Radiation Report

ADC128S102-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 ADC128S102-SEP high-speed, quad-channel digital isolator. 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 ADC128S102-SEP is SEL-free up to LET_{EFF} = 43 MeV-cm^2/mg at 125°C.

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1 Overview

The ADC128S102-SEP is a radiation-tolerant, eight-channel, 50-kSPS to 1-MSPS, 12-bit analog-to-digital converter. The device uses single-ended CMOS technology and an SPI or MICROWIRE™ (serial I/O) interface standard. The voltage range is from 2.7 V to 5.25 V for both supplies, VA and VD. The digital inputs are not prone to latch-up and can be asserted before the digital supply.

http://www.ti.com/product/ADC128S102-SEP

Table 1-1. Overview Information(1)

DESCRIPTION	DEVICE INFORMATION
TI part number	ADC128S102-SEP
MLS number	ADC128S102PWTSEP
Device function	Radiation-tolerant, eight-channel, 50-kSPS to 1-MSPS, 12-bit ADC
Technology	CMOS7
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)

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2 SEE Mechanisms

The primary single-event effect (SEE) event of interest in the ADC128S102-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. The CMOS7 process node was used for the ADC128S102-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 ADC128S102-SEP exhibited no SEL with heavy-ions up to a of LET_{EFF} = 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 5.25 V on VA and VD supply voltage. 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 shows a functional block diagram for this device.

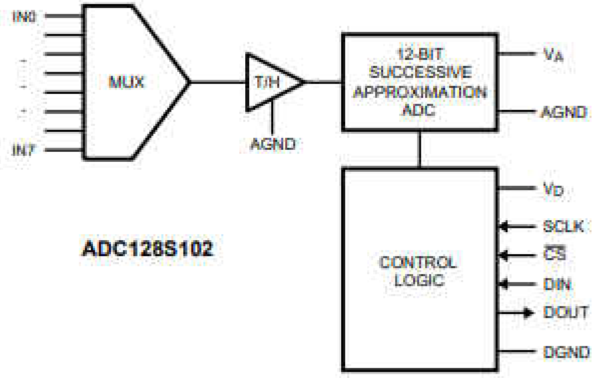

Figure 2-1. Functional Block Diagram of the ADC128S102-SEP

3 Test Device and Test Board Information

The ADC128S102-SEP is packaged in a 16-pin, TSSOP shown with the pinout in Figure 3-1. Figure 3-2 shows the biasing configuration used for both the SEL and SET tests.

ADC128S102-SEP pinout diagram. The package was decap'ed to reveal the die face for all heavy ion testing.

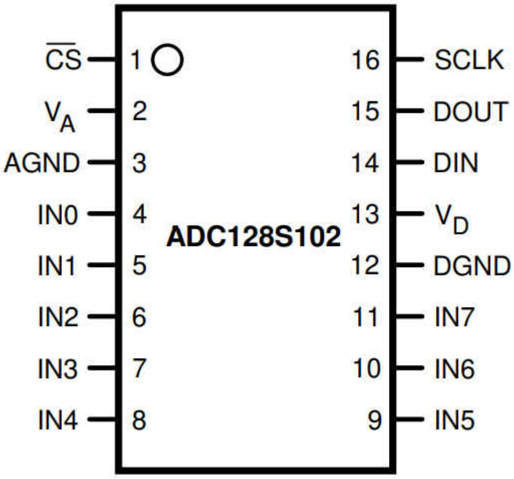

Figure 3-1. ADC128S102-SEP Pinout Diagram

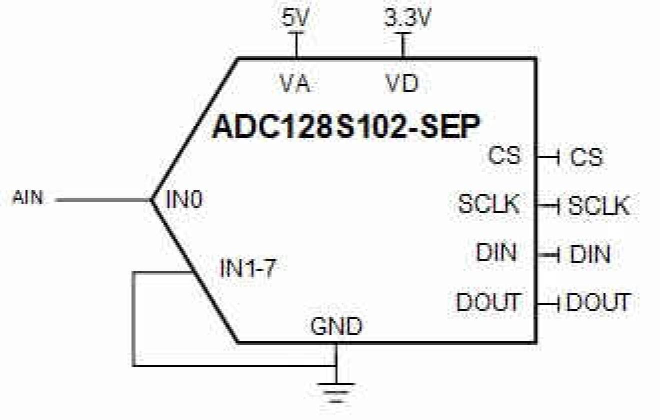

Figure 3-2. ADC128S102-SEP Bias Configuration

4 Irradiation Facility and Setup

The heavy ion species used for the SEE studies on this product were provided and delivered by the 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 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 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/s-cm^{2}and a fluence of approximately 10^7 ions/cm were used for two runs. The VA supply voltage is supplied externally onboard with the highest recommended voltage setting of 5.25 V for VA and VD. The run duration to achieve this fluence was approximately 2 minutes. As shown in Table 5-1, no SEL events were observed during all four runs. Figure 5-1 shows a plot of the current versus time.

Table 5-1. ADC128S102-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)
16	40	125	Ag	0°	1.00E+05	1.00E+07	43

No SEL events were observed, indicating that the ADC128S102-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 at 125°C (1 × 10^7), the upper-bound cross section (using a 95% confidence level) is calculated in Equation 1:

$$\sigma\text{SEL} \leq 3.67 \times 10^{-7}\ \text{cm}^2 \quad (1)$$

where:

- LET_{EFF} = 43 MeV-cm^2/mg
- T = 125°C

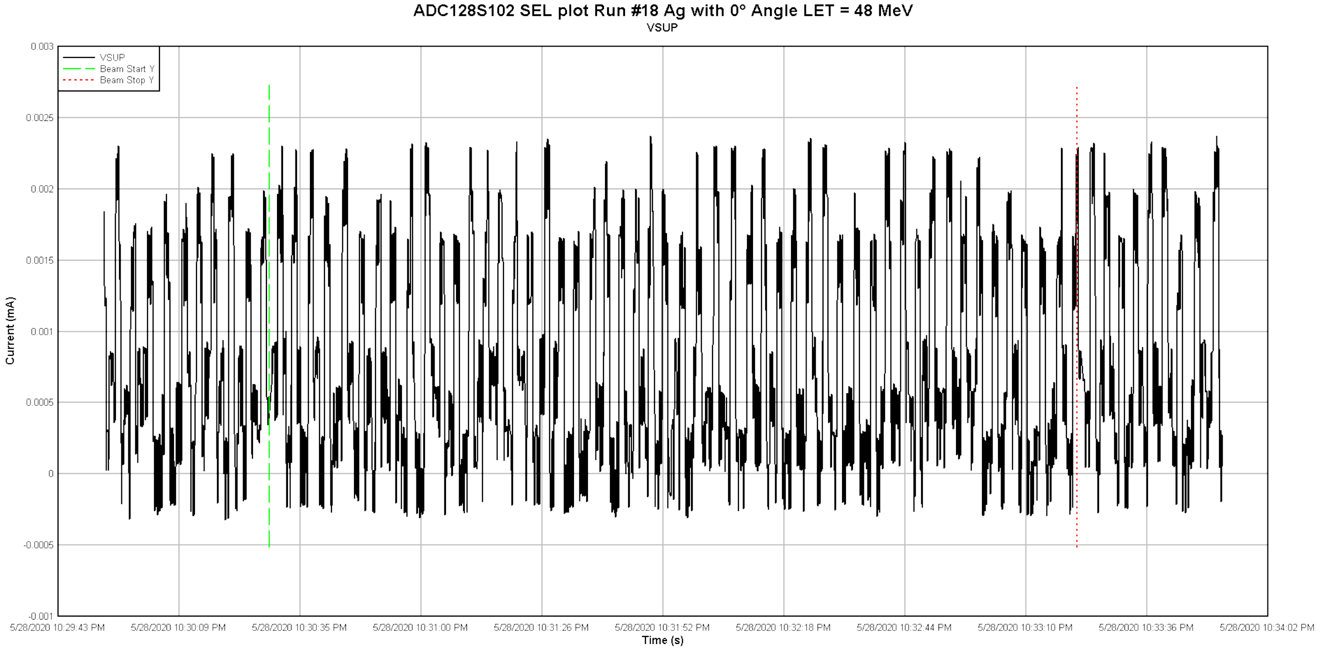

Figure 5-1. Current vs Time (I vs t) Data for Vs Current During SEL Run #18

5.2 Single-Event Transient Results

Study was performed to evaluate the cross section and transient effects with a bias voltage of 5.25 V on VA and VD.

To capture different SET signature events, the triggers were set with a ±2 degree variance. Heavy ions with LET_{EFF} 43 MeV-cm^2/mg were used to irradiate the devices. Flux of 10^4 ions/s-cm^2 and fluence of 10^6 ions/cm^2 were used during the exposure at room temperature.

The output temperature data was processed and analyzed. SET events were observed, a mean-fluence-to fail [5] method was used to calculate an upper-bound for the cross-section as, using 95% confidence intervals:

$$\sigma = X^2{}_{2(d+1);\ 100(1-\alpha/2)} / 2\eta F \tag{2}$$

where:

- LET_{EFF} = 43 MeV-cm^2/mg
- T = 25°C
- $\sigma_{\text{SET}} \leq 4.98 \times 10^{-7}$ cm² at 5.25-V bias, VA and VD

6 Summary

Radiation effects of the radiation-tolerant, eight-channel, 50-kSPS to 1-MSPS, 12-bit analog-to-digital converter, ADC128S102-SEP, was studied. This device passed a 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 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 3:

$$MTTF = \frac{2nT}{\chi^{2}_{2(d+1);\,100\left(1-\frac{\alpha}{2}\right)}} \tag{3}$$

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
- 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 to this equation for the purposes of this test, invert the inequality and substitute *F* (fluence) in the place of *T*, as shown in Equation 4:

$$MFTF = \frac{2nF}{\chi^{2}_{2(d+1);\,100\left(1-\frac{\alpha}{2}\right)}} \tag{4}$$

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 5:

$$\sigma = \frac{\chi^{2}_{2(d+1);\,100\left(1-\frac{\alpha}{2}\right)}}{2nF} \tag{5}$$

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). When *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 difference makes sense when considering 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 at 95%	Calculated Cross Section (cm^2)		
			Upper-Bound at 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. When 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.

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