Application Report

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-cm^2/mg were used to irradiate the devices with a fluence of 1 × 10^7 ions/cm^2. The results demonstrate that the INA240-SEP is SEL-free up to LET_{EFF} = 43 MeV-cm^2/mg at 125°C.

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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	1×10^6 – 1×10^7 ions/cm^2
Irradiation Temperature	125°C (for SEL testing)

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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-cm^2/mg at a fluence of 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 5.5 V on V_S supply voltage with a common-mode of 80 Volts. Heavy ions with LET_{EFF} = 43 MeV-cm^2/mg were used to irradiate the devices. Flux of 10^5 ions/s-cm^2 and fluence of 10^7 ions/cm^2 were used during the exposure at 125°C temperature.

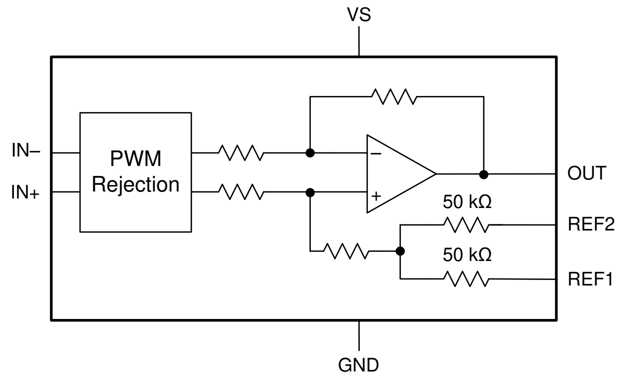

Figure 2-1. Functional Block Diagram of the INA240-SEP

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.

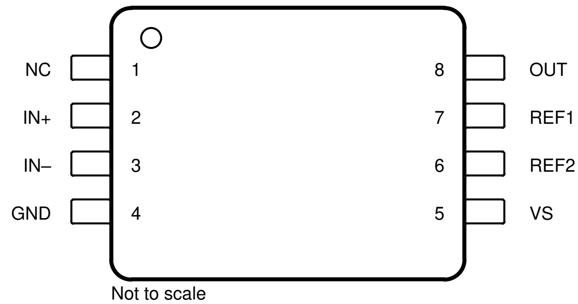

Figure 3-1. INA240-SEP Pinout Diagram

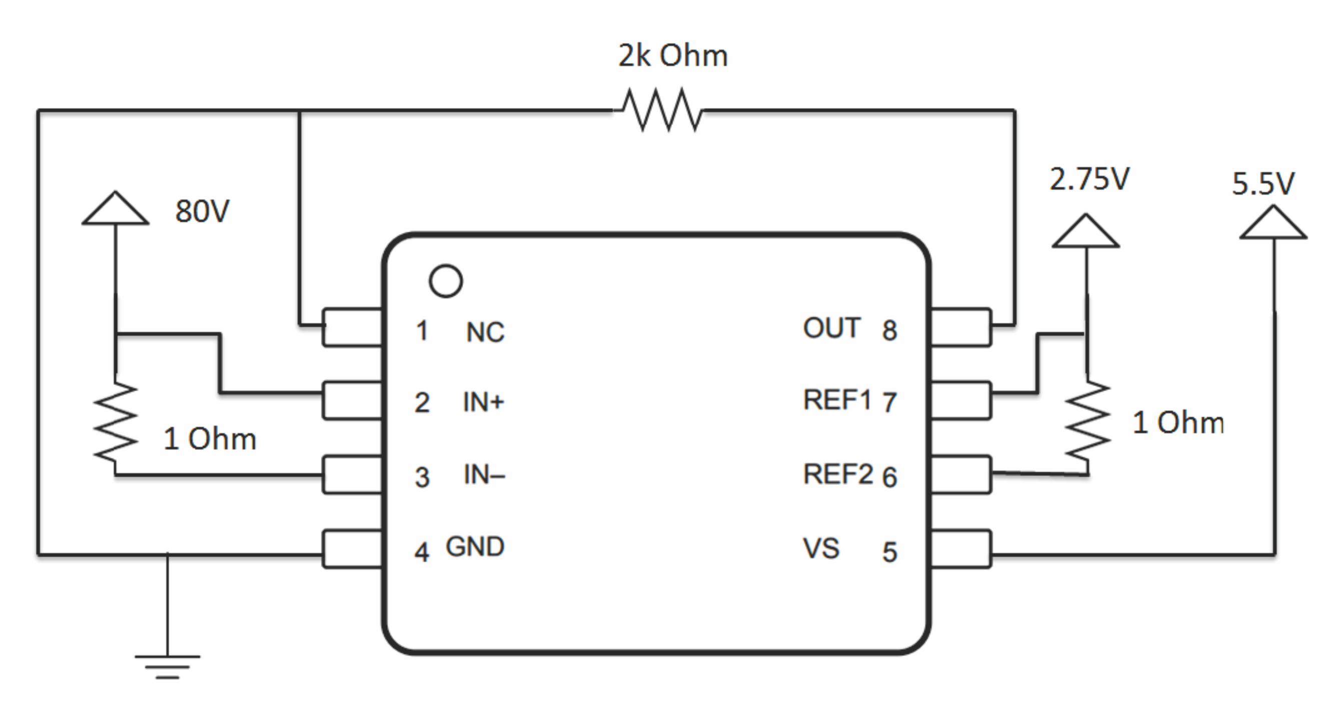

Figure 3-2. INA240-SEP Bias Diagram

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-cm^2 were used to provide heavy ion fluences between 10^6 and 10^7 ions/cm^2. 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 (^{47}Ag) ion with an angle-of-incidence of 0° for an LET_{EFF} = 43 MeV-cm^2/mg. The kinetic energy in the vacuum for this ion is 1.634 GeV (15-MeV/amu line). A flux of approximately 10^5 ions/cm^2-s and a fluence of approximately 10^7 ions were used for two runs. The Vs 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 Using ^{47}Ag 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-cm^2/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 × 10^7), the upper-bound cross-section (using a 95% confidence level) is calculated in Equation 1:

$$\sigma SEL \leq 1.84 \times 10^{-7}\ cm^2 \text{ for } LET_{EFF} = 43\ MeV\text{-}cm^2/mg \text{ and } T = 125°C. \quad (1)$$

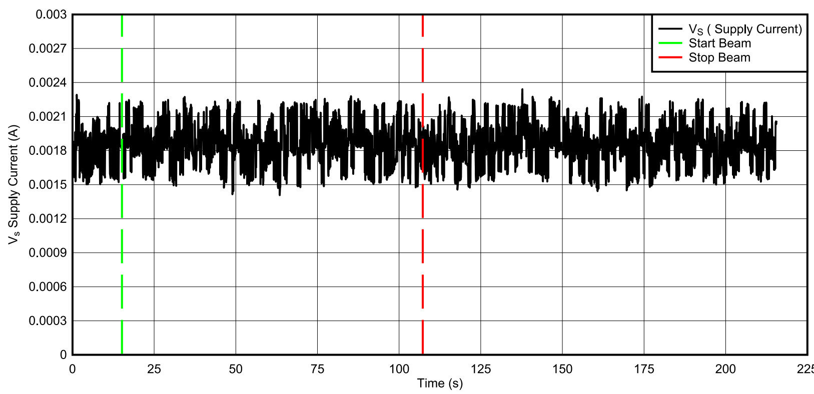

Figure 5-1. Current vs Time (I vs t) Data for Vs Current During SEL Run # 32

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 MeV-cm^2/mg and T = 125°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/cm^2) 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:

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

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 – α / 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:

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

Where:

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

- X^2 is the chi-square distribution evaluated at 100(1 – α / 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:

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

Assume that all tests are terminated at a total fluence of 10^6 ions/cm^2. Also assume there are a number of devices with very different performances that are tested under identical conditions. Assume a 95% confidence level (σ = 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)	χ^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,…100 observed events during fixed-fluence tests) assuming 10^6 ions/cm^2 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.