

INA240-SEP Single-Event Latch-Up (SEL) Radiation 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 INA240-SEP -4 V to 80 V, High- and Low-Side, Bidirectional, Zero Drift, Current-Sense Amplifier with Enhanced PWM Rejection. Heavy-ions with an LET_{EFF} of 43 MeV-cm²/mg were used to irradiate the devices with a fluence of 1×10^7 ions/cm². The results demonstrate that the INA240-SEP is SEL-free up to LET_{EFF} = 43 MeV-cm²/mg at 125°C.

Table of Contents

Trademarks.....	1
1 Overview.....	2
2 SEE Mechanisms.....	3
3 Test Device and Test Board Information.....	4
4 Irradiation Facility and Setup.....	5
5 Results.....	6
5.1 SEL Results.....	6
6 Summary.....	7
A Confidence Interval Calculations.....	8
B References.....	10

Trademarks

All other trademarks are the property of their respective owners.

1 Overview

The INA240-SEP is a current-sense amplifier that offers a wide common-mode range, precision, zero-drift topology, excellent common-mode rejection ratio (CMRR), and features an enhanced pulse width modulation (PWM) rejection. Enhanced PWM rejection reduces the effect of common-mode transients on the output signal that are associated with PWM signals.

www.ti.com/product/INA240-SEP

Table 1-1. Overview Information ⁽¹⁾

DESCRIPTION	DEVICE INFORMATION
TI Part Number	INA240-SEP
MLS Number	INA240PMPWTPSEP
Device Function	Radiation Hardened Ultra-Precise Current-Sense Amplifier w/ Enhanced PWM Rejection in Space Enhanced Plastic
Technology	ABCD6
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University
Heavy Ion Fluence per Run	$1 \times 10^6 - 1 \times 10^7$ ions/cm ²
Irradiation Temperature	125°C (for SEL testing)

- (1) 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 SEE Mechanisms

The primary single-event effect (SEE) events of interest in the INA240-SEP are single-event latch-up (SEL). From a risk/impact point-of-view, the occurrence of an SEL is potentially the most destructive SEE event and the biggest concern for space applications. The ABCD6 was used for the INA240-SEP. 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 INA240-SEP exhibited no SEL with heavy-ions up to an LET_{EFF} of 43 MeV-cm²/mg at a fluence of 10⁷ ions/cm² and a chip temperature of 125°C.

This study was performed to evaluate the SEL effects with a bias voltage of 5.5 V on V_S supply voltage with a common-mode of 80 Volts. Heavy ions with $LET_{EFF} = 43$ MeV-cm²/mg were used to irradiate the devices. Flux of 10⁵ ions/s-cm² and fluence of 10⁷ ions/cm² were used during the exposure at 125°C temperature.

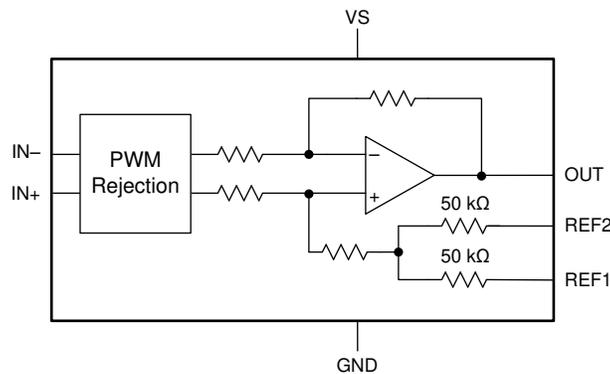


Figure 2-1. Functional Block Diagram of the INA240-SEP

3 Test Device and Test Board Information

The INA240-SEP is packaged in an 8-pin, TSSOP shown with pinout in Figure 3-1. Figure 3-2 shows the INA240-SEP bias diagram.

INA240-SEP pinout diagram. The package was decap'ed to reveal the die face for all heavy ion testing.

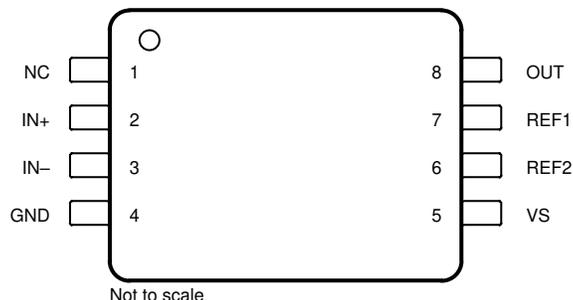


Figure 3-1. INA240-SEP Pinout Diagram

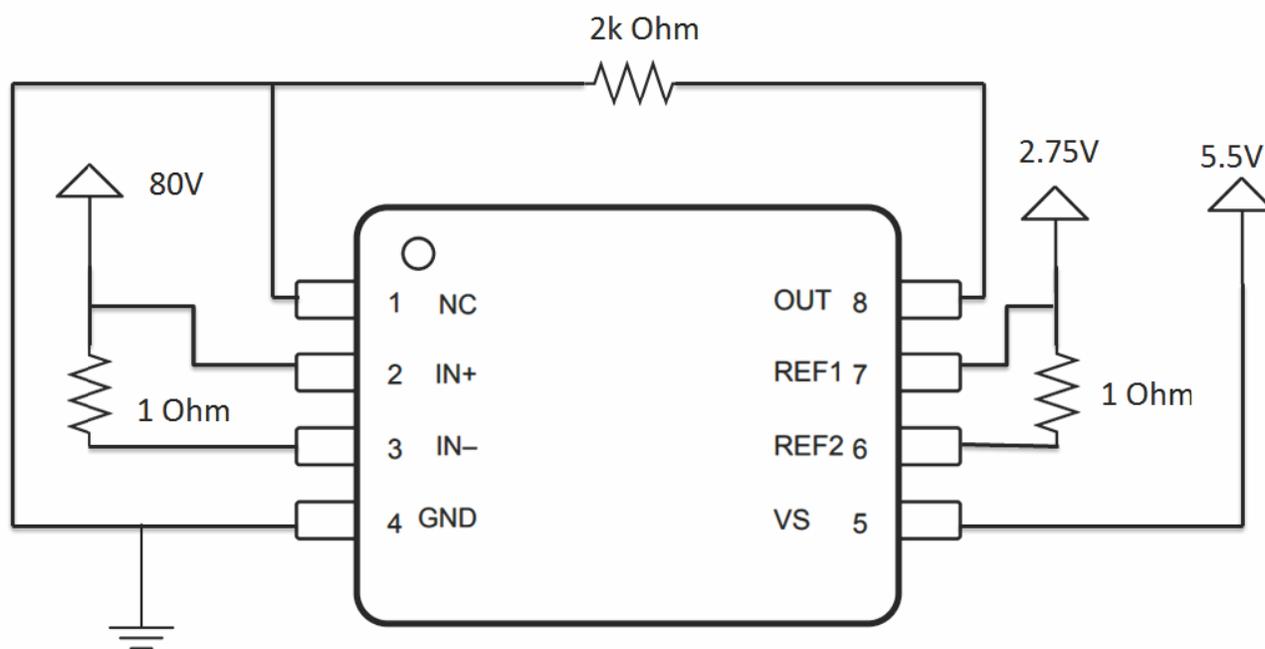


Figure 3-2. INA240-SEP Bias Diagram

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 [3] using a superconducting cyclotron and advanced electron cyclotron resonance (ECR) ion source. Ion beams are delivered with high uniformity over a 1-inch diameter circular cross sectional area for the in-air station. Uniformity is achieved by means of magnetic defocusing. The intensity of the beam is regulated over a broad range spanning several orders of magnitude. For the bulk of these studies, ion fluxes between 10^4 and 10^5 ions/s-cm² were used to provide heavy ion fluences between 10^6 and 10^7 ions/cm². For these experiments Silver (Ag) ions were used. Ion beam uniformity for all tests was in the range of 91% to 98%.

5 Results

5.1 SEL Results

During SEL characterization, the device was heated using forced hot air, maintaining the IC temperature at 125°C. The temperature was monitored by means of a K-type thermocouple attached as close to the IC as possible. The species used for the SEL testing was a silver (⁴⁷Ag) ion with an angle-of-incidence of 0° for an LET_{EFF} = 43 MeV-cm²/mg. The kinetic energy in the vacuum for this ion is 1.634 GeV (15-MeV/amu line). A flux of approximately 10⁵ ions/cm²-s and a fluence of approximately 10⁷ ions were used for two runs. The V_s supply voltage is supplied externally onboard at the recommended maximum voltage setting of 5.5 V and a common-mode voltage of 80 V. Run duration to achieve this fluence was approximately 2 minutes. No SEL events were observed during all four runs shown in [Table 5-1](#). [Figure 5-1](#) shows a plot of the current vs time.

Table 5-1. INA240-SEP SEL Conditions Using⁴⁷Ag at an Angle-of-Incidence of 0°

RUN #	DISTANCE (mm)	TEMPERATURE (°C)	ION	ANGLE	FLUX (ions·cm ² /mg)	FLUENCE (# ions)	LET _{EFF} (MeV·cm ² /mg)
31	40	125	Ag	0°	1.00E+05	1.00E+07	43
32	40	125	Ag	0°	1.00E+05	1.00E+07	43

No SEL events were observed, indicating that the INA240-SEP is SEL-immune at LET_{EFF} = 43 MeV-cm²/mg and T = 125°C. Using the MFTF method described in [Appendix A](#) and combining (or summing) the fluences of the two runs @ 125°C (2 × 10⁷), the upper-bound cross-section (using a 95% confidence level) is calculated in [Equation 1](#):

$$\sigma_{SEL} \leq 1.84 \times 10^{-7} \text{ cm}^2 \text{ for LET}_{EFF} = 43 \text{ MeV-cm}^2/\text{mg and } T = 125^\circ\text{C.} \tag{1}$$

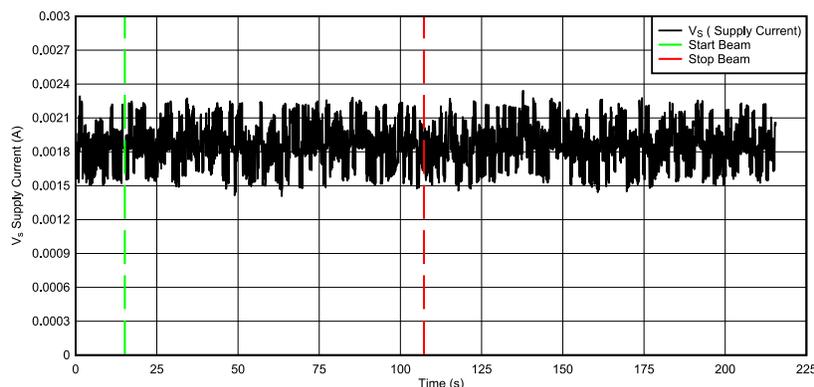


Figure 5-1. Current vs Time (I vs t) Data for Vs Current During SEL Run # 32

6 Summary

Radiation effects of Radiation Hardened Ultra-Precise Current-Sense Amplifier w/ Enhanced PWM Rejection in Space Enhanced Plastic, INA240-SEP, was studied. This device passed total dose rate of up to 30 krad(Si) and is latch-up immune up to $LET_{EFF} = 43 \text{ MeV-cm}^2/\text{mg}$ and $T = 125^\circ\text{C}$.

A Confidence Interval Calculations

For conventional products where hundreds of failures are seen during a single exposure, one can determine the average failure rate of parts being tested in a heavy-ion beam as a function of fluence with high degree of certainty and reasonably tight standard deviation, and thus have a good deal of confidence that the calculated cross-section is accurate.

With radiation-hardened parts however, it is difficult to determine the cross-section 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, the use of 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, one expects a failure rate 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/cm²) while the DUT is monitored for failures. This 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 hence it is a fixed fluence test [5]). Calculating a confidence interval specifically provides a range of values which is likely to contain the parameter of interest (the actual number of failures/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 would bracket the true population parameter in about 95% of the cases.

To estimate the cross-section from a null-result (no fails observed for a given fluence) with a confidence interval, we start with the standard reliability determination of lower-bound (minimum) mean-time-to-failure for fixed-time testing (an exponential distribution is assumed) in [Equation 2](#):

$$MTTF = \frac{2nT}{\chi^2(d+1); 100(1-\frac{\alpha}{2})} \quad (2)$$

Where:

- *MTTF* is the minimum (lower-bound) mean-time-to-failure,
- *n* is the number of units tested (presuming each unit is tested under identical conditions),
- *T* is the test time,
- and χ^2 is the chi-square distribution evaluated at $100(1 - \alpha / 2)$ confidence level
- *d* is the degrees-of-freedom (the number of failures observed).

With slight modification for our purposes we invert the inequality and substitute *F* (fluence) in the place of *T* as shown in [Equation 3](#):

$$MFTF = \frac{2nF}{\chi^2(d+1); 100(1-\frac{\alpha}{2})} \quad (3)$$

Where:

- *MFTF* is mean-fluence-to-failure
- *F* is the test fluence

- χ^2 is the chi-square distribution evaluated at $100(1 - \alpha / 2)$ confidence
- d is the degrees-of-freedom (the number of failures observed).

The inverse relation between $MTTF$ and failure rate is mirrored with the $MFTF$. Thus the upper-bound cross-section is obtained by inverting the $MFTF$ as shown in Equation 4:

$$\sigma = \frac{\chi^2(d+1); 100(1 - \frac{\alpha}{2})}{2nF} \quad (4)$$

Assume that all tests are terminated at a total fluence of 10^6 ions/cm². Also assume there are a number of devices with very different performances that are tested under identical conditions. Assume a 95% confidence level ($\sigma = 0.05$). Note that as d increases from 0 events to 100 events, the actual confidence interval becomes smaller, indicating that the range of values of the true value of the population parameter (in this case the cross-section) is approaching the mean value + 1 standard deviation. This makes sense when one considers that as more events are observed the statistics are improved such that uncertainty in the actual device performance is reduced.

Table A-1. Experimental Example Calculation of MFTF and σ Using a 95% Confidence Interval (1)

Degrees-of-Freedom (d)	2(d + 1)	$\chi^2 @ 95\%$	Calculated Cross-Section (cm ²)		
			Upper-Bound @ 95% Confidence	Mean	Average + Standard Deviation
0	2	7.38	3.69E-06	0.00E+00	0.00E+00
1	4	11.14	5.57E-06	1.00E-06	2.00E-06
2	6	14.45	7.22E-06	2.00E-06	3.41E-06
3	8	17.53	8.77E-06	3.00E-06	4.73E-06
4	10	20.48	1.02E-05	4.00E-06	6.00E-06
5	12	23.34	1.17E-05	5.00E-06	7.24E-06
10	22	36.78	1.84E-05	1.00E-05	1.32E-05
50	102	131.84	6.59E-05	5.00E-05	5.71E-05
100	202	243.25	1.22E-04	1.00E-04	1.10E-04

- (1) Using a 95% confidence interval for several different observed results ($d = 0, 1, 2, \dots, 100$ observed events during fixed-fluence tests) assuming 10^6 ions/cm² for each test. Note that as the number of observed events increases the confidence interval approaches the mean.

B 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. TAMU Radiation Effects Facility website. <http://cyclotron.tamu.edu/ref/>
4. "The Stopping and Range of Ions in Matter" (SRIM) software simulation tools website. www.srim.org/index.htm#SRIMMENU
5. D. Kececioglu, "Reliability and Life Testing Handbook", Vol. 1, PTR Prentice Hall, New Jersey, 1993, pp. 186-193.
6. ISDE CRÈME-MC website. <https://creme.isde.vanderbilt.edu/CREME-MC>
7. A. J. Tylka, J. H. Adams, P. R. Boberg, et al., "CREME96: A Revision of the Cosmic Ray Effects on Micro-Electronics Code", *IEEE Trans. on Nucl. Sci.*, Vol. 44(6), Dec. 1997, pp. 2150-2160.
8. 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 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, 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 will 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 (www.ti.com/legal/termsofsale.html) 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.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2020, Texas Instruments Incorporated