Radiation Report

INA1H182-SEP Single-Event Effects (SEE) Radiation Report

TEXAS INSTRUMENTS

ABSTRACT

Studies were performed to characterize the effects of heavy-ion irradiation on the single-event latch-up (SEL) performance of the INA1H182-SEP radiation-tolerant, low offset, low-noise, radiation-tolerant, high-precision instrumentation amplifier. For device qualification, heavy ions with an LET_{EFF} of 45.9MeV-cm^2/mg were used to irradiate the devices with a fluence of 1 × 10^7 ions/cm^2. The results demonstrated that the INA1H182-SEP is SEL-free up to the specified surface LET_{EFF} = 43MeV-cm^2/mg at 125°C.

Characterization of single-event transients (SET) and correlation testing of SEL were also performed, up to a surface LET_{EFF} = 45.9MeV-cm^2/mg at 25°C.

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1 Overview

The INA1H182-SEP is a radiation-tolerant, high precision instrumentation amplifier that offers low power consumption. A single external resistor sets any gain from 1 to 10,000. The device has high precision as a result of super-beta input transistors, which provide low input offset voltage, offset voltage drift, low input bias current, and low noise. The inputs of the INA1H182-SEP device are individually protected for over voltages up to ±40V. At gain (G) = 1, the common-mode rejection ratio exceeds 90dB across the full input common-mode range. This device runs on a single 4V to 18V supply or dual ±2V to ±9V supplies.

Table 1-1. Overview Information (1)

Description	Device Information
TI Part Number	INA1H182-SEP
DLA VID	V62/25653
Device Function	INA1H182-SEP Radiation-Tolerant, Low Offset, Low-Noise, High-Precision Instrumentation Amplifier.
Fab Technology	BICMOS
Fab Process	BICOM-3XHV
Exposure Facilities	Single Event Effects Facility, Cyclotron Institute, Texas A&M University
Heavy Ion Fluence per Run	1×10^7 ions/cm^2
Irradiation Temperature	125°C (for SEL testing) And 25°C (for SET testing)

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2 SEE Mechanisms

The primary single-event effect (SEE) of interest in the INA1H182-SEP is single-event latch-up (SEL). From a risk and potential impact point-of-view, the occurrence of an SEL is possibly the most destructive SEE event and the biggest concern for space applications. A BICMOS process node was used for the INA1H182-SEP, though the device is primarily bipolar. CMOS circuitry often 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 the power is removed or until the device is destroyed by the high-current state.

The INA1H182-SEP is specified as SEL-free to a surface LET_{EFF} of 43MeV-cm^2/mg, at a fluence of 10^7 ions/cm^2 and a chip temperature of 125°C. The INA1H182-SEP was shown in characterization to exhibit no SEL with heavy ions up to a surface LET_{EFF} of 45.9MeV-cm^2/mg, at a fluence of 10^7 ions/cm^2 and a chip temperature of 125°C.

3 Irradiation Facilities and Telemetry

For SEL qualification and SET characterization testing, heavy ion species were provided and delivered by the TAMU Cyclotron Radiation Effects Facility (3) using a superconducting cyclotron and advanced electron cylotron resonance (ECR) ion source. Ion beams were delivered with high uniformity over a 1-inch diameter circular cross sectional area for the in-air station. Uniformity is achieved by magnetic defocusing. The intensity of the beam is regulated over a broad range spanning several orders of magnitude. These measurements are real-time continuous and establish dosimetry and integrated fluence. An ion flux of 10^5 ions/s-cm^2 was used to provide heavy ion fluences to 10^7 ions/cm^2 for most runs. Ion flux was increased to 1.5×10^7 ions/s-cm^2 for some runs, to show SEL immunity at multiple flux rates and to explore the effect of flux rate on transient event counts.

An additional SET characterization test session was performed at the MSU Facility for Rare Isotope Beams(4) (FRIB) using a linear particle accelerator ion source. An ion flux of 10^5 ions / s-cm^2 was used to provide heavy ion fluences to 10^7 ions/cm^2 for these runs.

For MSU SET testing, the FRIB "degrader wheel" was employed to adjust the ion energy. The wheel is positioned between the beam "window" or output, and the device under test. The wheel features multiple slots where a foil degrading element of known thicknesses can be loaded. When the wheel is rotated to an "open" slot, only the 70mm air gap and the copper foil in the LINAC path serve to degrade the ion energy. When the wheel is remotely rotated to a slot with a given aluminum degrading foil thickness, the ions pass through the aluminum foil as well, and are slowed accordingly. The slower rate decreases the effective ion range in silicon but increases the effective Linear Energy Transfer (LET_{eff}) in MeV-cm^2/mg, effectively shifting *along* the Bragg curve. Use of the degrader wheel allows multiple LET_{eff} values to be achieved per beam species and LINAC energy level.

4 Test Device and Test Board Information

The INA1H182-SEP is packaged in an 8-pin VSSOP (DGK) package. Figure 4-1 shows the pinout diagram. The package lid was removed to reveal the die face for all heavy ion testing.

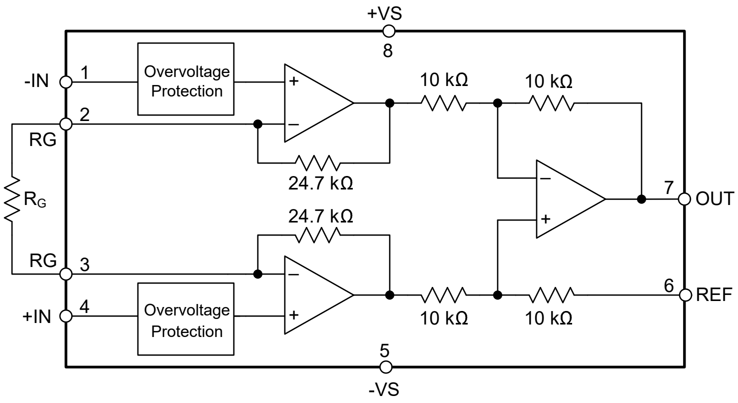

Figure 4-1. INA1H182-SEP Pinout Diagram

Each device under test (DUT) used in INA1H182-SEP qualification studies came from the same wafer fab and assembly lot and were used for single-event effect qualification and characterization. Across the SEL, SET, and absolute-maximum supply extended SEL characterization tests performed, five different devices were evaluated. Some lookahead testing was also performed on units from different assembly lots, and had no significant differences observed in the test results.

4.1 Qualification Circuits and Boards

The INA1H182-SEP was biased in a variety of different conditions for SEE testing at the recommended minimum and recommended maximum supply voltages. Midsupply or GND was used for REF. Current was monitored over time for both supplies VS+, VS- and the instrumentation amplifier inputs -IN and +IN.

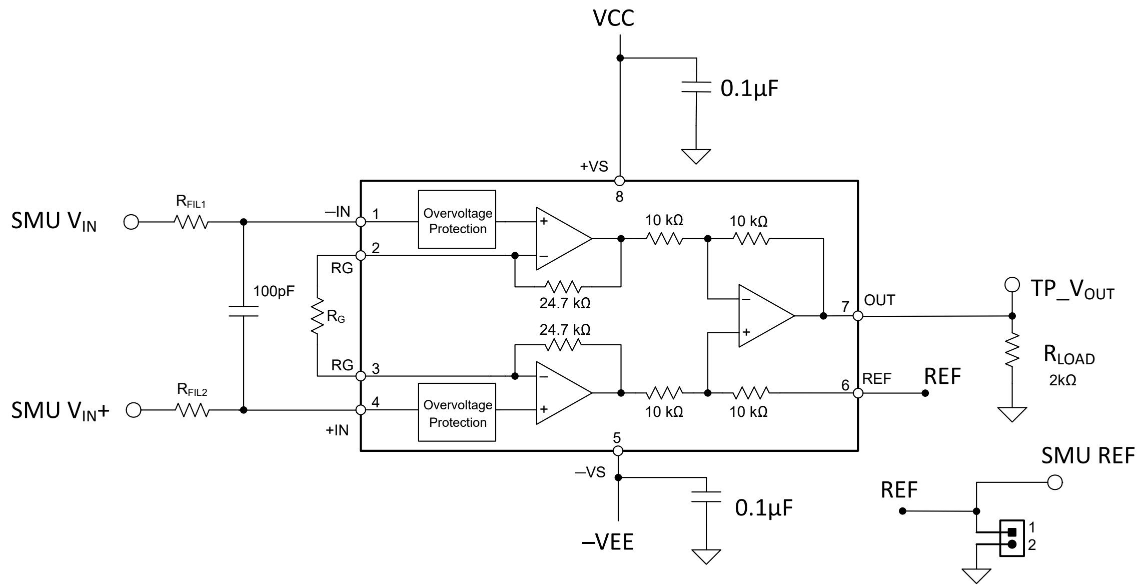

Figure 4-2. INA1H182-SEP SEE Qualification Bias Diagram

Input and supply voltages were provided by SMU PXI cards, connected with banana cables. The board used for testing incorporated jumpers can also test with high V_{CM} and 0V V_{DIFF}; low V_{CM} and high V_{DIFF}; and high V_{CM} and constant V_{DIFF}. For all testing, the device outputs were monitored using oscilloscope PXI cards, connected with BNC cables. A 100Ω of series isolation resistance was used to drive the cable capacitance. A 2kΩ output load to midsupply was present for all DUTs. The gain of the INA1H182-SEP is configured by the RG resistors. For SEL qualification, the device was configured on a gain of 1000V/V using a 49.4Ω RG resistor. For SET tests, RG was set to 499Ω for a gain of 100V/V.

Figure 4-3 shows an example of the INA1H182-SEP device mounted through a socket on a characterization board. During SEL qualification, the device was heated using forced hot air, maintaining an IC temperature at

125°C. During SEL testing, the devices were soldered into a coupon board, allowing direct airflow access to the heater. For SET testing, devices were mounted in a socket for the easy exchange of units.

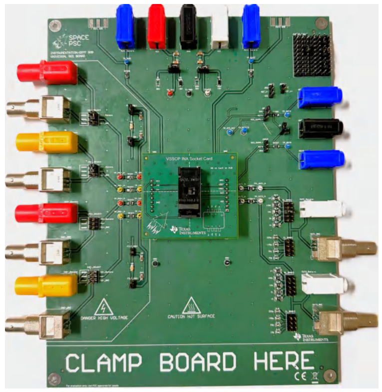

Figure 4-3. Characterization Board

4.2 Characterization Devices and Test Board Schematics

Heavy ions were used to irradiate the devices. A nominal flux of 1 × 10^5 ions/s-cm^2 was used for SEL characterization, at 125°C die temperature. Nominal flux of 1 × 10^5 ions/s-cm^2 was used for SET characterization, at ambient temperature.

For SEE characterization, the INA1H182-SEP was biased with bipolar split supplies. The circuit was connected as shown on Figure 4-4. Different supply voltages, input common-mode voltages and differential voltage conditions were tested.

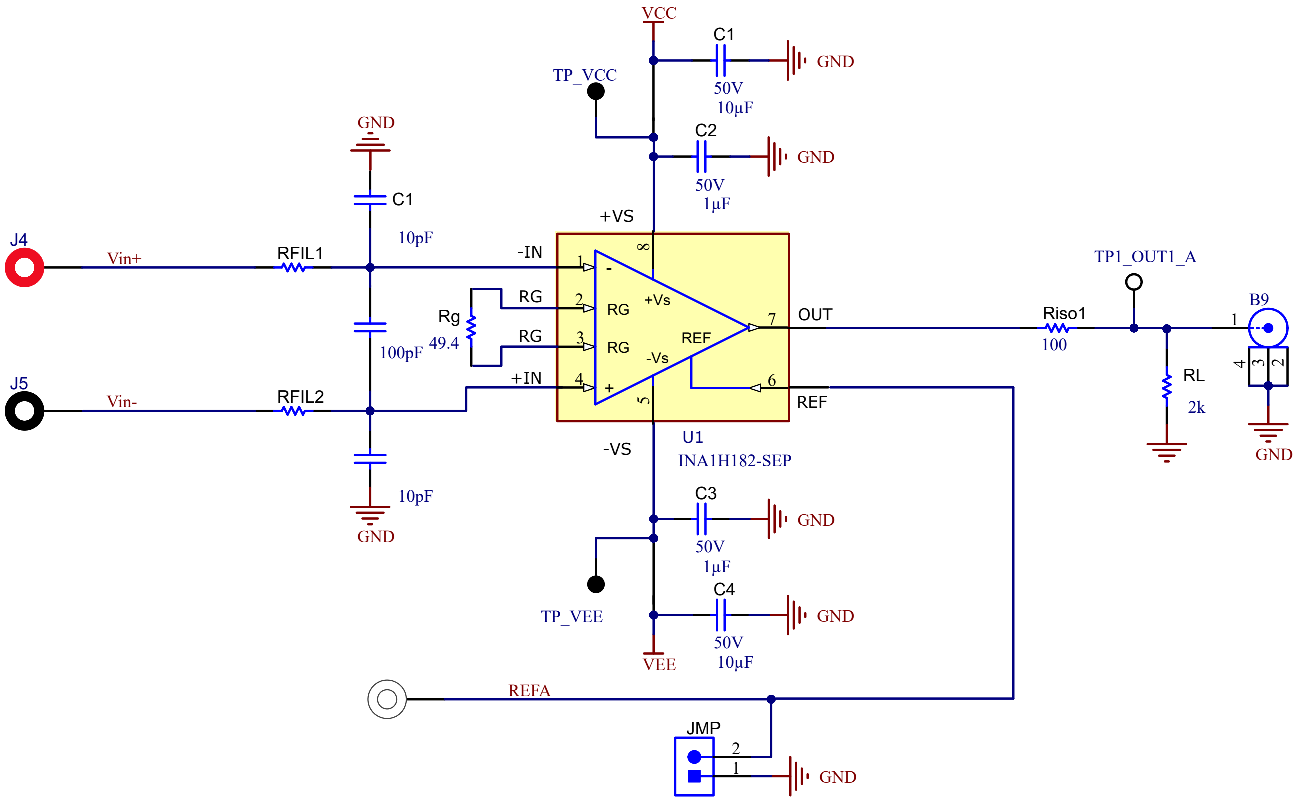

Figure 4-4. SEE Characterization Circuit Block Diagram

Input and supply voltages were provided by SMU PXI cards, connected with banana cables. Figure 4-5 shows the decoupling supply capacitance scheme used. Current was monitored over time for both V+ and V-. For SEL qualification, the device was configured on a gain of 1000V/V using a 49.4Ω RG resistor. For SET tests, the device was tested on gain of 100V/V using a 499Ω RG resistor. Additional SET test sessions were performed at gains of 1V/V, 20V/V and 50V/V.

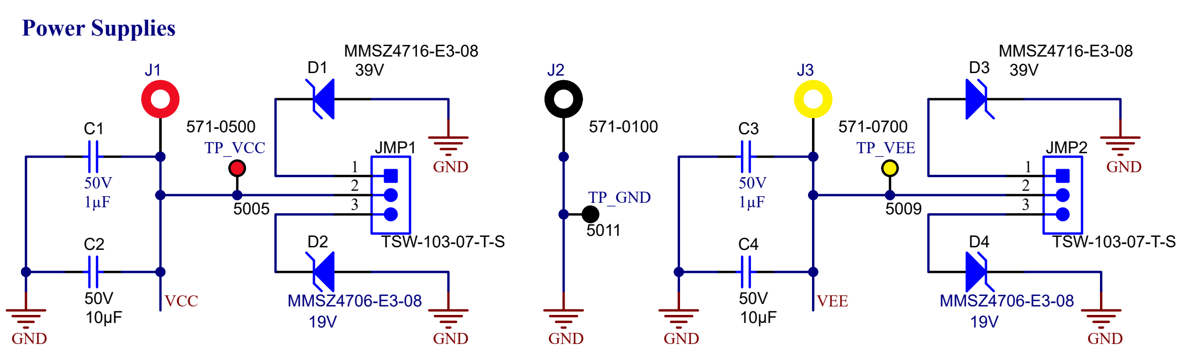

Figure 4-5. Characterization Board Voltage Supply Connections

The positive and negative inputs of the difference amplifier are driven with separate SMU sources, allowing control of the differential and common-mode voltage input signals. Figure 4-5 shows the input SMU connections and optional filters.

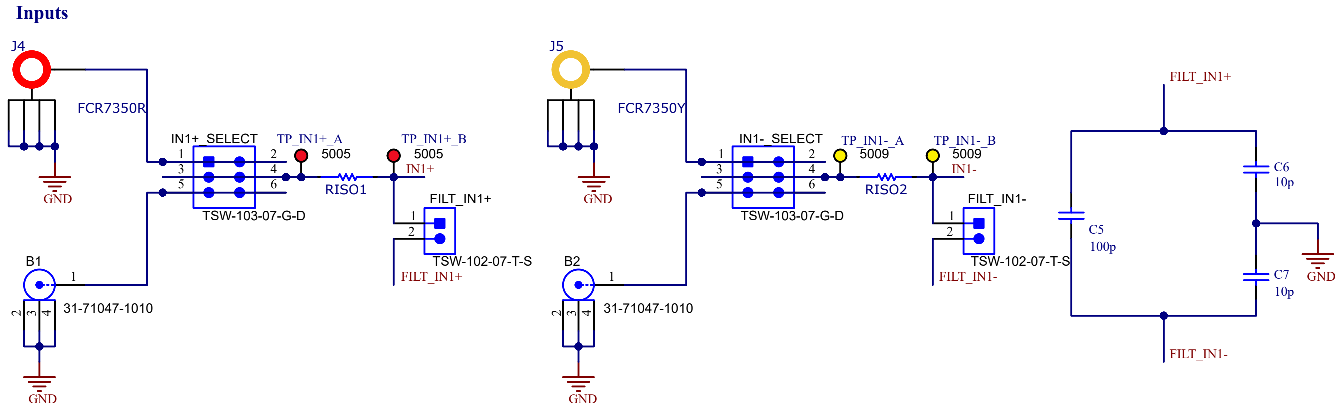

Figure 4-6. Characterization Board Input Connections

For SET testing, the device outputs were monitored using oscilloscope PXI cards, connected with BNC cables. 100Ω of series isolation resistance was used on the output channel to drive the cable capacitance. Figure 4-5 shows the output oscilloscope connections and optional load resistors and capacitors.

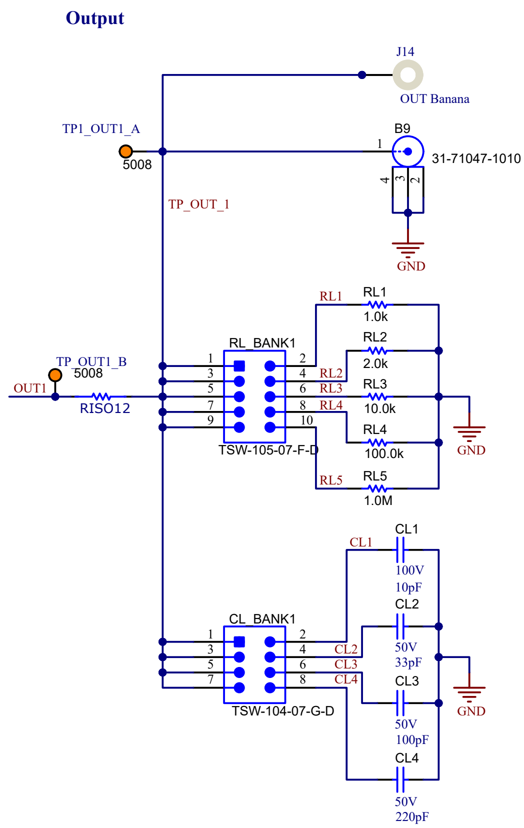

Figure 4-7. Characterization Board Output Connections

5 Results

5.1 SEL Qualification Results: TAMU Cyclotron Radiation Effects Facility

During SEL qualification, the device was heated using forced hot air, maintaining an IC temperature at 125°C. The temperature was monitored using a thermal camera. The species used for the SEL testing was a silver (^{109}Ag) ion with an angle-of-incidence of 0° and an air gap of 27.7mm, for an LET_{EFF} = 45.9MeV-cm^2/mg. each run targeted a nominal flux of 10^5ions/s-cm^2 and fluence of 10^7ions/cm^2. This testing used three DUTs which experienced a cumulative total fluence of approximately 14 × 10^7 ions/cm^2 with no failures observed.

Table 5-1 shows a summary of the conditions for the three SEL test runs. The run numbers listed are the actual run numbers from the testing session, and the flux, fluence, and dose in silicon for each run come from the test session log provided by the Cyclotron Institute at Texas A&M University. Figure 5-2 and related figures show example plots of the supply currents versus time.

Table 5-1. INA1H182-SEP SEL Testing Summary, ^{109}Ag Ion, 125°C Die Temperature

Run #	DUT	V+ Supply (V)	V- Supply (V)	Input V_{CM} (V)	Input V_{DIFF} (V)	Gain (V/V)	Mean Flux (ions/s-cm^2)	Fluence (ions/cm^2)	Dose in Silicon (Rad)
1	SEL_D1	9	-9	7	0.001	1000	1.08 × 10^5	1.00 × 10^7	7516
2	SEL_D1	9	-9	-7	0.001	1000	1.17 × 10^5	9.96 × 10^6	7454
4	SEL_D1	2.5	-2.5	0.5	0.001	1000	1.02 × 10^5	9.96 × 10^6	7548
5	SEL_D1	2.5	-2.5	-0.5	0.001	1000	1.12 × 10^5	9.99 × 10^6	7481
6	SEL_D4	9	-9	7	0.001	1000	1.04 × 10^5	1.00 × 10^7	7514
7	SEL_D4	9	-9	-7	0.001	1000	1.01E × 10^5	1.00 × 10^7	7490
8	SEL_D4	2.5	-2.5	0.5	0.001	1000	1.01 × 10^5	1.01 × 10^7	7552
9	SEL_D4	2.5	-2.5	-0.5	0.001	1000	1.04 × 10^5	1.00 × 10^7	7488
10	SEL_D5	9	-9	7	0.001	1000	1.21 × 10^5	1.50 × 10^7	11190
11	SEL_D5	9	-9	-7	0.001	1000	1.17 × 10^5	1.50 × 10^7	11200
13	SEL_D5	2.5	-2.5	0.5	0.001	1000	1.22 × 10^5	1.50 × 10^7	11220
14	SEL_D5	2.5	-2.5	-0.5	0.001	1000	1.40E × 10^5	1.50 × 10^7	11200

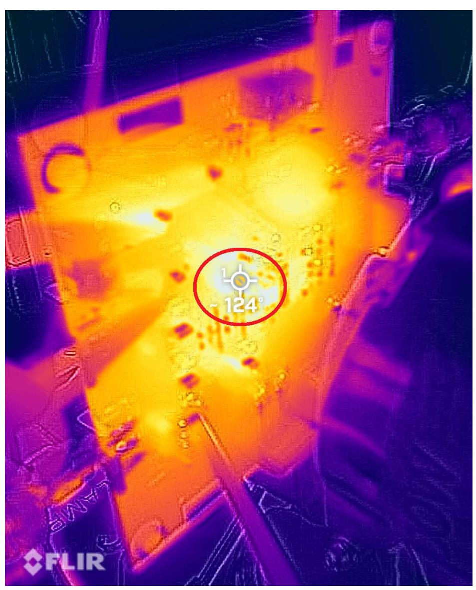

Figure 5-1. Thermal Image During Set Up

The INA1H182-SEP specified maximum voltage supply is ±9V. On a separate test session, unit SEL_D2 was tested at the absolute maximum rated supply of ±10V at LET_{EFF} = 45.9MeV-cm^2/mg and T = 125°C without any failures observed. See Table 5-2 for a summary of the conditions in each test run.

Table 5-2. INA1H182-SEP SEL Test Summary at absolute maximum supply, ^{109}Ag Ion, 125°C Die Temperature

Run #	DUT	V+ Supply (V)	V- Supply (V)	Input V_{CM} (V)	Input V_{DIFF} (V)	Gain (V/V)	Mean Flux (ions × cm^2/mg)	Fluence (ions/cm^2)	Dose in Silicon (rad)
1	SEL_D2	9	-9	0	0.001	1000	9.987×10^4	1.003×10^7	7508
2	SEL_D2	10	-10	0	0.001	1000	9.630×10^4	9.987×10^6	7475

The amplifier inputs of the INA1H182-SEP are individually protected for voltages up to ±40V. Internal circuitry on each input provides low series impedance under normal signal conditions. If the input is overloaded, the protection circuitry limits the input current to a value of approximately 8mA.

The INA1H182-SEP was tested for input over-voltage up to ±40V, at LET_{EFF} = 45.9MeV-cm^2/mg and T = 125°C without any failures observed. The device was post-tested after the stress test to verify normal operation. See Table 5-3 for a summary of the conditions in the test runs.

Table 5-3. INA1H182-SEP SEL Test Summary for Input Over-voltage Protection, ^{109}Ag Ion, 125°C Die Temperature

Run #	DUT	V+ Supply (V)	V- Supply (V)	Input V_{CM} (V)	Input V_{DIFF} (V)	Gain (V/V)	Mean Flux (ions × cm^2/mg)	Fluence (ions/cm^2)	Dose in Silicon (rad)
3	SEL_D2	9	-9	15	0.001	1000	9.255×10^4	9.997×10^6	7481
4	SEL_D2	9	-9	20	0.001	1000	8.859×10^4	1.000×10^7	7481
5	SEL_D2	9	-9	25	0.001	1000	9.031×10^4	1.003×10^7	7502
6	SEL_D2	9	-9	35	0.001	1000	9.131×10^4	1.002×10^7	7502
8	SEL_D2	9	-9	40	0.001	1000	8.839×10^4	1.001×10^7	7488

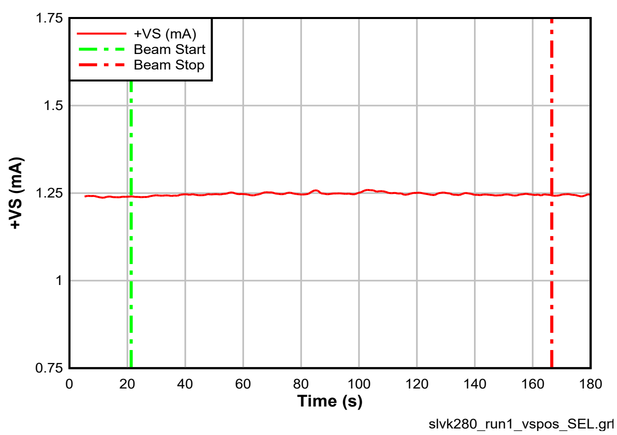

Figure 5-2. Current Versus Time (I Versus t) Data for +VS for DUT SEL-D2 Run 1

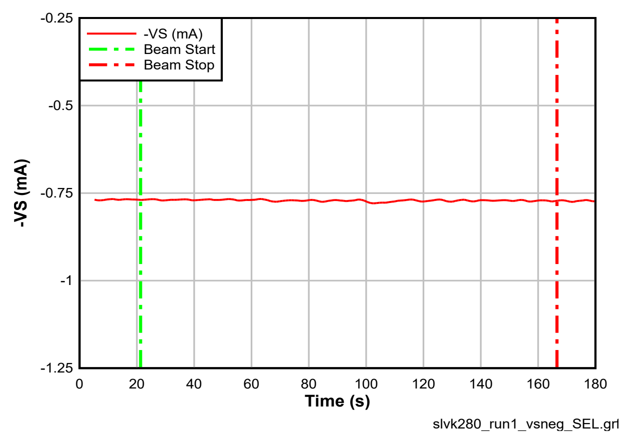

Figure 5-3. Current Versus Time (I Versus t) Data for -VS for DUT SEL-D2 Run 1

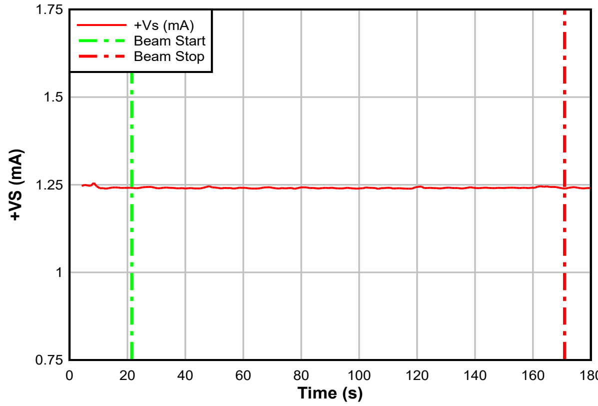

Figure 5-4. Current Versus Time (I Versus t) Data for +VS for DUT SEL-D2 Run 2

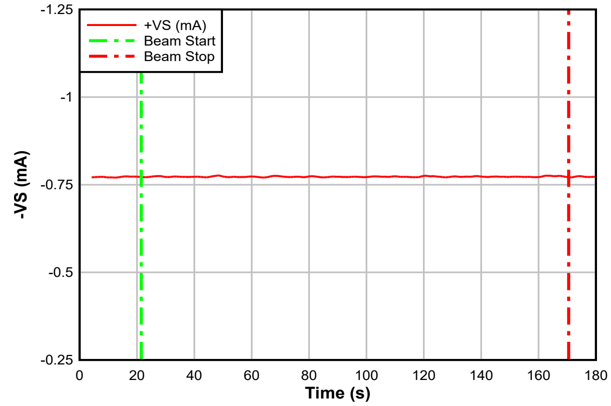

Figure 5-5. Current Versus Time (I Versus t) Data for -VS for DUT SEL_D2 Run 2

No SEL events were observed, which indicates that the INA1H182-SP is SEL-immune at LET_{EFF} = 45.9MeV-cm^2/mg and T = 125°C. Using the MFTF method described in Confidence Interval Calculations and combining (or summing) the fluences of the two runs at 125°C (2 × 10^7), the upper-bound cross-section (using a 95% confidence level) is calculated in Equation 1:

$$\sigma SEL \leq 1.84 \times 10^{-7} cm^2 \text{ for } LET_{EFF} = 45.9 MeV-cm^2/mg \text{ and } T = 125°C \quad (1)$$

5.2 SET Characterization Results

A fresh DUTs were used for SET characterization. The conditions for each run are summarized on Table 5-4 below. The run numbers listed are the acutal run numbers from the testing session, and the flux, fluence, and dose silicon foreach run are pulled forn the test session log provided by the Texas A & M K500 Cyclotron facility.

Unit SET_DUT6 was configured with a gain of 100V/V using a RG resistor of 499Ω. The device was tested at maximum specified supply voltage range of ±9V (or 18V total supply) and input common mode voltage (V_{CM}) of ±5V with a input differential voltage V_{DIFF} of ±50mV. The REF pin was biased at mid-supply (0V). The device output channel was loaded with a 2kΩ resistance to GND (mid-supply). Tests were repeated at a supply voltage of ±2.5V (or 5V total supply) with V_{CM} =±0.4V and V_{DIFF} of ±10mV.

Since the device was set on a high gain of 100V/V, the instrumentation amplifier output amplifies extrinsic noise present in the test environment. The oscilloscopes were set to a *window* trigger mode that captured any events where the output shifted by ±200mV or more.

The INA1H182-SEP devices were exposed to LET levels varying from 46.7MeV-cm^2/mg to 1.33MeV-cm^2/mg. An ambient temperature of approximately 25°C was recorded in the facility at the time of these tests. Test runs 39 - 46 involved the testing of a different product not related to the INA1H182-SEP, and therefore are excluded in this report.

Table 5-4. TAMU SET Characterization Run Summary

Run Number	DUT	Supply (V)	V_{DIFF} (V)	V_{CM} (V)	Gain (V/V)	Ion	LETeff (MeV-cm^2/mg)	Flux (ions/s-cm^2)	Fluence (ions/ cm^2)	Total Ionizing Dose (rad)	Events
15	SET_D6	±9	5	0.05	100	^{109}Ag	46.7	8.95×10^4	1.00×10^7	7504	2517
16	SET_D6	±9	-5	-0.05	100	^{109}Ag	46.7	7.84×10^4	9.96×10^6	7543	2220
17	SET_D6	±2.5	0.4	0.01	100	^{109}Ag	46.7	1.17×10^5	1.00×10^7	7511	1374
18	SET_D6	±2.5	-0.4	-0.01	100	^{109}Ag	46.7	1.00×10^5	1.01×10^7	7523	1625
19	SET_D6	±9	5	0.05	100	^{84}Kr	33.5	1.10×10^5	9.96×10^6	5348	1049
20	SET_D6	±9	-5	-0.05	100	^{84}Kr	33.5	1.11×10^5	9.94×10^6	5366	900
21	SET_D6	±2.5	0.4	0.01	100	^{84}Kr	33.5	1.08×10^5	1.00×10^7	5373	704
22	SET_D6	±2.5	-0.4	-0.01	100	^{84}Kr	33.5	1.16×10^5	9.96×10^6	5346	703
23	SET_D6	±9	5	0.05	100	^{84}Kr	29.5	9.93×10^4	1.00×10^7	4719	881
24	SET_D6	±9	-5	-0.05	100	^{84}Kr	29.5	8.06×10^4	1.00×10^7	4731	721
25	SET_D6	±2.5	0.4	0.01	100	^{84}Kr	29.5	7.31×10^4	9.97×10^6	4706	505
26	SET_D6	±2.5	-0.4	-0.01	100	^{84}Kr	29.5	1.17×10^5	1.00×10^7	4728	485
27	SET_D6	±9	5	0.05	100	^{63}Cu	19.6	1.10×10^5	9.99×10^6	3129	584
28	SET_D6	±9	-5	-0.05	100	^{63}Cu	19.6	1.15×10^5	1.00×10^7	3135	486
29	SET_D6	±2.5	0.4	0.01	100	^{63}Cu	19.6	1.13×10^5	9.96×10^6	3121	334
30	SET_D6	±2.5	-0.4	-0.01	100	^{63}Cu	19.6	1.07×10^5	1.00×10^7	3144	270
31	SET_D6	±9	5	0.05	100	^{40}Ar	8.41	1.10×10^5	9.95×10^6	1340	82
32	SET_D6	±9	5	0.05	100	^{40}Ar	8.41	1.12×10^5	9.96×10^6	1342	71
33	SET_D6	±2.5	0.4	0.01	100	^{40}Ar	8.41	1.12×10^5	1.00×10^7	1347	31
34	SET_D6	±2.5	-0.4	-0.01	100	^{40}Ar	8.41	1.16×10^5	1.01E+07	1348	19
35	SET_D6	±9	5	0.05	100	^{20}Ne	2.73	1.13×10^5	1.01×10^7	439	17
36	SET_D6	±9	-5	-0.05	100	^{20}Ne	2.73	1.13×10^5	1.00×10^7	437	19
37	SET_D6	±2.5	0.4	0.01	100	^{20}Ne	2.73	1.20×10^5	1.00×10^7	438	18
38	SET_D6	±2.5	-0.4	-0.01	100	^{20}Ne	2.73	1.22×10^5	9.98×10^6	436	0
47	SET_D6	±9	5	0.05	100	^{14}N	1.33	1.15×10^5	9.99×10^6	213	22
48	SET_D6	±9	-5	-0.05	100	^{14}N	1.33	1.15×10^5	9.96×10^6	212	19
49	SET_D6	±2.5	0.4	0.01	100	^{14}N	1.33	1.03×10^5	9.98×10^6	212	7

Table 5-4. TAMU SET Characterization Run Summary (continued)

Run Number	DUT	Supply (V)	V_{DIFF} (V)	V_{CM} (V)	Gain (V/V)	Ion	LETeff (MeV-cm^2/mg)	Flux (ions/s-cm^2)	Fluence (ions/ cm^2)	Total Ionizing Dose (rad)	Events
50	SET_D6	±2.5	-0.4	-0.01	100	^{14}N	1.33	1.17×10^5	1.00×10^7	213	0

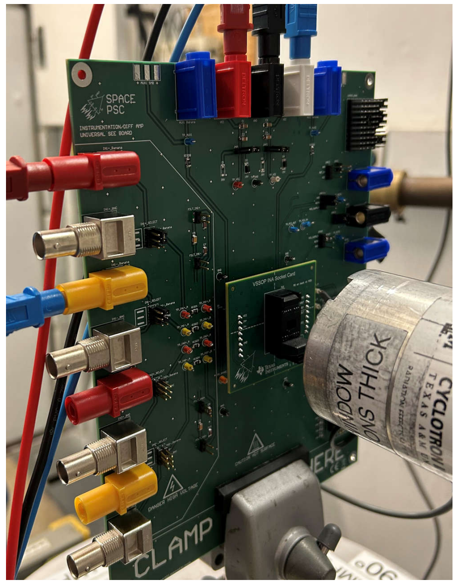

Figure 5-6. Device Under Test Lined Up With the Beam

A separate SET testing session was performed with 3 additional fresh devices at the MSU Facility for Rare Isotope Beams (FRIB) using a linear particle accelerator ion source. The run numbers listed are the actual run numbers from the testing session, and the flux, fluence, and dose silicon for each run are pulled from the test session log provided by the MSU FRIB Linac facility. A summary of the conditions in test runs performed is provided on Table 5-5.

Devices were tested up at the operating supply of ±9V with different gains of 1V/V, 20V/V, 50V/V and 100V/V. The devices were exposed to a LET level of 50.4MeV-cm^2/mg. The oscilloscope card was set to a *window* trigger mode that captured any events where the output shifted by ±200mV or more.

Table 5-5. MSU FRIB SET Run Summary

Run Number	DUT	Supply (V)	V_{DIFF} (V)	V_{CM} (V)	Gain (V/V)	Ion	LETeff (MeV-cm^2/mg)	Flux (ions/s-cm^2)	Fluence (ions/cm^2)	Total Ionizing Dose (rad)	Events
61	SET_B1	±9	0.100	0.05	20	^{129}Xe	50.4	1.047×10^5	9.840×10^6	7940	12041
65	SET_B2	±9	0.040	0.020	50	^{129}Xe	50.4	1.067×10^5	9.924×10^6	8008	12018
69	SET_B3	±9	0.020	0.010	100	^{129}Xe	50.4	1.038×10^5	1.007×10^7	8129	8364
73	SET_B4	±9	2.000	1.000	1	^{129}Xe	50.4	1.082×10^5	1.002×10^7	8082	15256

5.3 Analysis

The information in this section describes general characteristics of the SET response characteristics of the device, and may not be accurate for all use cases or conditions. In-circuit results vary according to application specifics. TI's customers are responsible for determination of components for their purposes, and validating and testing design implementation to confirm system functionality.

The data suggest the rate at which the INA1H182-SEP exhibits SET events, and the magnitude of those events, is a function of several factors. These include supply voltage, input common-mode voltage (V_{CM}), differential input voltage (V_{DIFF}) beam flux, ion energy and instrumentation amplifier gain.

Generally, when the INA1H182-SEP experiences an SET, the device output presents sudden *spikes* and are usually resolved within 10µs of the trigger event. A small percentage of these captures show measurable undershoot or overshoot behavior after the initial spike as the output settles.

Device SET_D6 was evaluated at the Texas A&M University Cyclotron with ion energy in *descending* order, from 45.9MeV-cm^2/mg to 1.33MeV-cm^2/mg. This device was evaluated with both positive and negative polarity V_{CM} and V_{DIFF} input voltages.

The INA1H182-SEP susceptibility to SET increases as ion energy level increases. Factors such as the time between decap and testing (time the die is exposed to air), annealing time between runs, and simple device-to-device variation can also play a potential role in the differing event counts. Correlating any single factor to the event counts is difficult due to the complexities and practical challenges of the testing.

Table 5-6. TAMU SET Characterization Session Sum of Event Counts Per Device

LET (MeV-cm^2/mg)	Parameter	DUT-SET1	
		Vs = 5V	Vs = 18V
46.7	Events	2999	4737
	Fluence (Ions/cm^2)	2.008E+07	1.998E+07
	Cross Section (cm^2)	1.49E-04	2.37E-04
33.5	Events	1407	1949
	Fluence (Ions/cm^2)	1.997E+07	1.990E+07
	Cross Section (cm^2)	7.05E-05	9.79E-05
29.5	Events	990	1602
	Fluence (Ions/cm^2)	1.999E+07	2.002E+07
	Cross Section (cm^2)	4.95E-05	8.00E-05
19.6	Events	604	1070
	Fluence (Ions/cm^2)	2.000E+07	2.000E+07
	Cross Section (cm^2)	3.02E-05	5.35E-05
8.41	Events	50	153
	Fluence (Ions/cm^2)	2.005E+07	1.992E+07
	Cross Section (cm^2)	2.49E-06	7.68E-06
2.73	Events	18	36
	Fluence (Ions/cm^2)	2.001E+07	2.006E+07
	Cross Section (cm^2)	9.00E-07	1.79E-06
1.33	Events	7	41
	Fluence (Ions/cm^2)	1.998E+07	1.995E+07
	Cross Section (cm^2)	3.50E-07	2.05E-06

Table 5-7 shows the transient event summary using three additional fresh devices at the MSU Facility for Rare Isotope Beams (FRIB). The instrumentation amplifier is sensitive to extrinsic noise signals at the inputs, especially at the higher gain configurations. Testing at the radiation facilities has shown that the beam area is an electrically noisy environment, which can lead to false trigger events. Due to the extrinsic noise present on this test setup and the use of the higher gain configuration, this study focuses on only transient events larger than ±200mV at the amplifier output using a post-processing *window* trigger. Note that the INA1H182-SEP also experiences transient events of less than ±100mV. Appendix A shows notable oscilloscope captures.

Table 5-7. MSU FRIB Session Transient Event Summary for 18V Supply

Gain (V/V)	Run	Processed Events > ±0.200V	Trans Duration Avg (µs)	Trans Duration Std Dev (µs)	Avg Peak from Nom (V)	Std Dev Peak from Nom (V)	Min Trans Peak (V)	Max Trans Peak (V)	Avg Abs Peak from Nom (V)	Std Dev Abs Peak from Nom (V)
1	73	9842	0.942	1.073	-0.262	1.871	-8.955	8.925	0.749	1.734
20	61	11022	1.053	0.988	-0.241	1.763	-8.973	8.957	0.747	1.615
50	65	11099	1.234	1.037	-0.219	1.716	-8.977	8.980	0.787	1.540
100	69	10767	1.796	1.646	-0.252	1.679	-8.982	8.957	0.832	1.480

6 Summary

Single-event effects of the INA1H182-SEP radiation-hardened, high common-mode voltage difference amplifier were studied. The device was shown through characterization to be latch-up immune up to surface LET_{EFF} = 43MeV-cm^2/mg and T = 125°C.

A Transient Results Appendix

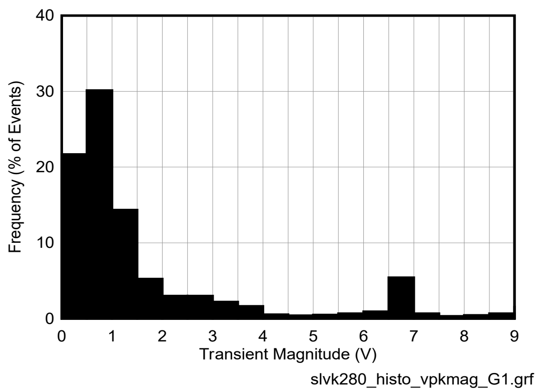

Figure A-1. Transient Event Magnitude Histogram, 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, G=1V/V

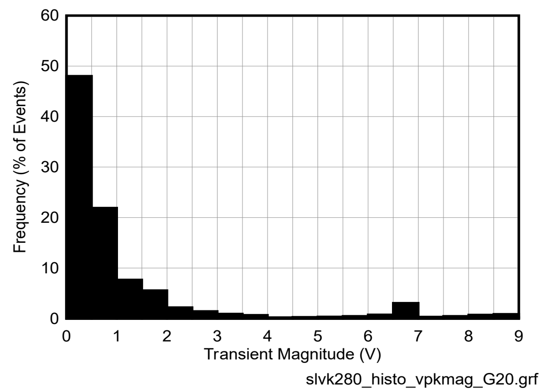

Figure A-2. Transient Event Magnitude Histogram, 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, G=20V/V

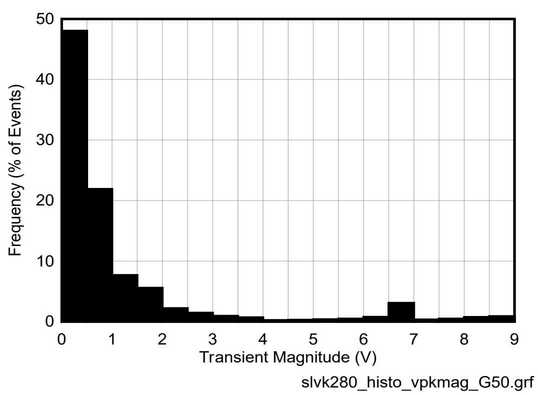

Figure A-3. Transient Event Magnitude Histogram, 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, G=50V/V

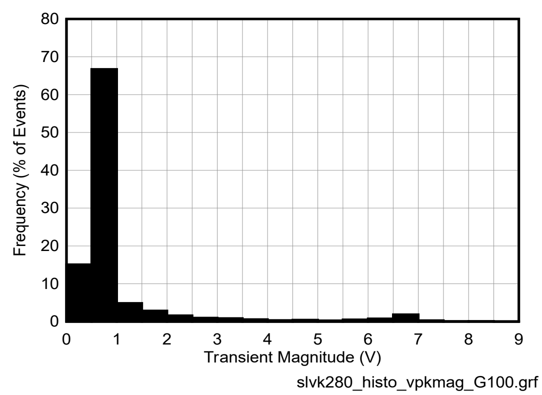

Figure A-4. Transient Event Magnitude Histogram, 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, G=100V/V

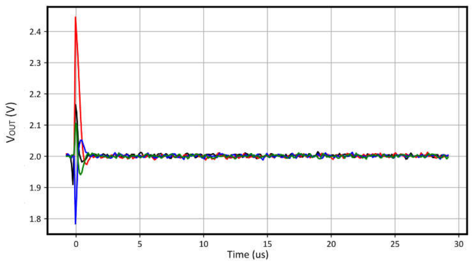

Figure A-5. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Typical Transients, G=1V/V, Run 73, MSU

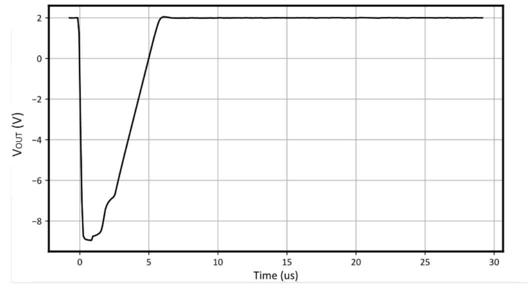

Figure A-6. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Negative Output Transient, G=1V/V, Run 73, Upset 558, MSU

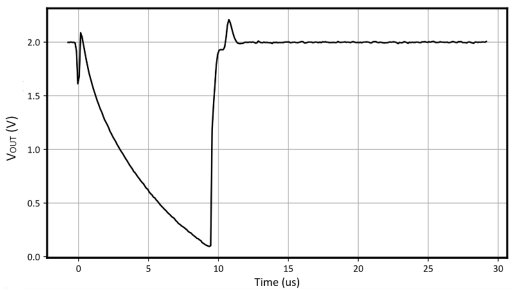

Figure A-7. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Long Negative Output Transient, G=1V/V, Run 73, Upset 8720, MSU

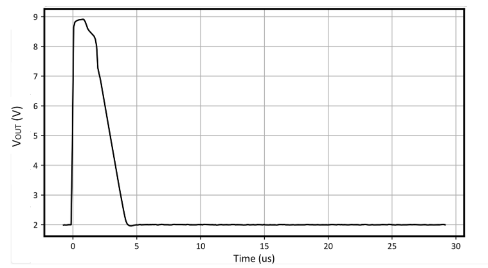

Figure A-8. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Pos Out Transient, G=1V/V, Run 73, Upset 3089, MSU

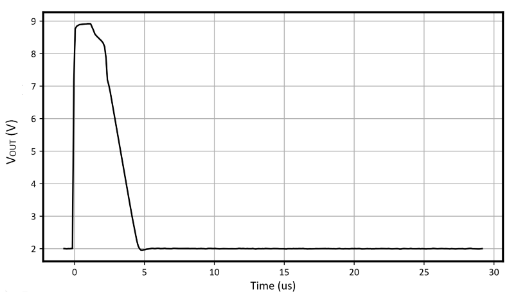

Figure A-9. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Long Pos Out Transient, G=1V/V, Run 73, Upset 13950, MSU

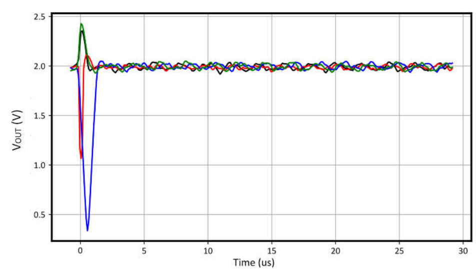

Figure A-10. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Typical Transients, Gain=20V/V, Run 61, MSU

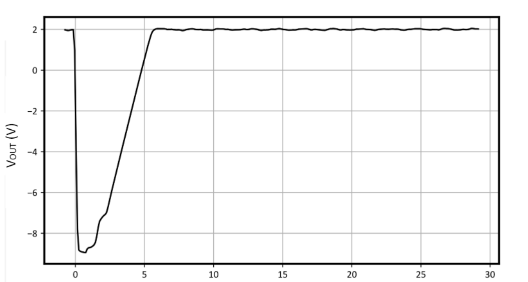

Figure A-11. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Negative Output Transient, G=20V/V, Run 61, Upset 8685, MSU

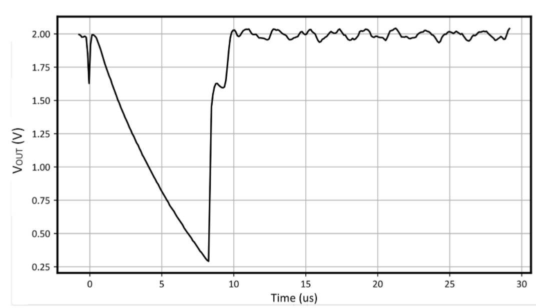

Figure A-12. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Long Negative Output Transient, G=20V/V, Run 61, Upset 1434, MSU

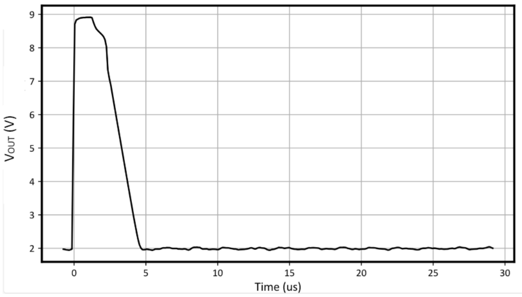

Figure A-13. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Positive Output Transient, G=20V/V, Run 61, Upset 3464, MSU

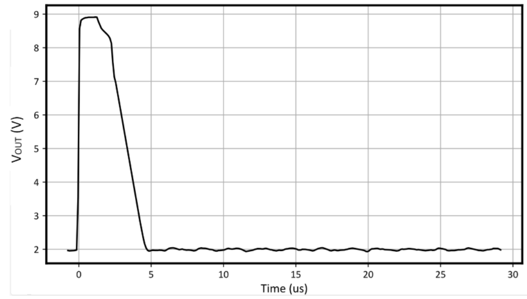

Figure A-14. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Long Positive Out Transient, Gain=20V/V, Run 61, Upset 211, MSU

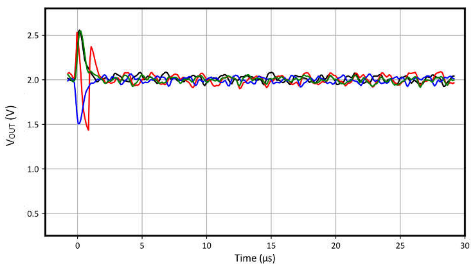

Figure A-15. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Typical Transients, Gain=50V/V, Run 65, MSU

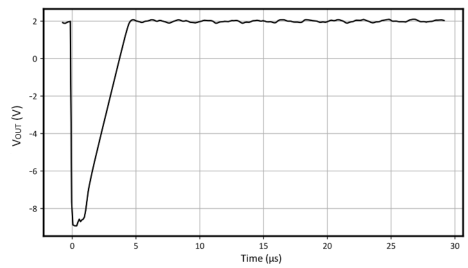

Figure A-16. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Negative Output Transient, G=50V/V, Run 65, Upset 11650, MSU

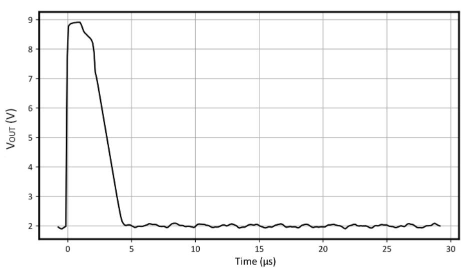

Figure A-17. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Positive Output Transient, G=50V/V, Run 65, Upset 406, MSU

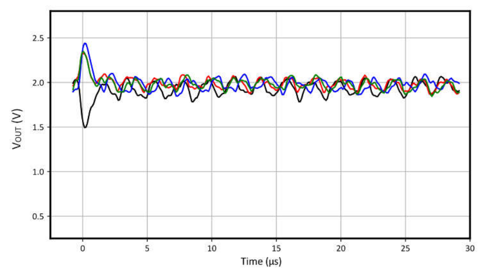

Figure A-18. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Typical Transients, G=100V/V, Run 69, MSU

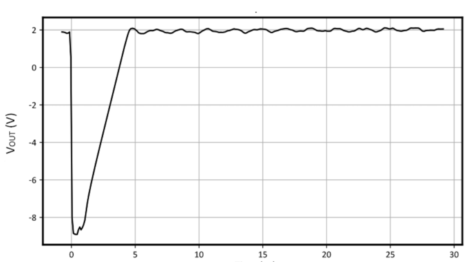

Figure A-19. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Negative Output Transient, G=100V/V, Run 69, Upset 6509, MSU

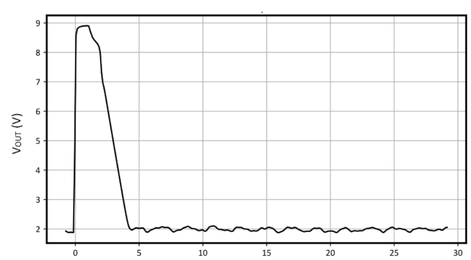

Figure A-20. 18V Supply, LET_{EFF} = 50.4MeV-cm^2/mg, Large Positive Output Transient, G=100V/V, Run 69, Upset 5339, MSU

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