

INA951-SEP Single-Event Effects (SEE) Radiation Test Report



ABSTRACT

The purpose of this study is to characterize the effects of heavy-ion irradiation on the single-event effect (SEE) performance of the INA951-SEP. Heavy-ions with an LET_{EFF} of up to $45.2\text{MeV}\times\text{cm}^2/\text{mg}$ were used to irradiate the devices with a fluence of $1.5\times 10^7\text{ions}/\text{cm}^2$. The results demonstrate that the INA951-SEP is SEL-free up to $LET_{EFF} = 45.2\text{MeV}\times\text{cm}^2/\text{mg}$ at 125°C , and a dynamic SET cross section is presented.

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1 Introduction

The INA951-SEP is a current sense amplifier that can measure voltage drops across shunt resistors over a wide common-mode range from -4V to 80V . The negative common-mode voltage allows the device to operate below ground, thus accommodating precise measurement of recirculating currents in half-bridge applications. The combination of a low offset voltage, small gain error and high DC CMRR enables highly accurate current measurement. The INA951-SEP is not only designed for DC current measurement but also for high-speed applications, like fast over-current protection, with a high bandwidth of 1.3MHz and an 85dB AC CMRR (at 50kHz).

The INA951-SEP operates from a single 2.7V to 10V supply, drawing 1.5mA of supply current. The INA951-SEP is available with a gain option of 20V/V . The INA951-SEP is specified over an operating temperature range of -55°C to $+125^{\circ}\text{C}$ and is offered in a space-saving 5-pin, SOT-23 package.

The following table lists general device information and test conditions. See the [INA951-SEP product page](#) for more detailed technical specifications, user-guides, and application notes.

Description	Device Information
TI part number	INA951-SEP
VID	V62/26605
Device function	Radiation-tolerant, current-sense amplifier
Technology	LBCSOI2
Exposure facility	Cyclotron Institute, Texas A&M University -- Facility for Rare Isotope Beams (FRIB), Michigan State University
Flux	1.0×10^4 , 1.0×10^5
Heavy ion fluence per run	1.0×10^6 , 1.0×10^7 - 1.5×10^7
Irradiation temperature	25° (for SET testing), 125° (for SEL testing)
Lot number	5640552

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2 Single-Event Effects

The primary single-event effect (SEE) event of interest in the INA951-SEP is the destructive single-event latch-up (SEL). When considering risk and impact, the occurrence of a SEL is potentially the most destructive SEE event and the biggest concern for space applications. In mixed technologies such as the linear BiCMOS (LBCSOI2) process used for INA951-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). 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 INA951-SEP exhibited no SEL with heavy-ions up to a of LET_{EFF} = 45.2 MeV×cm²/mg at a fluence up to 1.5×10^7 ions/cm² and a chip temperature of 125°C.

This study was performed to evaluate the SEL effects with a bias voltage of 10V on V_s. Heavy ions with LET_{EFF} = 45.2MeV×cm²/mg were used to irradiate the devices. Flux of 1×10^5 ions/s-cm² and fluence up to $1.0 - 1.5 \times 10^7$ ions/cm² were used during the exposure at 125°C temperature.

Figure 2-1 shows a functional block diagram for this device.

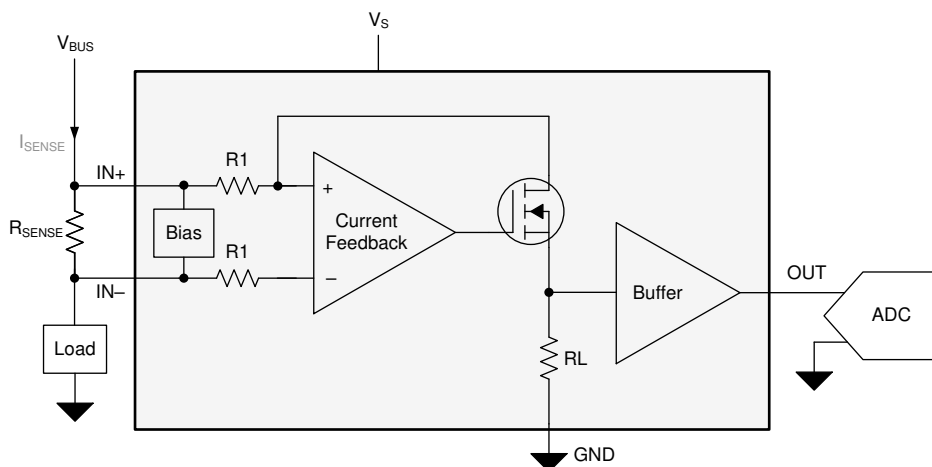


Figure 2-1. Functional Block Diagram of the INA951-SEP

3 Test Device and Test Board Information

The INA951-SEP is packaged in a 5-pin DBV (SOT-23). [Figure 3-1](#) shows the device with the bias board. [Figure 3-4](#) shows the biasing configuration used for both the SEL and SET tests.

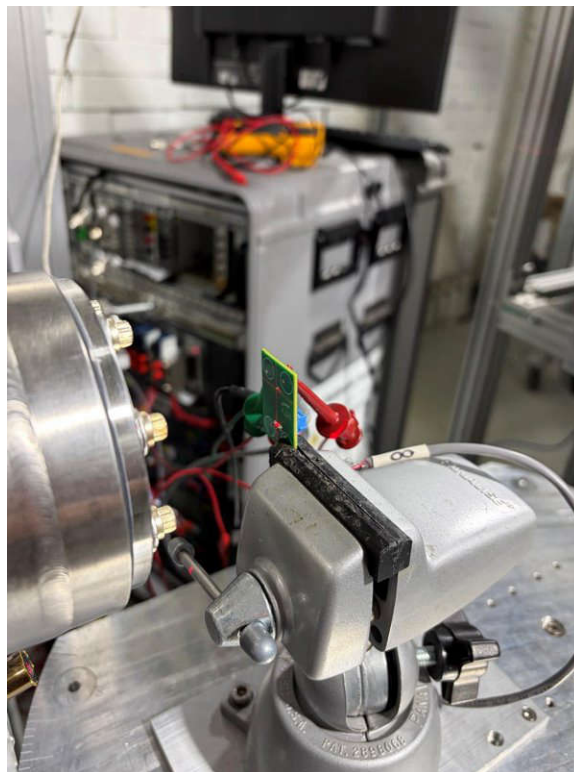


Figure 3-1. INA951-SEP Evaluation Board at MSU Facility for Rare Isotope Beams



Figure 3-2. INA951-SEP Temperature Reading during SEL Testing

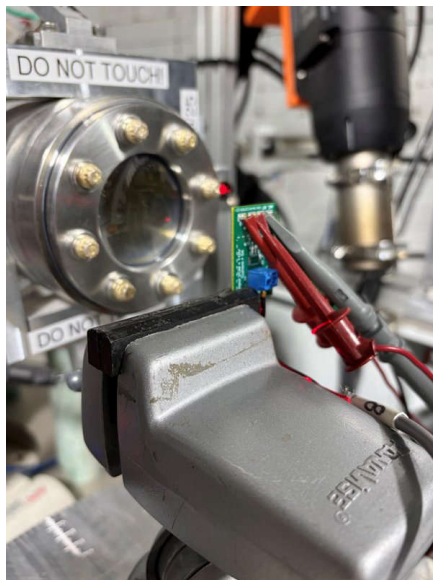


Figure 3-3. INA951-SEP Under Beam at TAMU Cyclotron Radiation Effects Facility

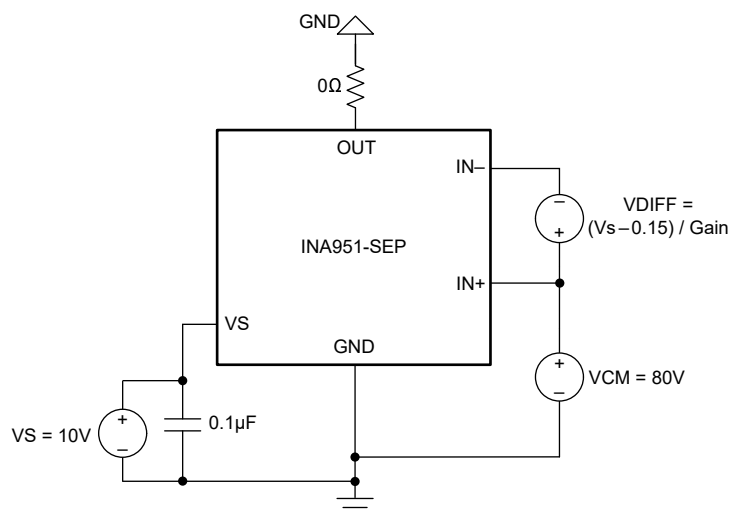


Figure 3-4. INA951-SEP Bias Configuration

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by the MSU Facility for Rare Isotope Beams using a superconducting cyclotron, 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 inch 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 the bulk of these studies, ion fluxes between 1×10^4 and 1×10^5 ions/s-cm² were used to provide heavy ion fluences between 1×10^6 and $1 - 1.5 \times 10^7$ ions/cm². For these experiments, Silver (Ag) ions were used.

5 Test Setup and Procedures

Three input supplies powers the INA951-SEP which provides V_S , $IN+$ and $IN-$. The V_S for the device was provided by an NI-PXIe-4137 SMU and ranged from 2.7V to 5.5V for SET and 10V for SEL. The input voltage $IN+$ and $IN-$ for the device was provided by a National Instruments (NI) PXIe-4139 / 4137 SMU and ranged from $-4V$ to 80V depending on the type of test. The last supply was a differential voltage provided by an floating NI-PXIe-4139 SMU and ranged from 0.1375V to 0.5925V.

The primary signal monitored on the EVM was V_{OUT} . A NI PXIe-5172 scope card monitors the V_{OUT} signal and triggers on a 10% window based on the nominal value of V_{OUT} . All SEL, and SET testing used these conditions.

A custom-developed LabVIEW™ program (PXI-RadTest) running on a HP™-Z4 desktop computer monitors and controls all equipment. The computer communicates with the PXI chassis through an MXI controller and NI PXIe-8381 remote control module.

Table 5-1 shows the connections, limits, and compliance values used during the testing. Figure 5-1 shows a block diagram of the setup used for SEE testing of the INA951-SEP.

Table 5-1. Equipment Settings and Parameters Used During the SEE Testing of the INA951-SEP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
$IN+$	NI-PXIe 4139	$\pm 60V$, 3A	3A	0.1375V, 0.2675V
$IN-$	NI-PXIe 4137-2	$\pm 200V$, 1A	1A	-4 to 80V
V_S	NI-PXIe 4137-1	$\pm 200V$, 1A	1A	2.7V to 12V
V_{OUT}	NI-PXIe-5172	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 *TAMU & MSU*. During the heavy-ion testing, the LabVIEW control program powers up the INA951-SEP device and sets the external sourcing and monitoring functions of the external equipment. After confirming functionality and stability, the beam shutter was opened to expose the device to the heavy-ion beam. The shutter remained open until the target fluence was achieved as determined by external detectors and counters. During irradiation, the NI scope cards continuously monitored the signals. When the output exceeded the pre-defined 10% window trigger, a data capture was initiated. No sudden increases in current were observed outside of normal fluctuations on any of the test runs, indicating that no SEL events occurred during any of the tests.

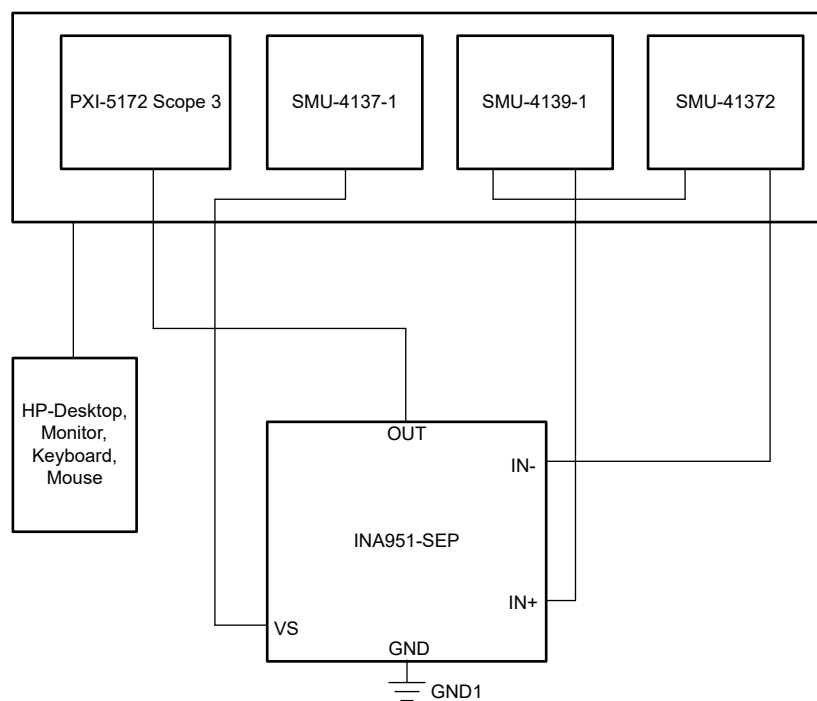


Figure 5-1. Block Diagram of the SEE Test Setup for the INA951-SEP

6 Destructive Single-Event-Effects (DSEE)

6.1 Single-Event Latch-Up Results

During SEL characterization, the device was heated using forced hot air, maintaining the device temperature at 125°C. The temperature was monitored by means of a K-type thermocouple attached as close to the device as possible and FLIR thermal image detector. The species used for SEL testing was a Silver (Ag) ion with an angle-of-incidence of 0° for an LETeff = 45.2MeV×cm²/mg. A flux of approximately 1.0 × 10⁵ions/s-cm² and a fluence of approximately 1.0 - 1.5 × 10⁷ions/cm were used for the runs. The external voltage with the highest recommended voltage of 10V is applied onboard Vs connector. The run duration to achieve this fluence was approximately two minutes. [Table 5-1](#) shows that no SEL events were observed during these runs. [Figure 5-1](#) shows the current plot versus time during beam exposure. All SEL data was collected from MSU.

Unit	Run #	Distance (mm)	Temperature (°C)	Ion	Angle	Flux	Fluence (# of ions)	LETeff (MeV)	Vs (V)	V _{CM} (V)	V _{DIFF} (V)
11	1	45	125	Ag	0	1.00 × 10 ⁵	1.50 × 10 ⁷	45.2	10	80	0.4925
11	3	45	125	Ag	0	1.00 × 10 ⁵	1.50 × 10 ⁷	45.2	10	-4	0.4925
12	4	45	125	Ag	0	1.00 × 10 ⁵	1.50 × 10 ⁷	45.2	10	80	0.4925
12	5	45	125	Ag	0	1.00 × 10 ⁵	1.50 × 10 ⁷	45.2	10	-4	0.4925
1	4	45	125	Ag	0	1.00 × 10 ⁵	1.00 × 10 ⁷	45.2	10	80	0.4925
2	6	45	125	Ag	0	1.00 × 10 ⁵	1.00 × 10 ⁷	45.2	10	80	0.4925
3	7	45	125	Ag	0	1.00 × 10 ⁵	1.00 × 10 ⁷	45.2	10	80	0.4925

7 Single Event Transient Results

SETs are defined as heavy-ion-induced transients upsets on VOUT of the INA951-SEP. SET testing was performed at room temperature with no external temperature control applied. VOUT SETs were characterized using a window trigger $\pm 10\%$ of the output voltage of 1.35V and 2.75V.

To capture the SETs, a NI-PXI-5172 scope card was used to continuously monitor VOUT directly from the evaluation board. The scope was programmed to record 5k samples with a sample rate of 1M samples per second (S/s) in case of an event (trigger).

The species used for the SET testing was a Silver (Ag), Krypton (Kr), Cobalt (Co) and Argon (Ar) with an angle-of-incident of 0° for an LETeff of 48.1, 29.2, 16.3 and 7.9MeV-cm²/mg respectively. Flux of approximately 10^4 ions/cm²×s and a fluence of approximately 10^6 ions/cm² were used for all runs of SET testing. For SET data collection, all but 1 runs were collected from MSU. Run 5 was collected from TAMU.

Table 7-1. INA951-SEP SET Conditions Using Ag, Kr, Co and Ar at an Angle-of-Incidence of 0°

Unit	Run Number	Facility	Distance (mm)	Temperature (°C)	Ion	Angle	Flux (Ions × cm ² / mg)	Fluence (Number of Ions)	LETeff (MeV × cm ² / mg)	Number of Events	Cross Section	Vs (V)	V _{CM} (V)	V _{DIFF} (V)	V _{OUT} (V)
13	12	MSU	74	25	Ag	0	1.00×10^4	1.00×10^6	48.1	243	2.43×10^4	2.7	48	0.0675	1.35
13	13	MSU	74	25	Ag	0	1.00×10^4	1.00×10^6	48.1	87	8.7×10^5	5.5	48	0.1375	2.75
14	14	MSU	74	25	Ag	0	1.00×10^4	1.00×10^6	48.1	167	1.67×10^4	2.7	48	0.0675	1.35
14	15	MSU	74	25	Ag	0	1.00×10^4	1.00×10^6	48.1	46	4.6×10^5	5.5	48	0.1375	2.75
14	16	MSU	74	25	Kr	0	1.00×10^4	1.00×10^6	29.2	121	1.21×10^4	2.7	48	0.0675	1.35
14	17	MSU	74	25	Kr	0	1.00×10^4	1.00×10^6	29.2	23	2.3×10^5	5.5	48	0.1375	2.75
13	18	MSU	74	25	Kr	0	1.00×10^4	1.00×10^6	29.2	208	2.08×10^4	2.7	48	0.0675	1.35
13	5	TAMU	40	25	Kr	0	1.00×10^4	1.00×10^6	30	79	8.9×10^5	5.5	48	0.1375	2.75
13	23	MSU	74	25	Co	0	1.00×10^4	1.00×10^6	16.3	139	1.39×10^4	2.7	48	0.0675	1.35
13	24	MSU	74	25	Co	0	1.00×10^4	1.00×10^6	16.3	36	3.6×10^5	5.5	48	0.1375	2.75
14	25	MSU	74	25	Co	0	1.00×10^4	1.00×10^6	16.3	122	1.22×10^4	2.7	48	0.0675	1.35
14	26	MSU	74	25	Co	0	1.00×10^4	1.00×10^6	16.3	41	4.1×10^5	5.5	48	0.1375	2.75
14	27	MSU	74	25	Ar	0	1.00×10^4	1.00×10^6	7.9	72	7.20×10^4	2.7	48	0.0675	1.35
14	28	MSU	74	25	Ar	0	1.00×10^4	1.00×10^6	7.9	7	7.0×10^6	5.5	48	0.1375	2.75
13	30	MSU	74	25	Ar	0	1.00×10^4	1.00×10^6	7.9	27	2.70×10^5	2.7	48	0.0675	1.35
13	312.7	MSU	74	25	Ar	0	1.00×10^4	1.00×10^6	7.9	0	0	5.5	48	0.1375	2.75

No SEL events were observed, indicating that the INA951-SEP is SEL-immune at LETeff = 45.2MeV cm²/mg and T = 125°C. Equation 1 calculates the upper-bound cross section (using a 95% confidence level) using the MFTF method and combining the fluences of the three runs at 125°C.

$$\sigma_{\text{SEL}} \leq 1.84 \times 10^{-7} \text{ cm}^2 \quad (1)$$

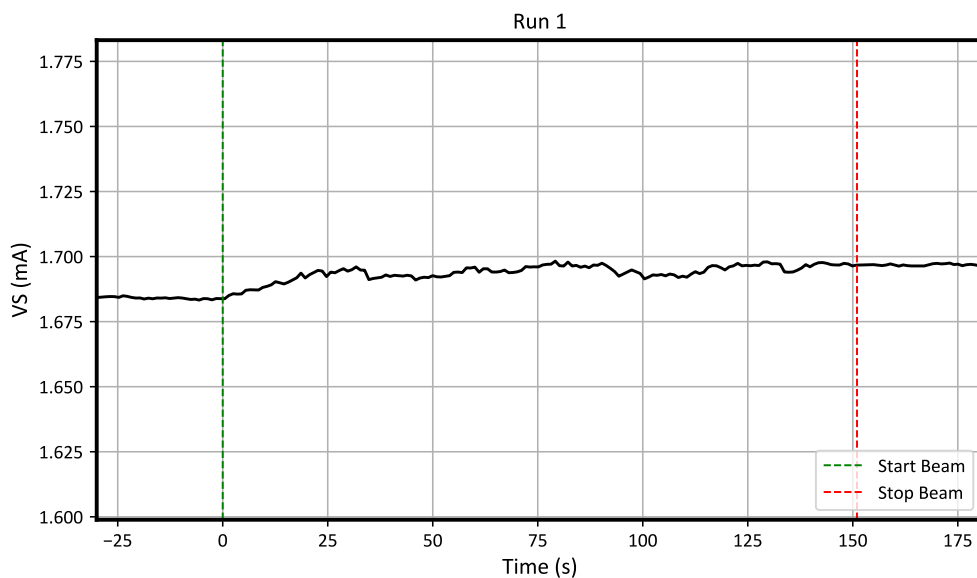


Figure 7-1. Current vs Time (I vs T) Data for V_S Current During SEL Run 1

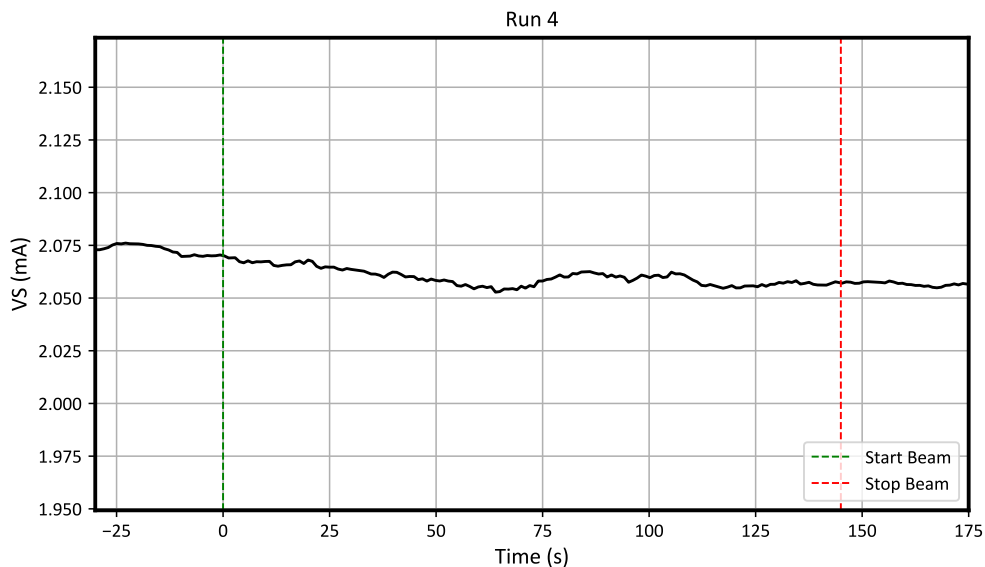


Figure 7-2. Current vs Time (I vs T) Data for V_S Current During SEL Run 4

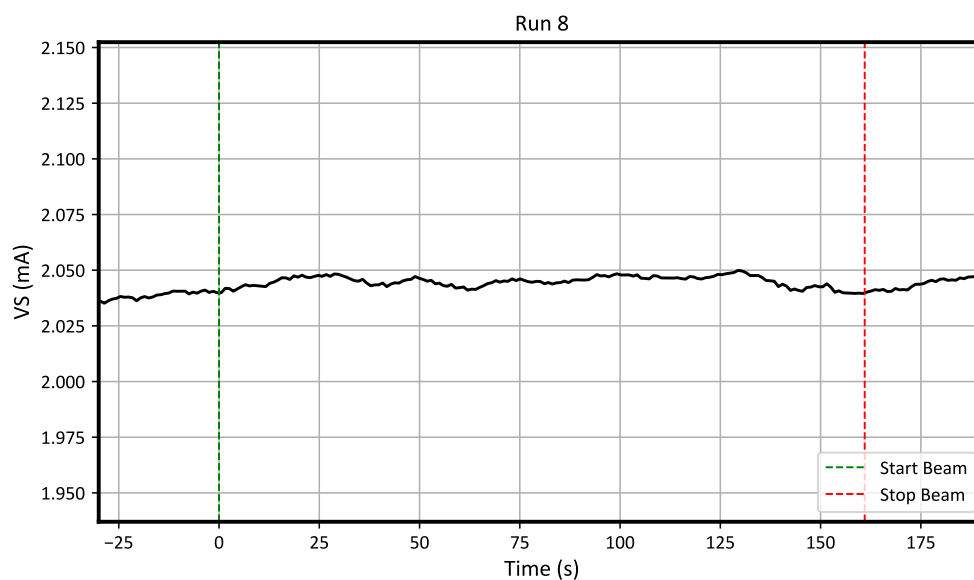


Figure 7-3. Current vs Time (I vs T) Data for V_S Current During SEL Run 8

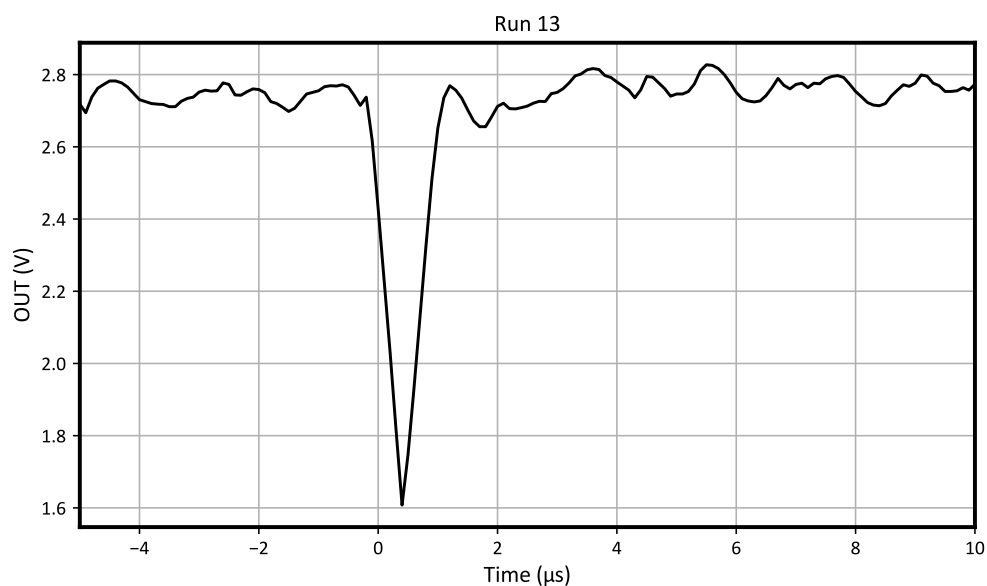


Figure 7-4. Largest Observed V_{out} Transient, SET Run 13, Upset 12

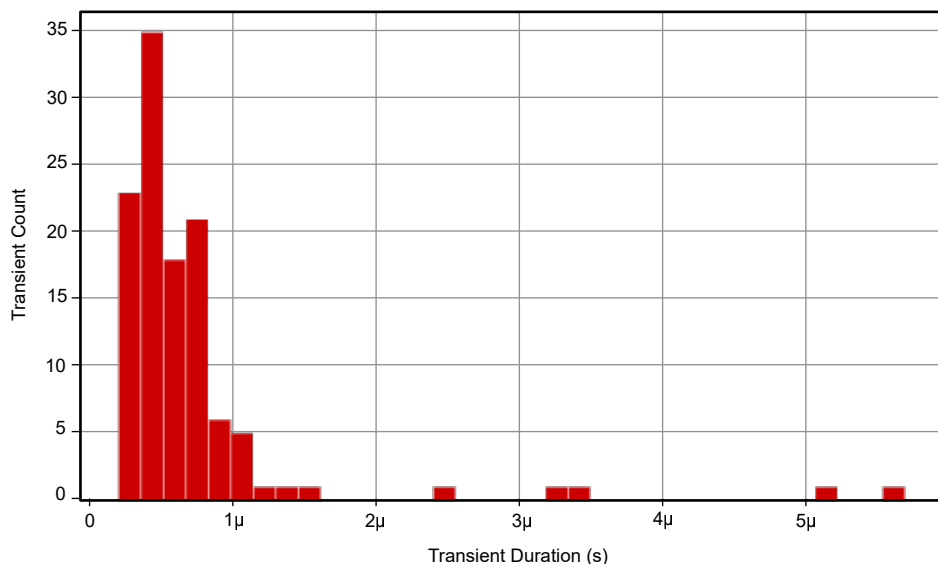


Figure 7-5. Transient Duration Histogram, $V_S = 5.5V$, $V_{CM} = 48V$, $V_{DIFF} = 0.2675V$

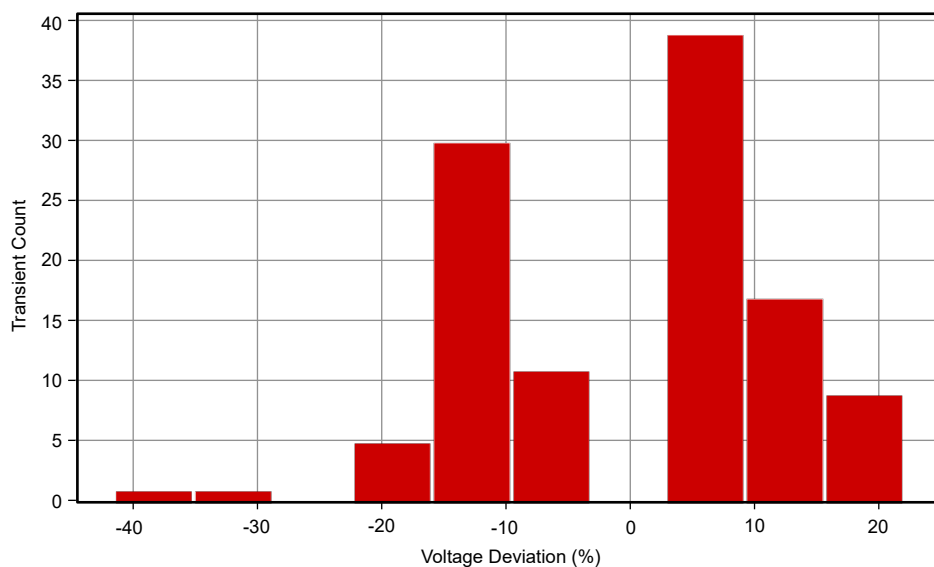


Figure 7-6. Transient Voltage Deviation Histogram, $V_S = 5.5V$, $V_{CM} = 48V$, $V_{DIFF} = 0.2675V$

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 note. 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). [Table 8-1](#) and [Table 8-2](#) shows the SET orbit rate for $V_s = 2.7V$ and $V_s = 5.5V$.

Table 8-1. SET ($V_{IN} = 2.7V$) 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)	7.9	55.13	3.93×10^{-5}	2.17×10^{-3}	2.17×10^4	1.26
GEO		465.65		1.83×10^{-2}	7.62×10^5	0.14

Table 8-2. SET ($V_{IN} = 5.5V$) 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)	7.9	55.13	3.68×10^{-6}	2.03×10^{-4}	8.48×10^3	13.46
GEO		465.65		1.72×10^{-3}	7.16×10^{-4}	1.59

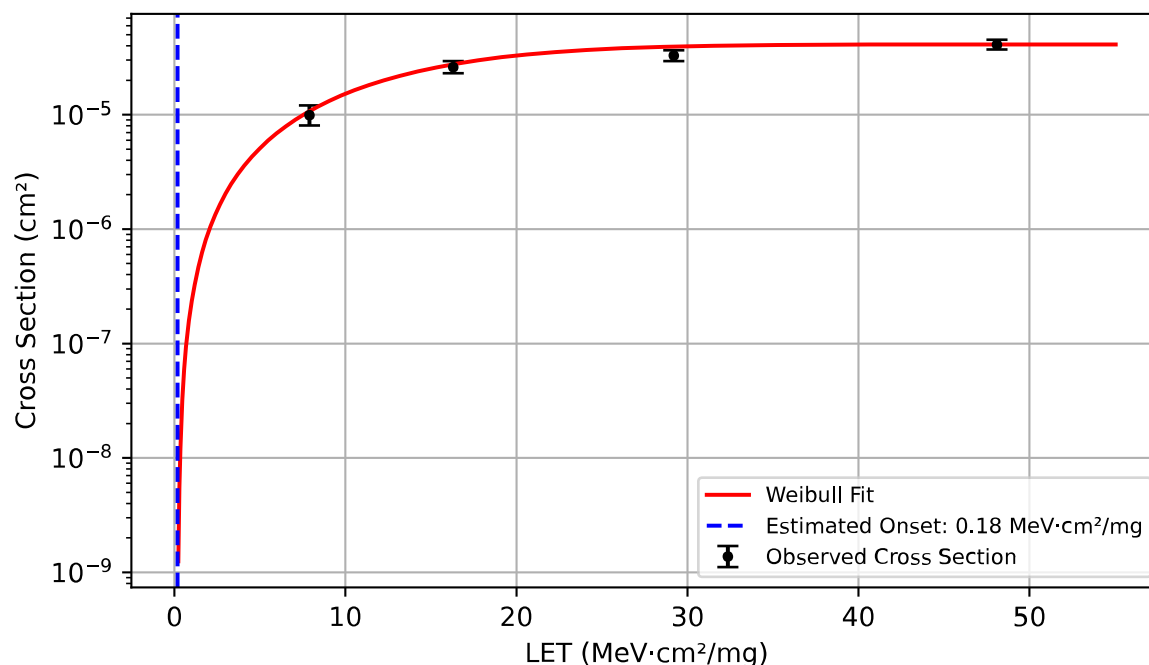


Figure 8-1. Weibull Fit $V_s = 2.7V$ SET

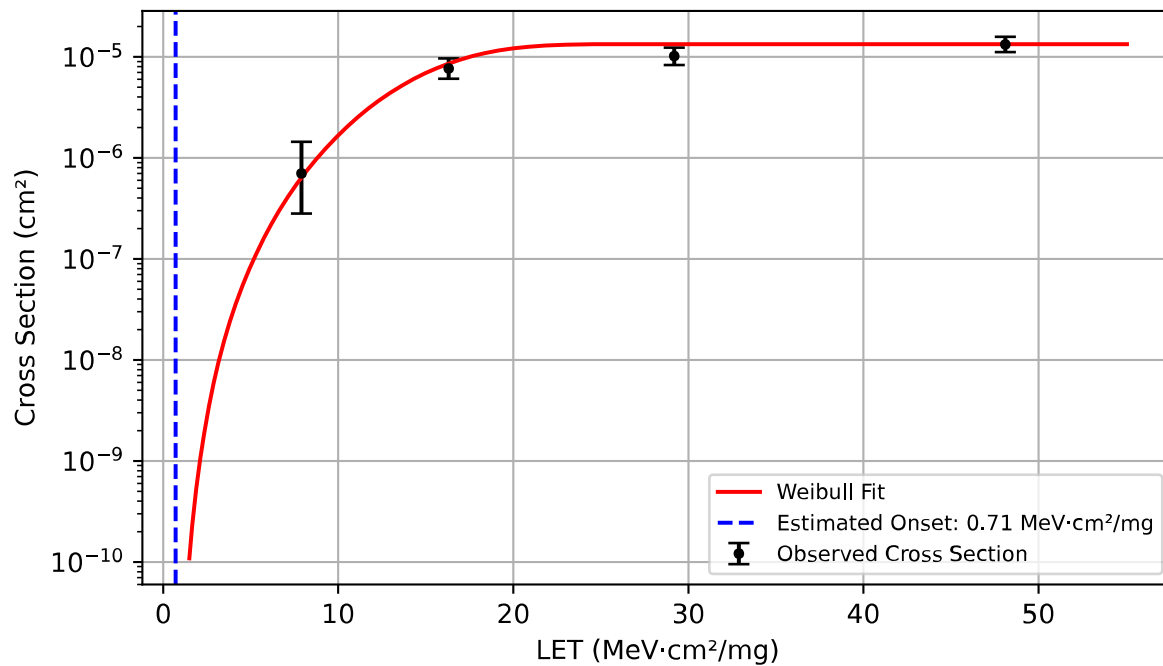


Figure 8-2. Weibull Fit $V_S = 5.5V$ SET

9 Summary

Radiation effects on the radiation-tolerant, ultra-precise, current sense amplifier INA951-SEP, was studied.

10 References

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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 * (June 2026) to Revision A (August 2026)	Page
• Updated VID number in Introduction section.....	2

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