Radiation Report

INA950-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 latch-up (SEL) performance of the INA950-SEP, an ultra-precise, current-sense amplifier. Heavy-ions with an LETEFF of 50.4MeV × cm^2 / mg were used to irradiate two production devices with a fluence of 1× 107 ions/cm2 and three production device with a fluence of 1 × 107 ions/cm^2 . The results demonstrate that the INA950-SEP is SEL-free up to LETEFF = 50.4MeV × cm^2 / mg at 125°C.

1 Overview

The INA950-SEP is a radiation-tolerant, single channel, ultra-precise, current-sense amplifier that can operate from a single 2.7V to 20V supply and consumes just 370µA. The INA950-SEP is a high-side only current-sense amplifier that offers a wide common-mode range, precision zero-drift topology, excellent common-mode rejection ratio (CMRR), high bandwidth, and a fast slew rate. The INA950-SEP is designed using a transconductance architecture with a current-feedback amplifier that enables low bias currents of 20µA and a common-mode voltage of 80V.

See the INA950-SEP product page on ti.com for more details.

Description	Device Information
TI Part Number	INA950-SEP
VID	V62/25635
Device Function	Radiation-tolerant, ultra-precise, 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	9148035

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2 SEE Mechanisms

The primary single-event effect (SEE) event of interest in the INA950-SEP is the destructive single-event latch-up (SEL). From a risk and impact point-of-view, 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 BiCMOS (LBCSOI2) process used for INA950 -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 process modifications applied for SEL-mitigation were sufficient as the INA950-SEP exhibited no SEL with heavy-ions up to a of LETEFF = 50.4MeV× cm^2 / mg at a fluence up to 1.0 × 10^7 ions / cm^2 and a chip temperature of 125°C.

This study was performed to evaluate the SEL effects with a bias voltage of 5.5V on Vs. Heavy ions with LETEFF = 50.4MeV × cm^2 / mg were used to irradiate the devices. Flux of 1 × 10^5 ions / s-cm^2 and fluence up to 1.0 × 10^7 ions / cm^2were used during the exposure at 125°C temperature.

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

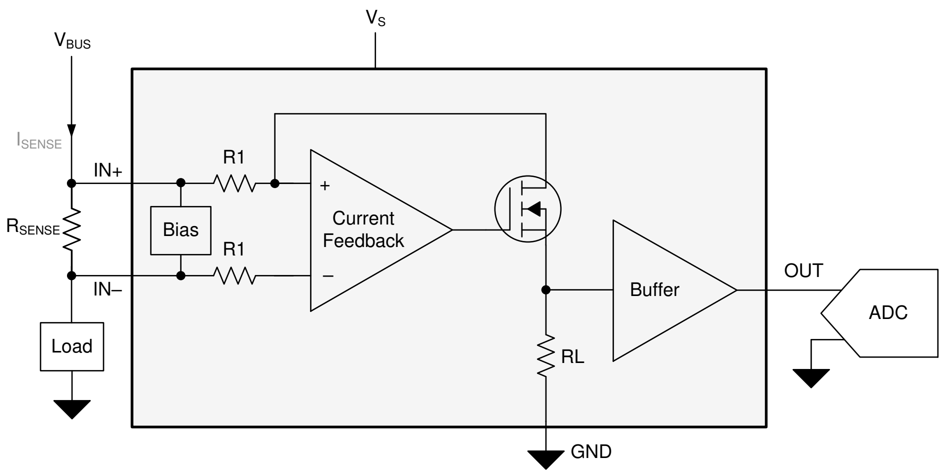

Figure 2-1. Functional Block Diagram of the INA950-SEP

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3 Test Device and Test Board Information

The INA950-SEP is packaged in a 8-pin PW (TSSOP) shown with the bias board in Figure 3-1 . Figure 3-4 shows the biasing configuration used for both the SEL and SET tests.

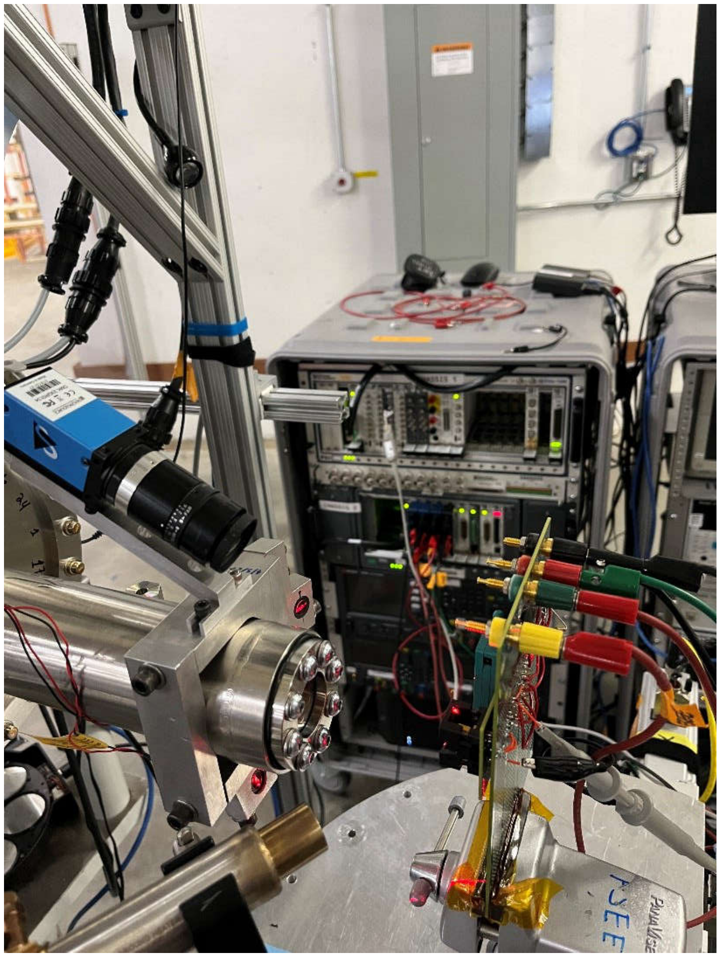

Figure 3-1. INA950-SEP Evaluation Board at MSU Facility for Rare Isotope Beams

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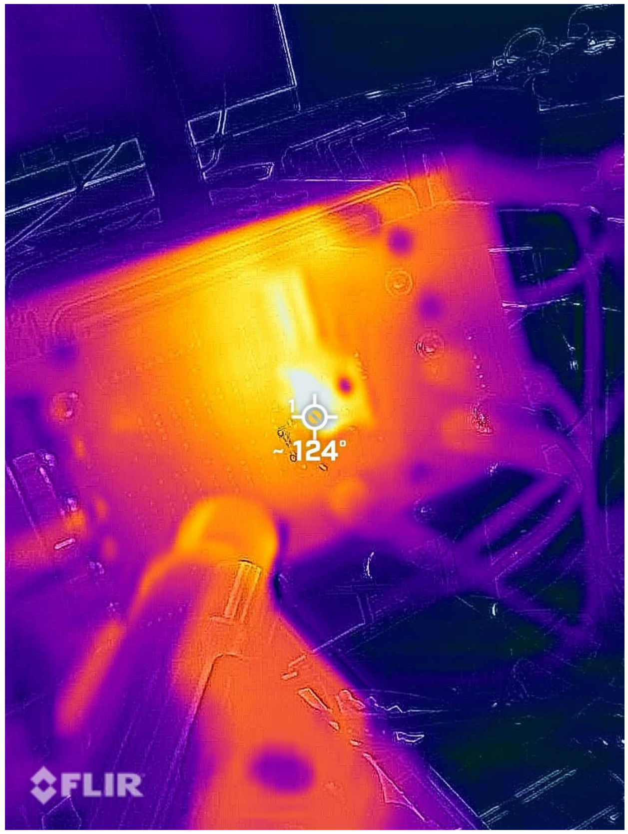

Figure 3-2. INA950-SEP Temperature Reading during SEL Testing

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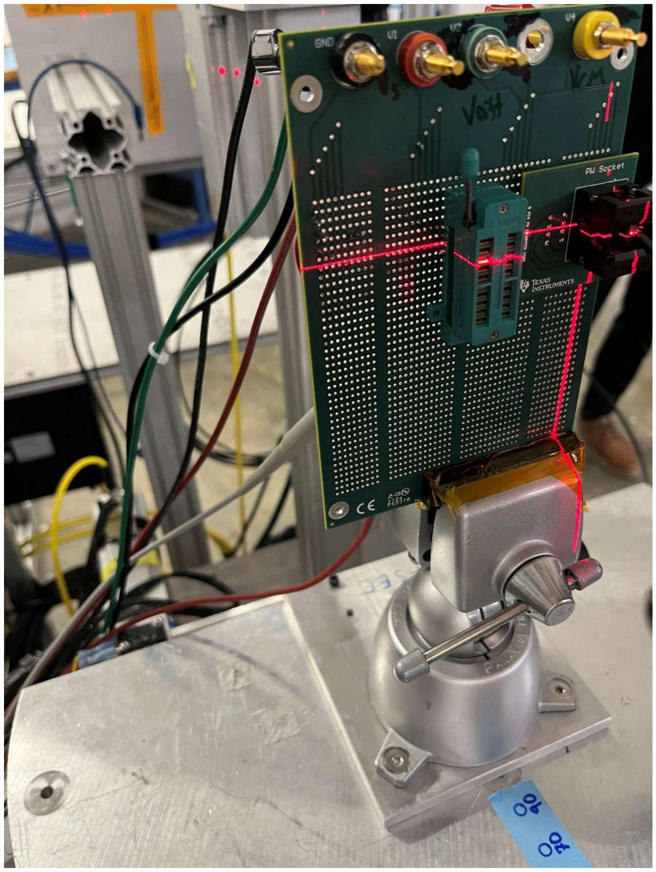

Figure 3-3. INA950-SEP Under Beam at TAMU Cyclotron Radiation Effects Facility

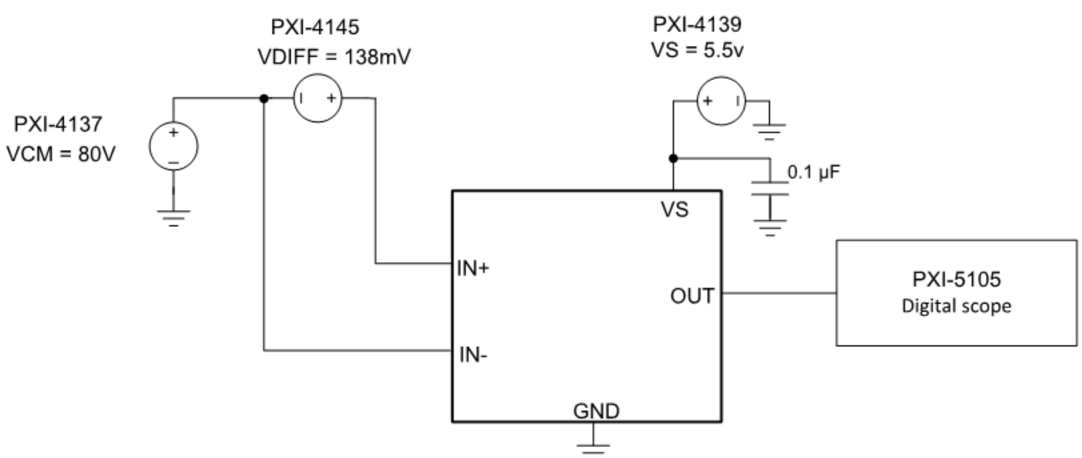

Figure 3-4. INA950-SEP Bias Configuration

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4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by the TAMU Cyclotron Radiation Effects Facility and MSU Facility for Rare Isotope Beams using a superconducting cyclotron, an advanced electron cyclotron resonance (ECR) ion source and a high-power superconducting linear accelerator (LINAC). 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 the bulk of these studies, ion fluxes between 1E4 and 1E5 ions/s-cm2 were used to provide heavy ion fluences between 1E6 and 1E7 ions / cm^2 . For these experiments Xenon (Xe) ions were used. Ion beam uniformity for all tests was in the range of 97% to 99%.

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5 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. The species used for SEL testing was a Xenon (Xe) ion with an angle-of-incidence of 0° for an LETEFF = 50.4 MeV × cm2 / mg. A flux of approximately 105 ion s/ s-cm^{2}and a fluence of approximately 107 ions / cm were used for three runs. The external voltage with the highest recommended voltage of 5.5V is applied onboard VA connector. The run duration to achieve this fluence was approximately two minutes. As listed in Table 5-1, no SEL events were observed during these three runs. Figure 5-1 shows the current plot versus time during beam exposure.

Unit	Run #	Distance (mm)	Temperature (°C)	Ion	Angle	Flux	Fluence (# of ions)	LETeff (MeV)	Vs (V)	Vcm (V)	Vdiff(V)
1	38	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	80	0.1375
1	39	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	48	0.1375
1	40	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	12	0.1375
1	41	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	5	0.1375
1	42	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	-20	0.1375
2	43	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	80	0.1375
2	44	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	48	0.1375
2	45	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	12	0.1375
2	46	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	5	0.1375
2	47	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	-20	0.1375
3	48	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	80	0.1375
3	49	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	48	0.1375
3	50	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	12	0.1375
3	51	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	5	0.1375
3	52	70	125	Xe	0	1.00E+05	1.00E+07	50.4	5.5	-20	0.1375

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6 Single Event Transient Results

SETs are defined as heavy-ion-induced transients upsets on VOUT of the INA950-SEP. SET testing was performed at room temperature (no external temperature control applied). VOUT SETs were characterized using a window trigger ±10% of the output voltage of 1.65V.

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 10k samples with a sample rate of 2M samples per second (S/s) in case of an event (trigger).

The species used for the SET testing was a Silver (Ag), a Krypton (Kr) and a Copper (Cu) with an angle-of-incident of 0° for an LETEFF of 47.5, 30.1, and 20.5MeV-cm^2/ mg respectively. Flux of approximately 10^4 ions / cm^2× s and a fluence of approximately 10^6 ions / cm^{2}were used for all runs of SET testing.

Table 6-1. INA950-SEP SET Conditions Using Ag, Kr, Cu at an Angle of-Incidence of 0°

Unit	Run Number	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)	Vdiff (V)	Vout (V)
18	8	40	25	Ag	0	1.00E+05	1.00E+07	47.5	195	2.24E-05	3.3	80	0.0825	1.62
18	9	40	25	Ag	0	1.00E+05	1.00E+07	47.5	214	2.45E-05	3.3	48	0.0825	1.62
18	11	40	25	Ag	0	1.00E+05	1.00E+07	47.5	179	2.07E-05	3.3	12	0.0825	1.62
18	12	40	25	Ag	0	1.00E+05	1.00E+07	47.5	170	1.98E-05	3.3	5	0.0825	1.62
18	13	40	25	Ag	0	1.00E+05	1.00E+07	47.5	170	1.98E-05	3.3	3.3	0.0825	1.62
18	49	40	25	Kr	0	1.00E+05	1.00E+07	30.1	56	7.27E-06	3.3	80	0.0825	1.61
18	50	40	25	Kr	0	1.00E+05	1.00E+07	30.1	61	7.84E-06	3.3	48	0.0825	1.63
18	51	40	25	Kr	0	1.00E+05	1.00E+07	30.1	46	6.14E-06	3.3	5	0.0825	1.63
18	52	40	25	Cu	0	1.00E+05	1.00E+07	20.5	50	6.59E-06	3.3	80	0.0825	1.62
18	53	40	25	Cu	0	1.00E+05	1.00E+07	20.5	49	6.48E-06	3.3	48	0.0825	1.63
18	54	40	25	Cu	0	1.00E+05	1.00E+07	20.5	47	6.25E-06	3.3	5	0.0825	1.62

No SEL events were observed, indicating that the INA950-SEP is SEL-immune at LETEFF = 50.4 MeV × cm^2 / mg and T = 125°C. Using the MFTF method shown in Section 8 and combining (or summing) the fluences of the three runs at 125°C , the upper-bound cross section (using a 95% confidence level) is calculated in Equation 1

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

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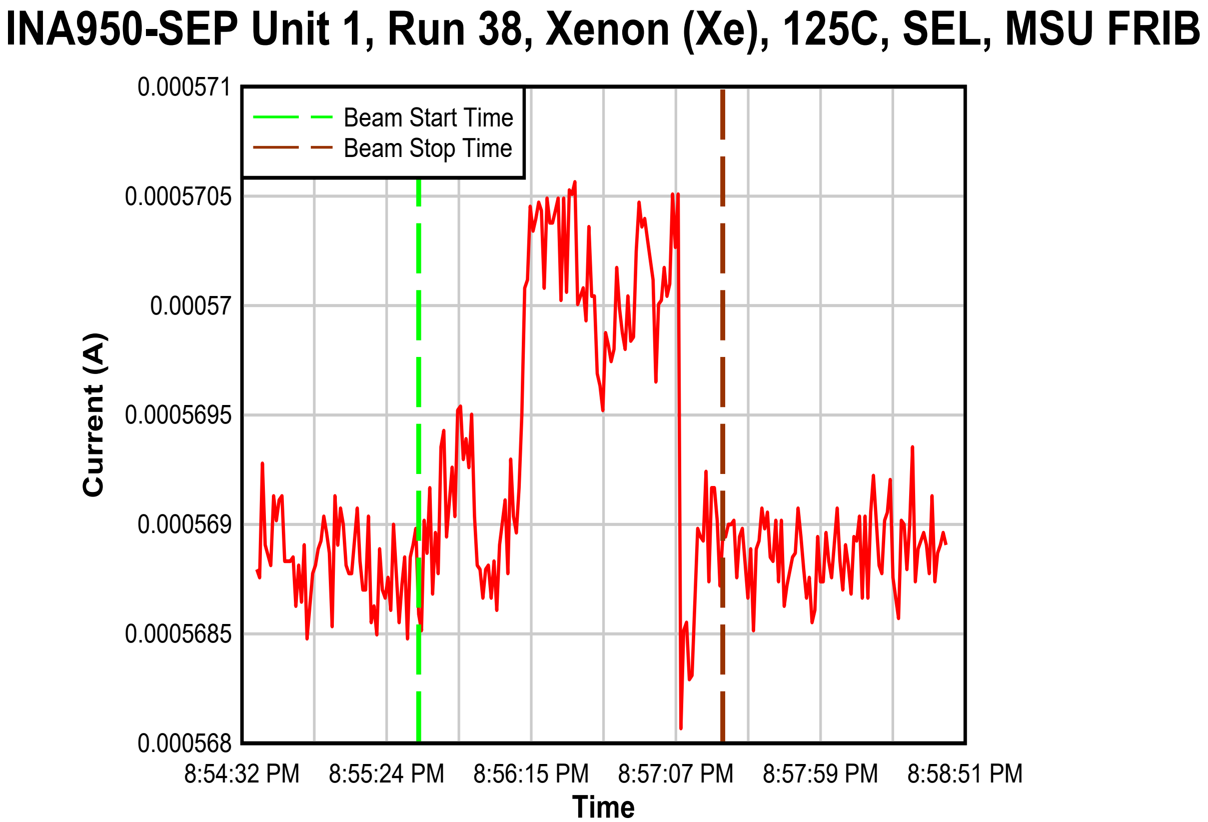

Figure 6-1. Current vs Time (I vs T) Data for VS Current During SEL Run 38

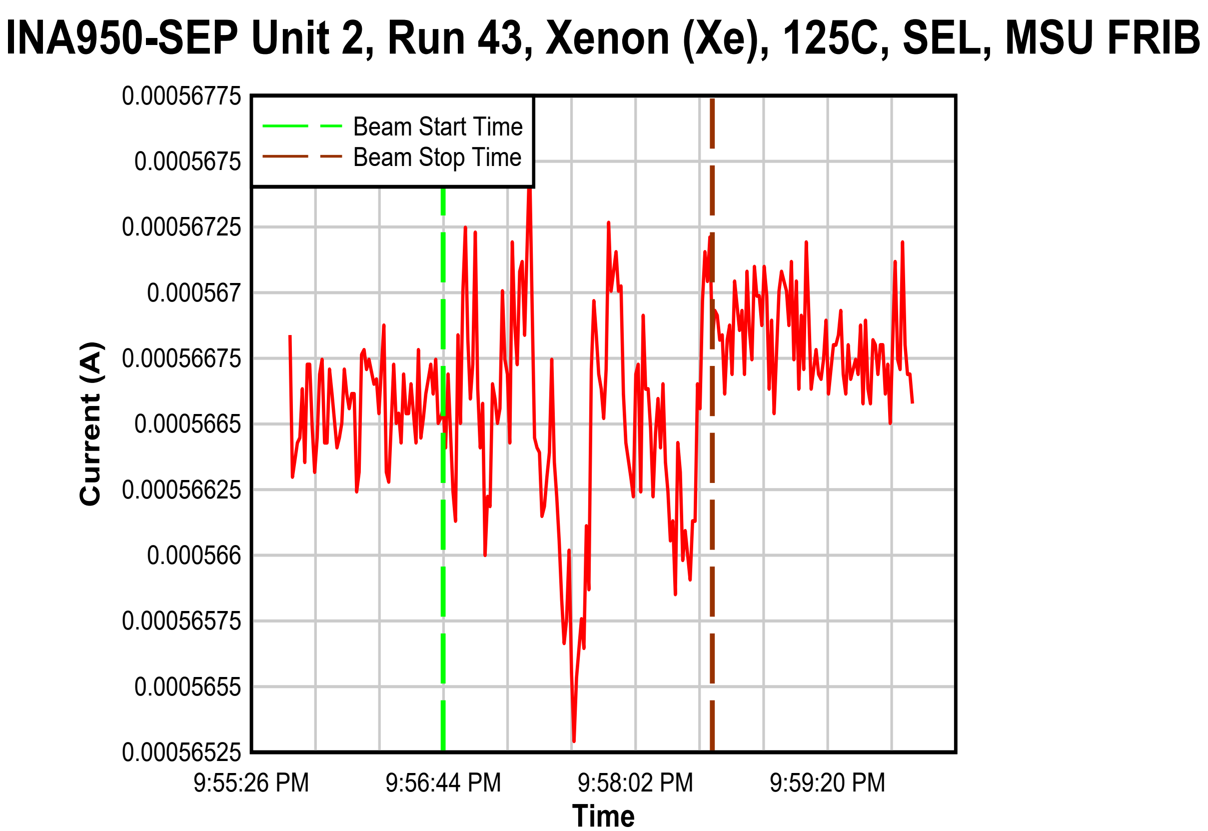

Figure 6-2. Current vs Time (I vs T) Data for VS Current During SEL Run 43

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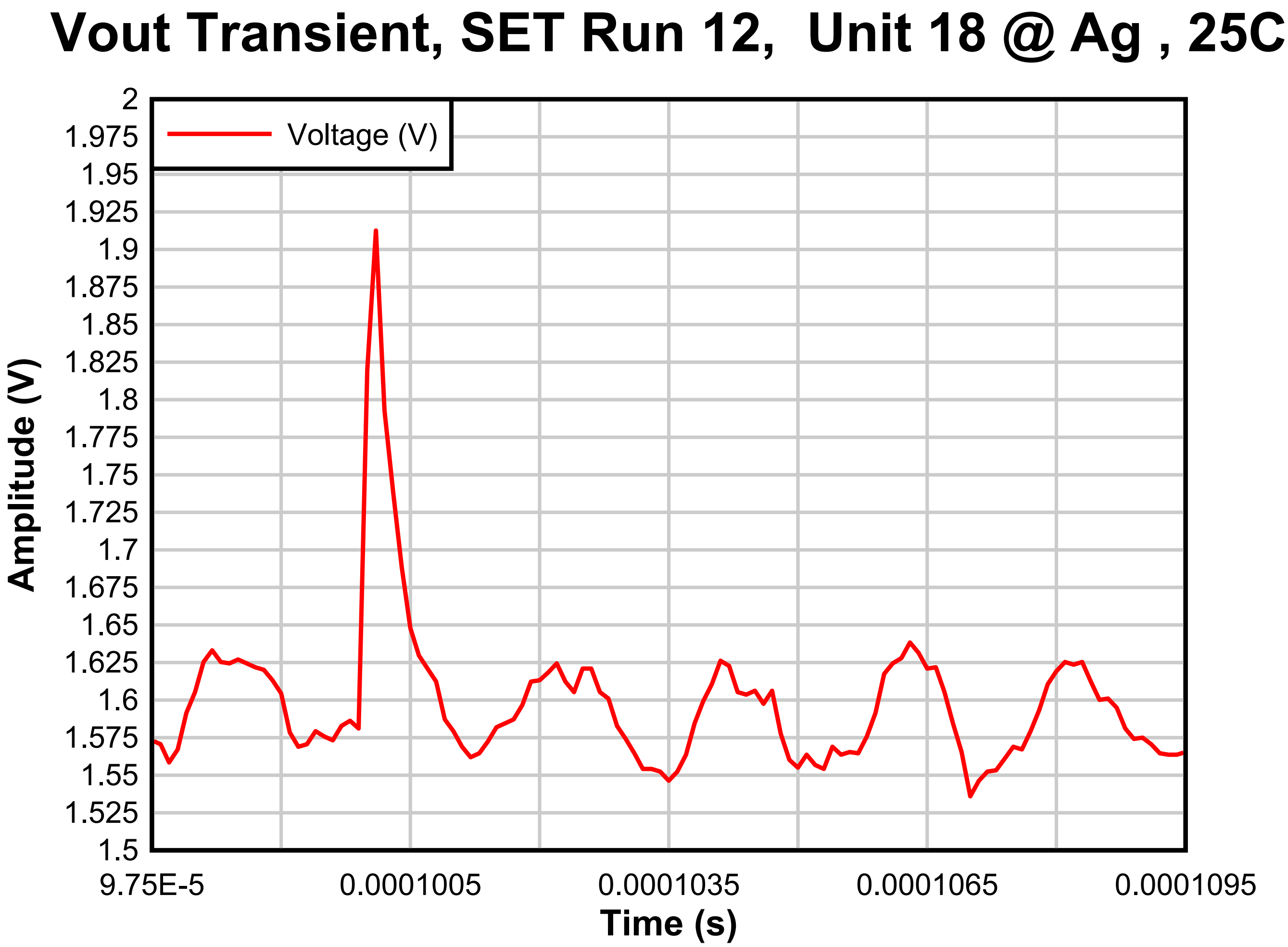

Figure 6-3. SET Plot

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7 Summary

Radiation effects on the radiation-tolerant, ultra-precise, current sense amplifier INA950-SEP, was studied. This device passed a total dose rate of up to 30krad(Si).

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8 Confidence Interval Calculations

For conventional products where hundreds of failures can occur during a single exposure, the average failure rate of devices can be determined by being tested in a heavy-ion beam as a function of fluence with a high degree of certainty and reasonably tight standard deviation, and thus obtain a good deal of confidence that the calculated cross section is accurate. With radiation-hardened parts however, determining the cross section is difficult because often few or no failures are observed during an entire exposure. Determining the cross section using an average failure rate with standard deviation is no longer a viable option, and the common practice of assuming a single error occurred at the conclusion of a null-result can end up in a greatly underestimated cross section. In cases where observed failures are rare or non-existent, using confidence intervals and the chi-squared distribution is indicated. The chi-squared distribution is particularly well-suited for the determination of a reliability level when the failures occur at a constant rate. In the case of SEE testing where the ion events are random in time and position within the irradiation area, a failure rate is expected that is independent of time (presuming that parametric shifts induced by the total ionizing dose do not affect the failure rate), and thus the use of chi-squared statistical techniques is valid (because events are rare, an exponential or Poisson distribution is usually used). In a typical SEE experiment, the device-under-test (DUT) is exposed to a known, fixed fluence (ions / cm^2) and the DUT is monitored for failures. This process is analogous to fixed-time reliability testing and, more specifically, time-terminated testing where the reliability test is terminated after a fixed amount of time whether or not a failure has occurred (in the case of SEE tests fluence is substituted for time and is therefore a fixed fluence test [5]). Calculating a confidence interval specifically provides a range of values that is likely to contain the parameter of interest (the actual number of failures per fluence). Confidence intervals are constructed at a specific confidence level. For example, a 95% confidence level implies that if a given number of units were sampled numerous times and a confidence interval estimated for each test, the resulting set of confidence intervals brackets the true population parameter in approximately 95% of the cases. To estimate the cross section from a null-result (no fails observed for a given fluence) with a confidence interval, start with the standard reliability determination of the lower-bound (minimum) mean-time-to-failure for fixed-time testing (an exponential distribution is assumed) in Equation 2:

$$MFTF = \frac{2nF}{\chi^2_{2(d+1);100\left(1-\frac{\alpha}{2}\right)}} \tag{2}$$

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9 References

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