Radiation Report

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 45.2MeV×cm^2/mg were used to irradiate the devices with a fluence of 1.5×10^{7}ions/cm^2. The results demonstrate that the INA951-SEP is SEL-free up to LET_{EFF} = 45.2MeV×cm^2/mg at 125°C, and a dynamic SET cross section is presented.

Table of Contents

Trademarks

LabVIEW™ is a trademark of National Instruments Corporation.
All trademarks are the property of their respective owners.

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°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	V62/25635
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

TI may provide technical, applications or design advice, quality characterization, and reliability data or service, providing these items shall not expand or otherwise affect TI's warranties as set forth in the Texas Instruments Incorporated Standard Terms and Conditions of Sale for Semiconductor Products and no obligation or liability shall arise from Semiconductor Products and no obligation or liability shall arise from TI's provision of such items.

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 process modifications applied for SEL-mitigation were sufficient as the INA951-SEP exhibited no SEL with heavy-ions up to a of LETEFF = 45.2 MeV×cm^2/mg at a fluence up to 1.5 × 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 10V on V_s. Heavy ions with LETEFF = 45.2MeV×cm^2/mg were used to irradiate the devices. Flux of 1 × 10^{5}ions/s-cm^2 and fluence up to 1.0 - 1.5 × 10^{7}ions/cm^{2}were used during the exposure at 125°C temperature.

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

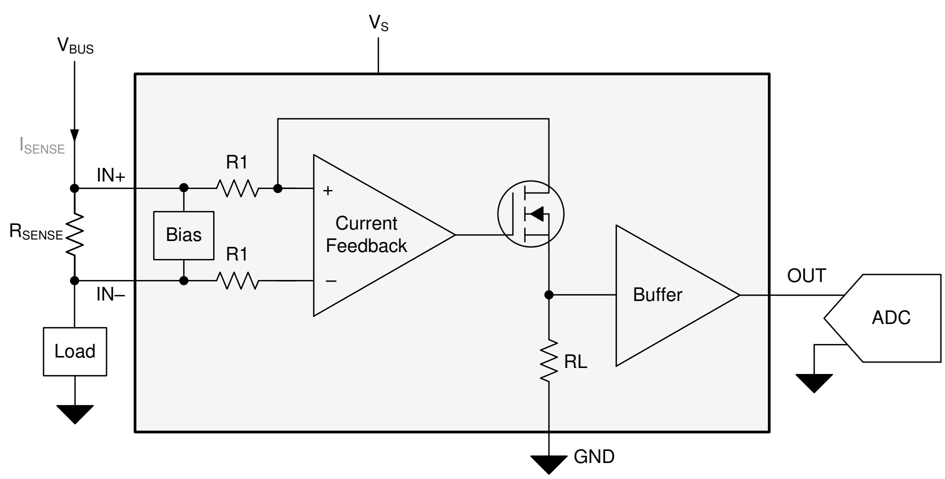

Figure 2-1. Functional Block Diagram of the INA951-SEP

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.

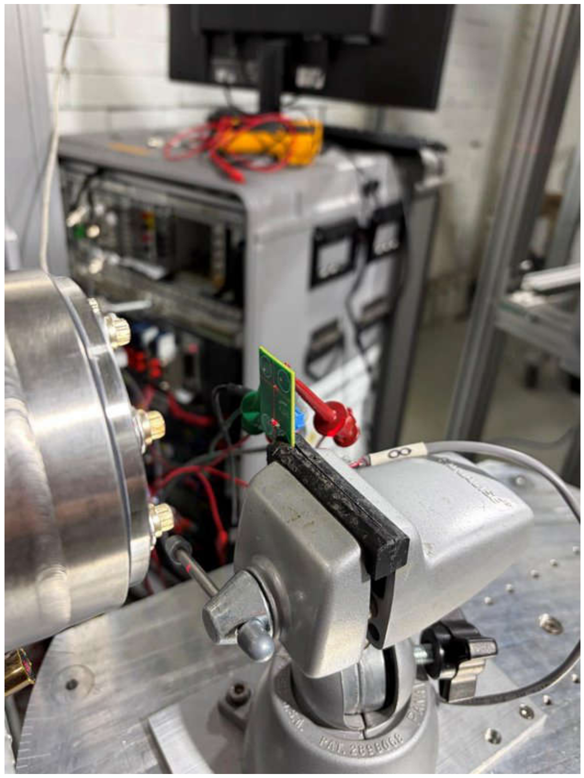

Figure 3-1. INA951-SEP Evaluation Board at MSU Facility for Rare Isotope Beams

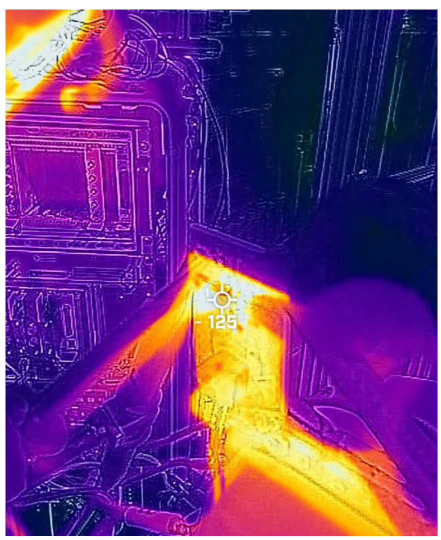

Figure 3-2. INA951-SEP Temperature Reading during SEL Testing

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

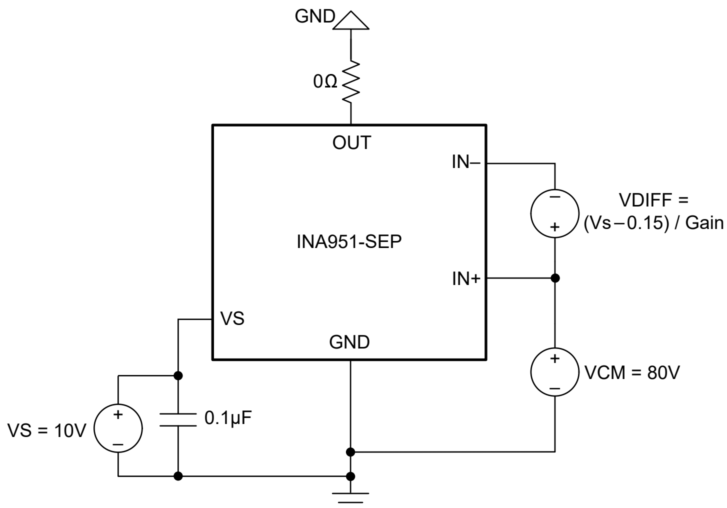

Figure 3-4. INA951-SEP Bias Configuration

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 1×10^5ions/s-cm^2 were used to provide heavy ion fluences between 1×10^6 and 1 - 1.5×10^7ions/cm^2. 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 VOUT. 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	±60V, 3A	3A	0.1375V, 0.2675V
IN-	NI-PXIe 4137-2	±200V, 1A	1A	–4to 80V
Vs	NI-PXIe 4137-1	±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.

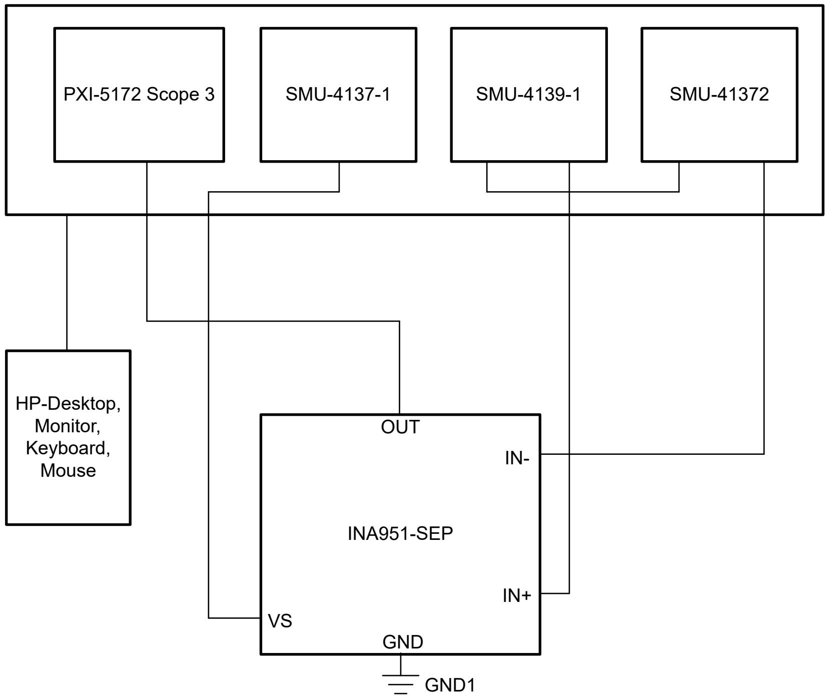

Figure 5-1. Block Diagram of the SEE Test Setup for the INA951-SEP

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×cm^2/mg. A flux of approximately 1.0 × 10^{5}ions/s-cm^{2}and a fluence of approximately 1.0 - 1.5 × 10^{7}ions/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 ±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-cm^2/mg respectively. Flux of approximately 10^4ions/cm^2×s and a fluence of approximately 10^6ions/cm^2 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 cm^2/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.

$$\sigma SEL \leq 1.84 \times 10^{-7} cm^2 \tag{1}$$

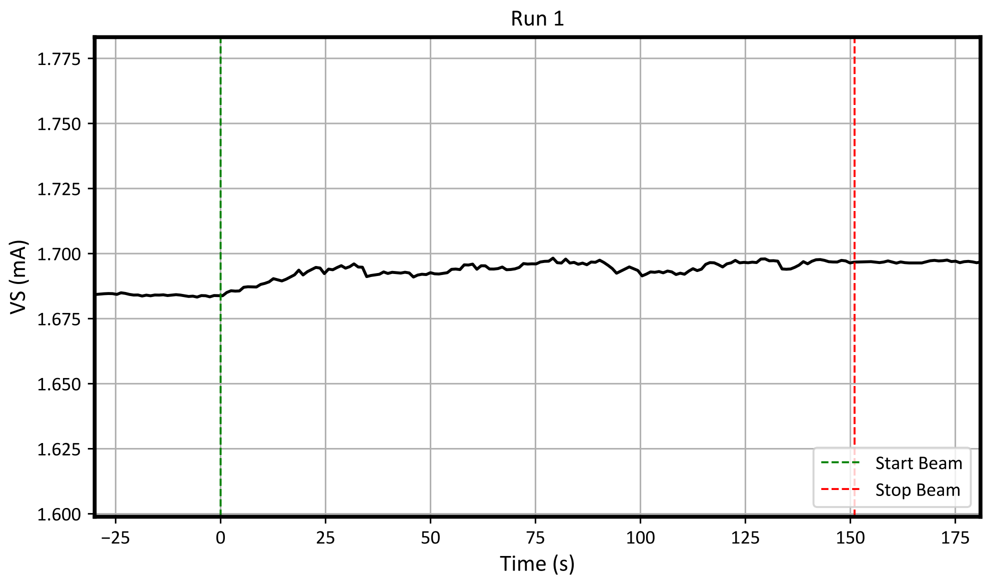

Figure 7-1. Current vs Time (I vs T) Data for V_S Current During SEL Run 1

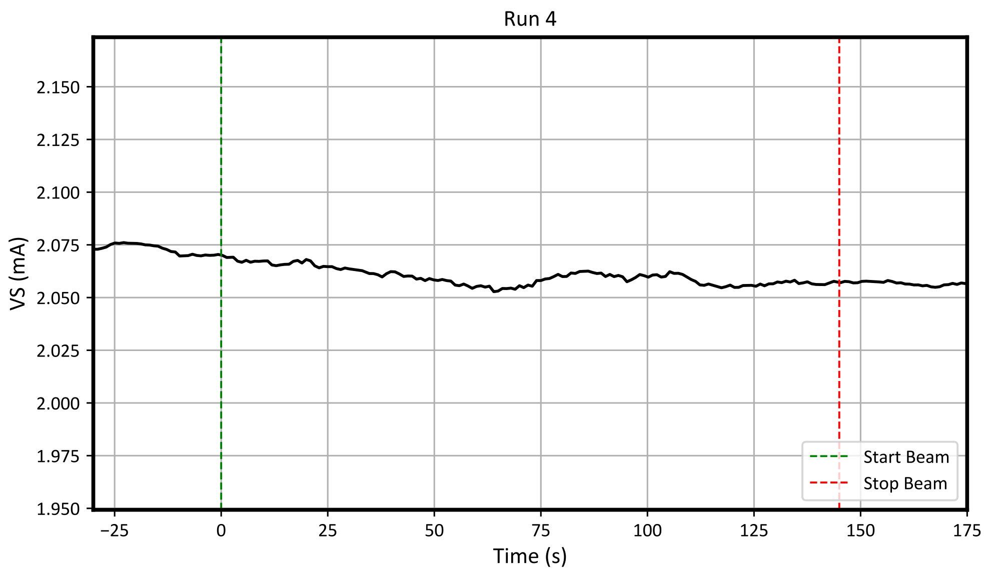

Figure 7-2. Current vs Time (I vs T) Data for V_S Current During SEL Run 4

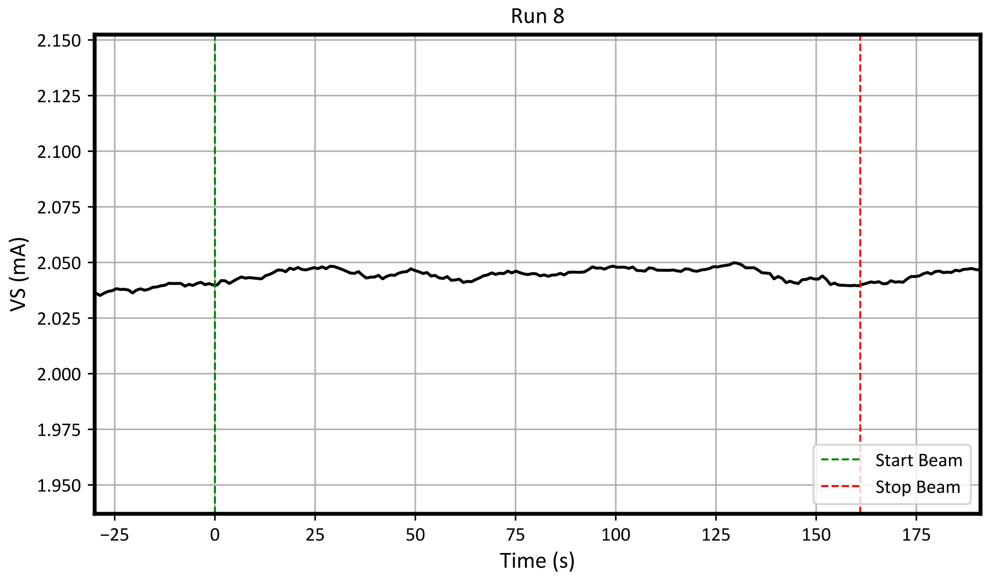

Figure 7-3. Current vs Time (I vs T) Data for V_S Current During SEL Run 8

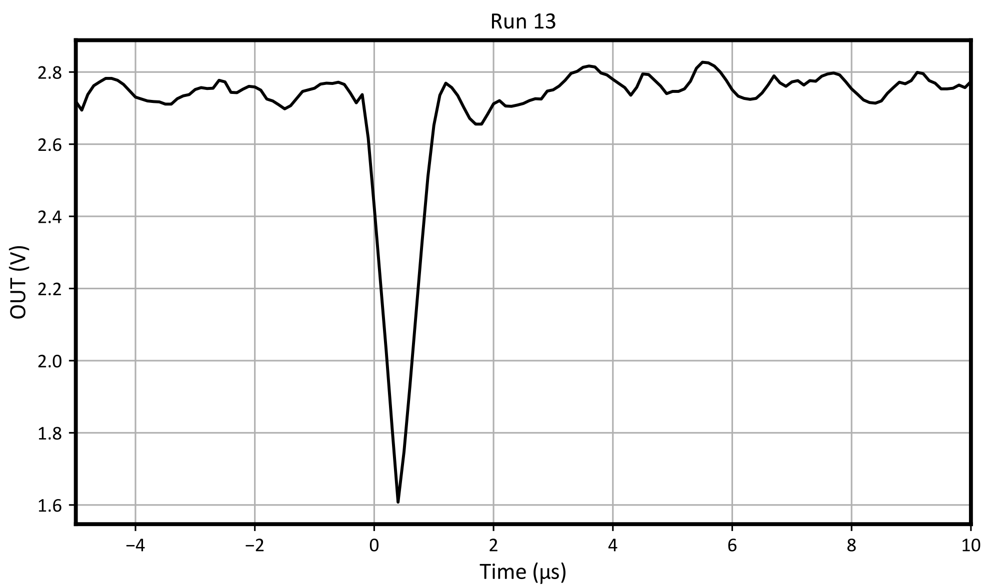

Figure 7-4. Largest Observed V_{out} Transient, SET Run 13, Upset 12

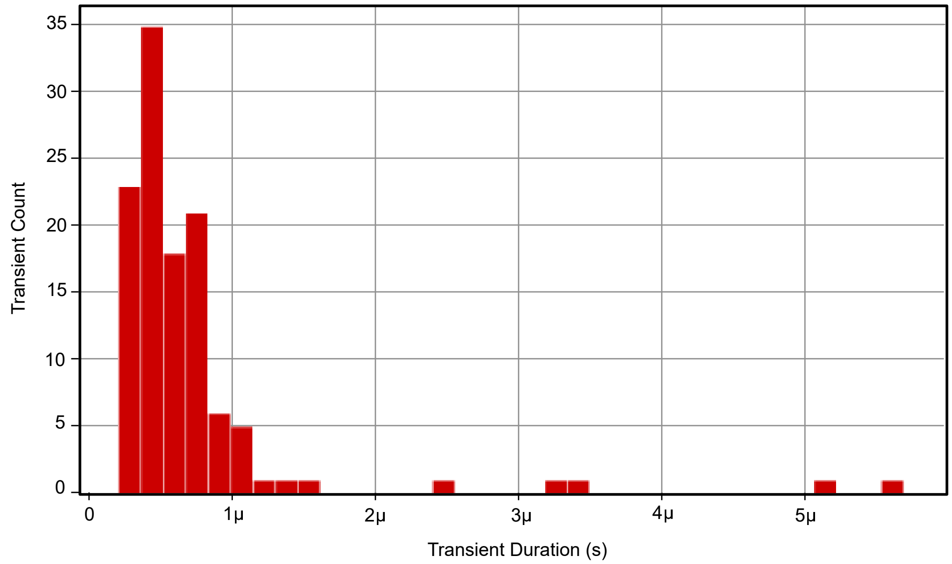

Figure 7-5. Transient Duration Histogram, V_s = 5.5V, V_{CM} = 48V, V_{DIFF} = 0.2675V

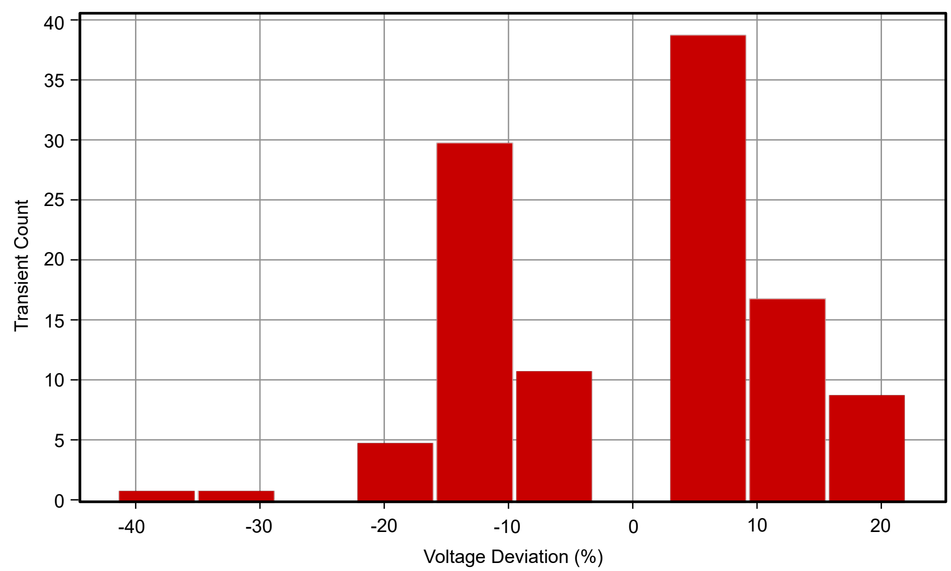

Figure 7-6. Transient Voltage Deviation Histogram, V_S = 5.5V, V_{CM} = 48V, V_{DIFF} = 0.2675V

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-cm²/mg)	CREME96 Integral FLUX (/day/cm²)	σSAT (cm²)	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-cm²/mg)	CREME96 Integral FLUX (/day/cm²)	σSAT (cm²)	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

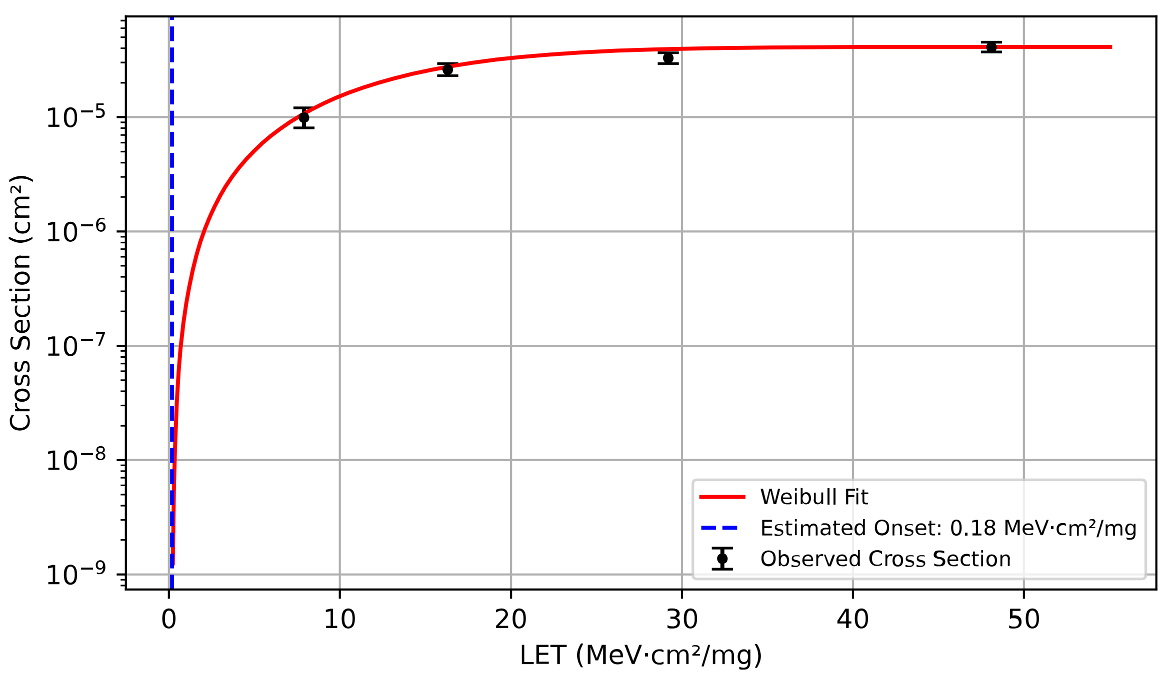

Figure 8-1. Weibul Fit V_S = 2.7V SET

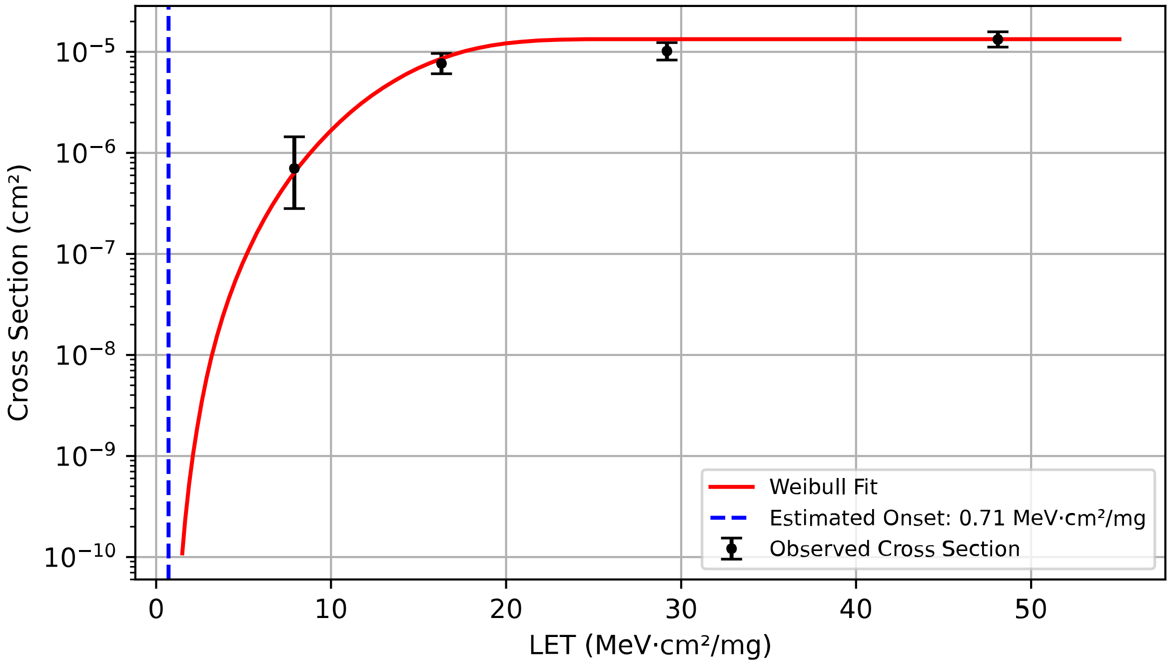

Figure 8-2. Weibul Fit V_S = 5.5V SET

9 Summary

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

10 References

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
2. G. Bruguier and J. M. Palau, "Single particle-induced latchup", IEEE Trans. Nucl. Sci., Vol. 43(2), Mar. 1996, pp. 522-532.
3. G. H. Johnson, J. H. Hohl, R. D. Schrimpf and K. F. Galloway, "Simulating single-event burnout of n-channel power MOSFET's," in IEEE Transactions on Electron Devices, vol. 40, no. 5, pp. 1001-1008, May 1993.
4. J. R. Brews, M. Allenspach, R. D. Schrimpf, K. F. Galloway,J. L. Titus and C. F. Wheatley, "A conceptual model of a single-event gate-rupture in power MOSFETs," in IEEE Transactions on Nuclear Science, vol. 40, no. 6, pp. 1959-1966, Dec. 1993.
5. G. H. Johnson, R. D. Schrimpf, K. F. Galloway, and R. Koga,“Temperature dependence of single event burnout in n-channel power MOSFETs [for space application],” IEEE Trans. Nucl. Sci., 39(6), Dec. 1992, pp.1605-1612.
6. Texas A&M University, *TAMU Radiation Effects Facility*, webpage.
7. Ziegler, James F. *The Stopping and Range of Ions in Matter*, webpage.
8. D. Kececioglu, *Reliability and Life Testing Handbook*, Vol. 1, PTR Prentice Hall, New Jersey, 1993, pp. 186-193.
9. Midwestern State University, *MSU FRIB*, webpage
10. A. J. Tylka, J. H. Adams, P. R. Boberg, et al.,"CREME96: A Revision of the Cosmic Ray Effects on MicroElectronics Code", IEEE Trans. on Nucl. Sci., Vol. 44(6), Dec. 1997, pp. 2150-2160.
11. A. J. Tylka, W. F. Dietrich, and P. R. Boberg, "Probability distributions of high-energy solar-heavy-ion fluxes from IMP-8: 1973-1996", IEEE Trans. on Nucl. Sci.,Vol. 44(6), Dec. 1997, pp. 2140-2149.

Important Limitations on Use of Data Exceeding Specified Limits

TI is providing this data for your convenience. However, we want to make clear the significant limitations of its usefulness as an indicator of how devices may perform in various applications.

THIS DATA IS PROVIDED "AS IS" WITHOUT ANY EXPRESS OR IMPLIED WARRANTY OF ANY KIND INCLUDING WARRANTIES OF MERCHANTABILITY, NONINFRINGEMENT OF INTELLECTUAL PROPERTY, OR FITNESS FOR ANY PARTICULAR PURPOSE. IN NO EVENT SHALL TI OR ITS SUPPLIERS BE LIABLE FOR ANY DAMAGES WHATSOEVER (INCLUDING, WITHOUT LIMITATION, DAMAGES FOR LOSS OF PROFITS, BUSINESS INTERRUPTION, LOSS OF INFORMATION) ARISING OUT OF THE USE OF OR INABILITY TO USE THE INFORMATION, EVEN IF TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

Your use of this data, and all consequences of such use, is solely your responsibility. You must perform sufficient engineering and additional qualification testing in order to properly evaluate your application and determine whether a candidate device is suitable for use in that application.

TI semiconductor components are specifically designed and manufactured to be used within the electrical, thermal, mechanical and other parameters set forth in TI's product data sheets. Quality and reliability data provided by Texas Instruments, such as MTBF and fit rate data, is intended to be an estimate of product performance based upon history only. It does not imply that any performance levels reflected in such data can be met if the product is operated outside the conditions expressly stated in the latest published data sheet for a device.

Plastic encapsulated TI semiconductor devices are neither designed nor warranted as suitable for use in military applications and/or military environments.

THIS INFORMATION SHOULD NOT BE USED TO ASSIST IN THE PRACTICE OF "UPRATING" OR "UPSCREENING" DEVICES FOR USE IN MILITARY OR OTHER CRITICAL APPLICATIONS. There are significant limitations of this information as an indicator of how commercial, off-the-shelf (COTS) devices may perform in such applications or environments, and about the hazards of using COTS devices in such applications. TI strongly believes that semiconductor components should never be used outside their specified tolerance levels as up-screening can lead directly to system or component failure. Such failures may present distinct risks to end-users and to third parties. TI cannot accept any responsibility for component or system failures that occur due to the misuse of its products, including misuse that may result from the practice of up-screening.

Any use of TI components beyond their rated limits voids all warranty responsibility of TI with respect to such devices, and also voids all responsibility of TI with respect to any applications assistance, product design, software performance or services of any kind that were or may have been performed in connection with the sale of any such devices. Further, resale of TI's products or services with statements different from or beyond the parameters stated by TI for that product or service in official TI data books or data sheets, or without the warnings or instructions provided by TI, voids all express and any implied warranties for the associated TI product or service, and is an unfair and deceptive business practice.

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you fully indemnify TI and its representatives against any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale, TI’s General Quality Guidelines, or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products. Unless TI explicitly designates a product as custom or customer-specified, TI products are standard, catalog, general purpose devices.

TI objects to and rejects any additional or different terms you may propose.