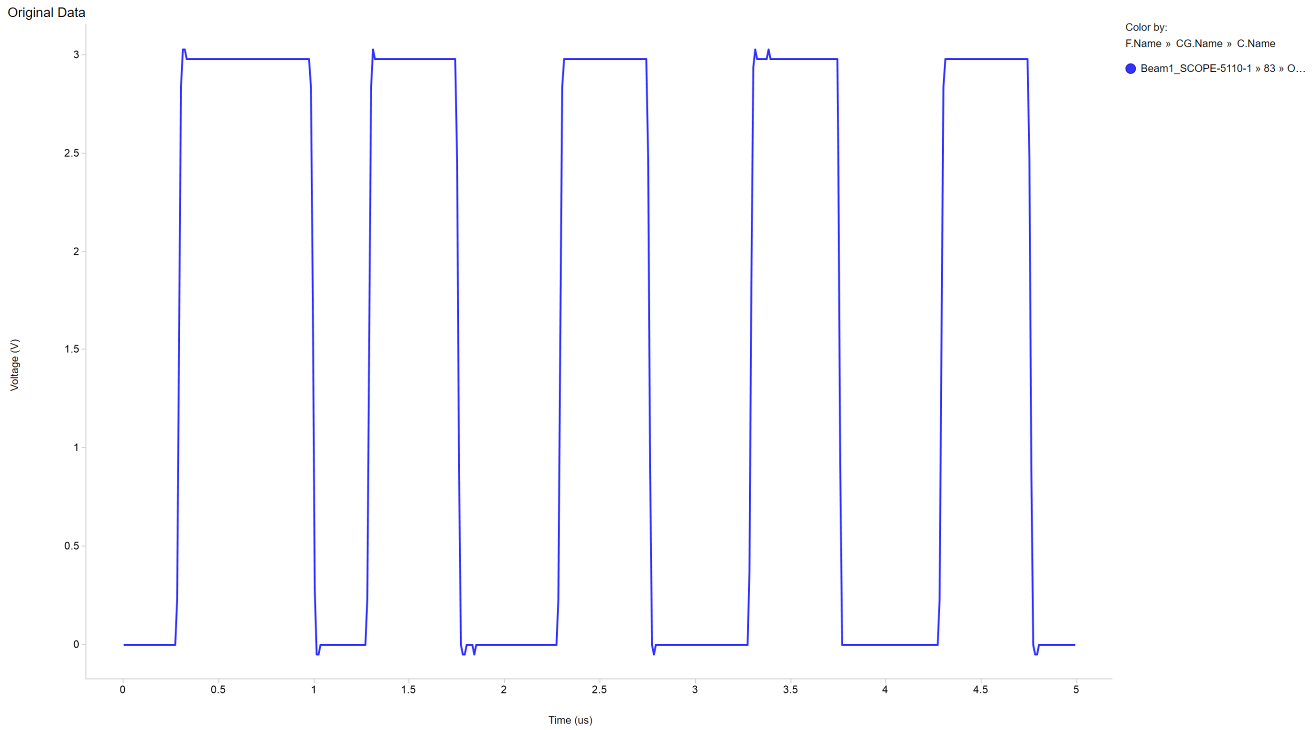

Figure 5-6. Single Event Transient on Dynamic Signal - Signal Stuck High

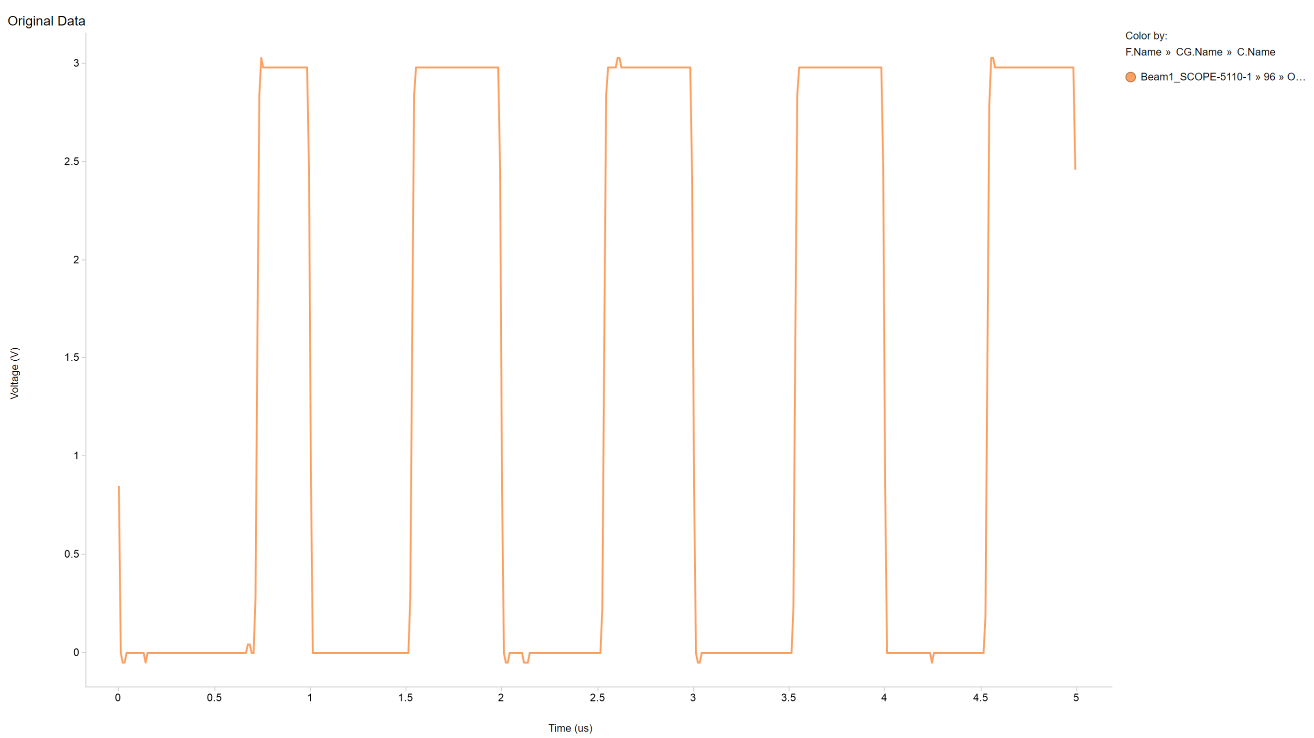

Figure 5-7. Single Event Transient on Dynamic Signal - Signal Stuck Low

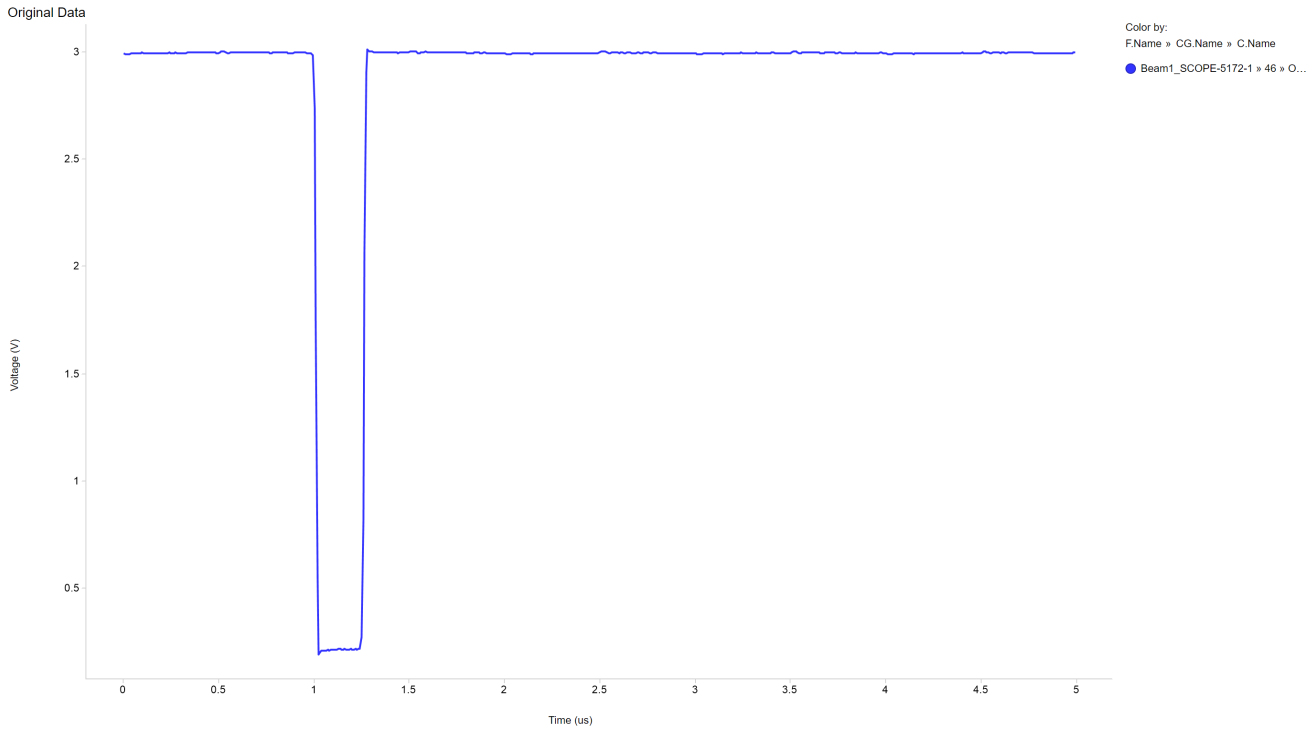

Figure 5-8. Single Event Transient on Static Signal - Low Glitch

Using the MFTF method shown in Single-Event Effects (SEE) Confidence Internal Calculations, the upper-bound cross-section (using a 95% confidence level) for static outputs (OUT4) is calculated as:

$$\sigma_{SET} \leq 7.23 \times 10^{-6} cm^2/\text{device for } LET_{EFF} = 47\ MeV \cdot cm^2/mg \text{ and } T = 25°C \quad (2)$$

Using the MFTF method shown in Single-Event Effects (SEE) Confidence Internal Calculations, the upper-bound cross-section (using a 95% confidence level) for dynamic outputs (OUT2) is calculated as:

$$\sigma_{SET} \leq 2.01 \times 10^{-5} cm^2/\text{device for } LET_{EFF} = 47\ MeV \cdot cm^2/mg \text{ and } T = 25°C \quad (3)$$

6 Summary

The purpose of this study was to characterize the effects of heavy-ion irradiation on the single-event latch-up (SEL) performance of the SN55LVRA4-SEP radiation-tolerant, quad channel differential line receiver. SEE performance was verified at minimum (3V) and maximum (3.6V) operating conditions. Heavy-ions with an LET_{EFF} of 50MeV-cm^2/ mg were used to irradiate four production devices and heavy-ions with an LET_{EFF} of 47MeV-cm^2/ mg were used to irradiate one production device with a fluence of 1×10^7 ions / cm^2. The results demonstrate that the SN55LVRA4-SEP is SEL-free up to LET_{EFF} = 50MeV-cm^2/ mg as 125°C. SET performance for the minimum (3V) and nominal (3.3V) operating voltages saw excursions, as shown and discussed in this report.

7 References

1. M. Shoga and D. Binder, "Theory of Single Event Latchup in Complementary Metal-Oxide Semiconductor Integrated Circuits", *IEEE Trans. Nucl. Sci., Vol. 33(6)*, Dec. 1986, pp. 1714-1717.
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