Radiation Report

ADC128S102-SEP Single-Event Latch-Up (SEL) Radiation Report

Abstract

The purpose of this study is to characterize the Single Event Effects (SEE) performance due to heavy-ion irradiation of the ADC128S102-SEP. Heavy-ions with Effective Linear Energy Transfer (LETEFF) of 48 MeV×cm2 /mg were used. A Flux of 10^4 to 10^5 ions/cm^2 ·s and Fluence of 10^6 to 10^7 ions/cm^2 per run were used for the different SEEs characterization. The results demonstrate that the ADC128S102-SEP is Single Event Latch-Up (SEL) free up to LETEFF = 48MeV × cm^2 /mg at T = 125°C. Single Event Transients (SET) are characterized at 25°C and no Single Event Functional Interrupts (SEFI) (power-cycle events) were seen up to 48MeV × cm^2 /mg.

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1 Introduction

The ADC128S102-SEP is a radiation-tolerant, 12-bit, eight-channel, 1-MSPS, analog-to-digital converter (ADC). The converter is based on a successive-approximation register (SAR) architecture with an internal track-and-hold circuit. The device can be configured to accept up to eight input signals at inputs IN0 through IN7.

The output serial data is straight binary and compatible with several standards, such as SPI, QSPI, MICROWIRE, and many common DSP serial interfaces.

The ADC128S102-SEP can be operated with independent analog and digital supplies. The analog supply (VA) can range from 2.7 V to 5.25 V, and the digital supply (VD) can range from 2.7V to VA. Normal power consumption using a 3V or 5V supply is 2.3mW and 10.7mW, respectively. The power-down feature reduces the power consumption to 16.5µW using a 3V supply and 30µW using a 5V supply.

See the product page for more information.

Table 1-1. Overview Information(1)

Description	Device Information
TI part number	ADC128S102-SEP
MLS number	ADC128S102PWTSEP
Device function	Radiation-tolerant, eight-channel, 50kSPS to 1MSPS, 12-bit ADC
Technology	CMOS7
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 Single-Event Effects (SEE)

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 SEE 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 LETEFF = 48 MeV×cm2/ mg at a fluence of 10**7** ions / cm2 and at T = 125°C.

This study was performed to evaluate the SEL effects with a bias voltage of 5.25V on VA and VD supply voltage. Heavy ions with LETEFF = 48 MeV×cm2 / mg were used to irradiate the devices. A flux of 105 ions/cm2×s and a fluence of 107 ions / cm2 were used during the exposure at T = 125°C.

The ADC128S102-SEP was characterized for SETs at a flux of 105 ions/cm2×s to reach a fluence of 107 ions / cm2 per run, at T = 25°C. The ADC128S102-SEP is SEFI-free up to 48 LETEFF at incident angle.

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

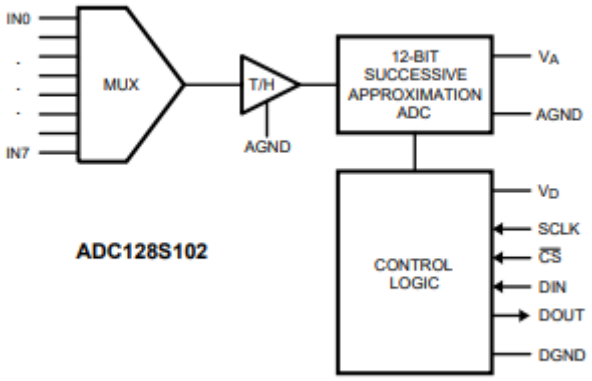


Figure 2-1. Functional Block Diagram of the ADC128S102-SEP

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3 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.

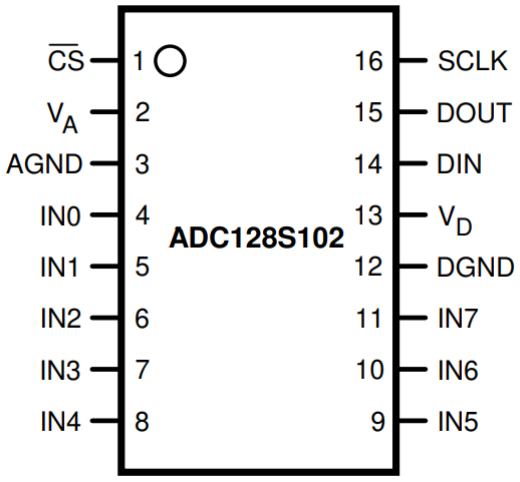


Figure 3-1. ADC128S102-SEP Pinout Diagram

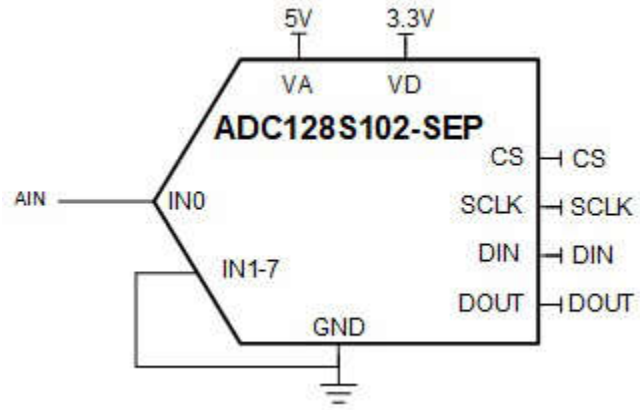


Figure 3-2. ADC128S102-SEP Bias Configuration

4 Irradiation Facility and Setup

The heavy ion species used for the SEE studies on this device were provided and delivered by the Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced Electron Cyclotron Resonance (ECR) ion source. At the fluxes used, the ion beam 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 de-focusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of 104 and 105 ions/cm**2**·s were used to provide heavy-ion fluences of 106 to 107 ions/cm2.

5 Single-Event Latch-Up (SEL) 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} = 48MeV-cm^2 / mg. The kinetic energy in the vacuum for this ion is 1.634GeV (15MeV/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 5.25V for VA and

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VD. The run duration to achieve this fluence was approximately two minutes. As listed 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 Number	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 Section 7 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:

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

where:

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

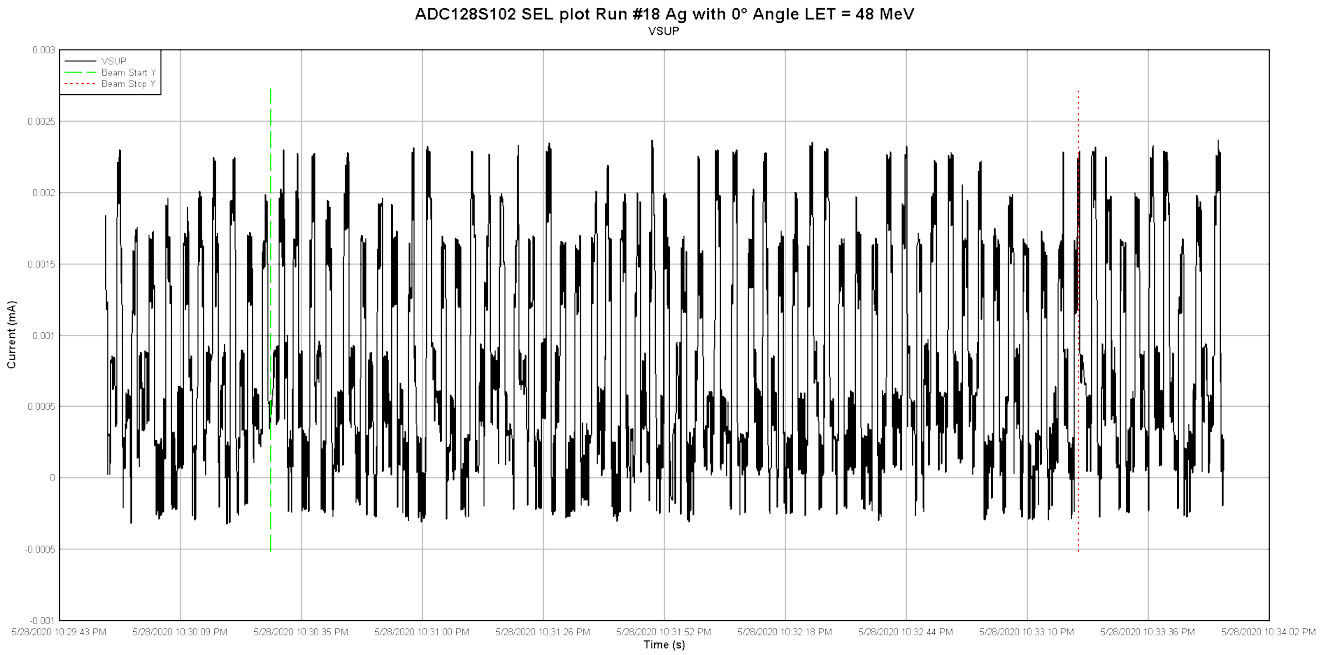


Figure 5-1. Current versus Time (I vs t) Data for versus Current During SEL Run 18

6 Single-Event Transient (SET) Results

For SET characterization, channel 0 was monitored and given input voltage that corresponded to 2000 LSB. The device was powered for VA and VD, and another PSU was used to provide a DC bias to input channel(s). The device was configured to continuously read. The device was characterized in the environment without irradiation beforehand, to identify the code outputs for the given input voltage.

For the purpose of this study, a SET is defined as a deviation in code values from the known un-irradiated device setup by +/-50 LSB.

Table 6-1. Test Conditions and Results

Runs	Test	Unit	Temp (C)	Ion	Angle	LETeff	Flux	Fluence	Events	Cross Section
11	SET		25	Ag	0	48	1×10^4	1×10^6	14	1.27×10^6

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7 Confidence Interval Calculations/ Event Rate 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 designed 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. 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 2:

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

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
- 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 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)

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

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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:

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

Assume that all tests are terminated at a total fluence of 10^6 ions / cm^2. 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 7-1. Experimental Example Calculation of MFTF and σ Using a 95% Confidence Interval

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

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8 Summary

The purpose of this study was to characterize the effect of heavy-ion irradiation on the Single Event-Effect (SEE) performance of the ADC128S102-SEP. Heavy-ions with LETEFF up to 48 MeV×cm2/mg were used for the SEE characterization. Flux of up to 105 ions/cm2·s and fluences up to 107 ions / cm2 per run were used. The SEE results demonstrated that the ADC128S102-SEP is SEL and SEFI free up to LETEFF = 48 MeV×cm2/ mg. The device is characterized for SETs up to LETEFF = 48 MeV×cm2/ mg.

9 References

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