Single-Event Effects Test Report of the ADS1278-SP Octal, 24-Bit ADC

ABSTRACT

The purpose of this study was to characterize the effects of heavy-ion irradiation on the single-event Latch Up (SEL) performance of the ADS1278-SP (octal) are 24-bit, delta-sigma (ΔΣ) analog-to-digital converters (ADCs) with data rates up to 128k samples per second (SPS), allowing simultaneous sampling of eight channels. Heavy-ions with an LET_{EFF} of 69.96 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 ADS1278-SP is SEL-free up to LET_{EFF} = 69.96 MeV-cm^2/mg at 125°C.

Contents

List of Figures

List of Tables

Trademarks

All trademarks are the property of their respective owners.

1 Overview

The ADS1278-SP device is a radiation-hardened, octal 24-bit, delta-sigma (ΔΣ) analog-to-digital converter (ADC) with data rates up to 128k samples per second (SPS), allowing simultaneous sampling of eight channels. Traditionally, industrial delta-sigma ADCs offering good drift performance use digital filters with large passband droop. As a result, they have limited signal bandwidth and are mostly suited for dc measurements. High-resolution ADCs in audio applications offer larger usable bandwidths, but the offset and drift specifications are significantly weaker than respective industrial counterparts. ADS1278-SP combines these types of converters allowing high-precision industrial measurement with excellent dc and ac specifications. The high-order, chopper-stabilized modulator achieves very low drift with low in-band noise. The onboard decimation filter suppresses modulator and signal out-of-band noise.

www.ti.com/product/ADS1278-SP/technicaldocuments

Table 1. Overview Information (1)

DESCRIPTION	DEVICE INFORMATION
TI Part Number	ADS1278-SP
MLS Number	ADS1278MHFQ-MLS
Device Function	24-Bit Analog-to-Digital Converters
Technology	TSMC 0.35-µm DPQM 3.3 V and 5 V
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	25°C and 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 ADS1278-SP are single-event latch-up (SEL), single-event burnout (SEB) and single-event transient (SET). From a risk/impact point-of-view, the occurrence of an SEL and SEB is potentially the most destructive SEE event and the biggest concern for space applications. The TSMC 0.35-µM DPQM 3.5 V and 5 V was used for the ADS1278-SP. CMOS circuitry introduces a potential for SEL and SEB 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 ADS1278-SP exhibited no SEL with heavy-ions up to an LET_{EFF} of 69.96 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 AVDD, 3.6 V on IOVDD and 2.2 V on DVDD. Heavy ions with LET_{EFF} = 69.96 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.

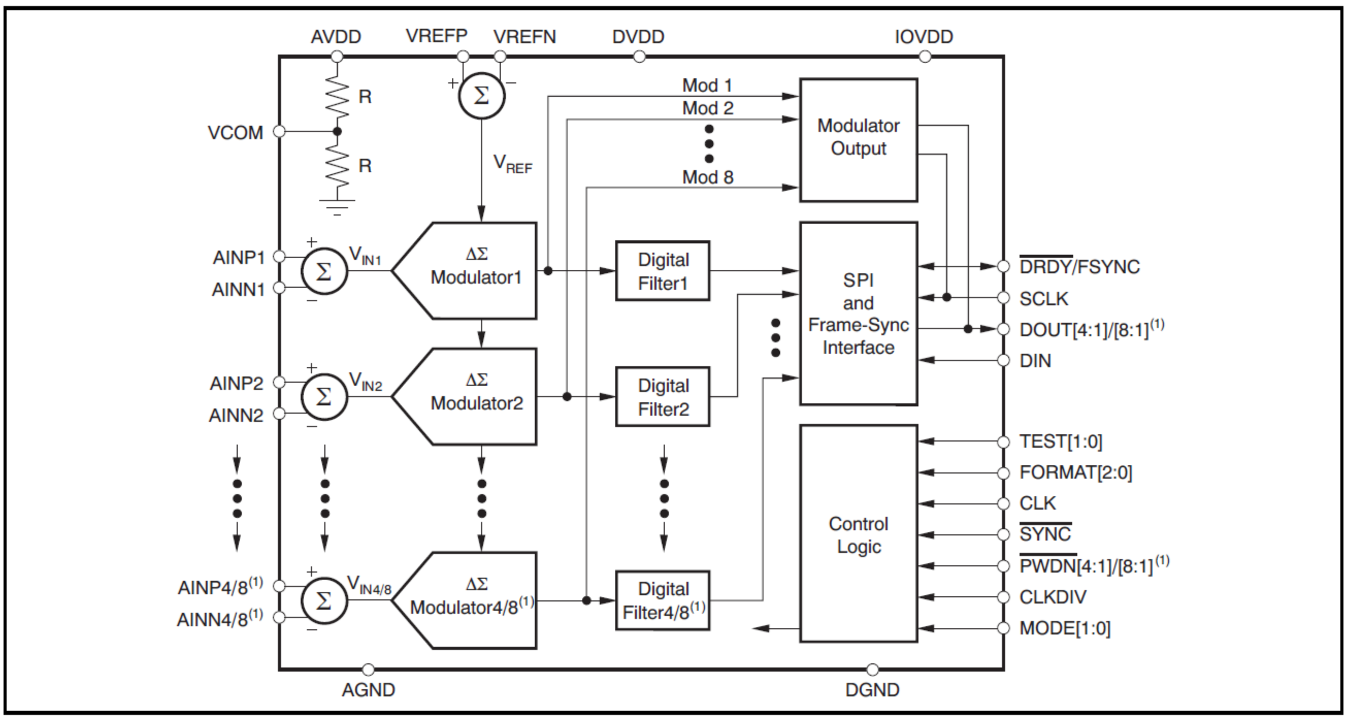
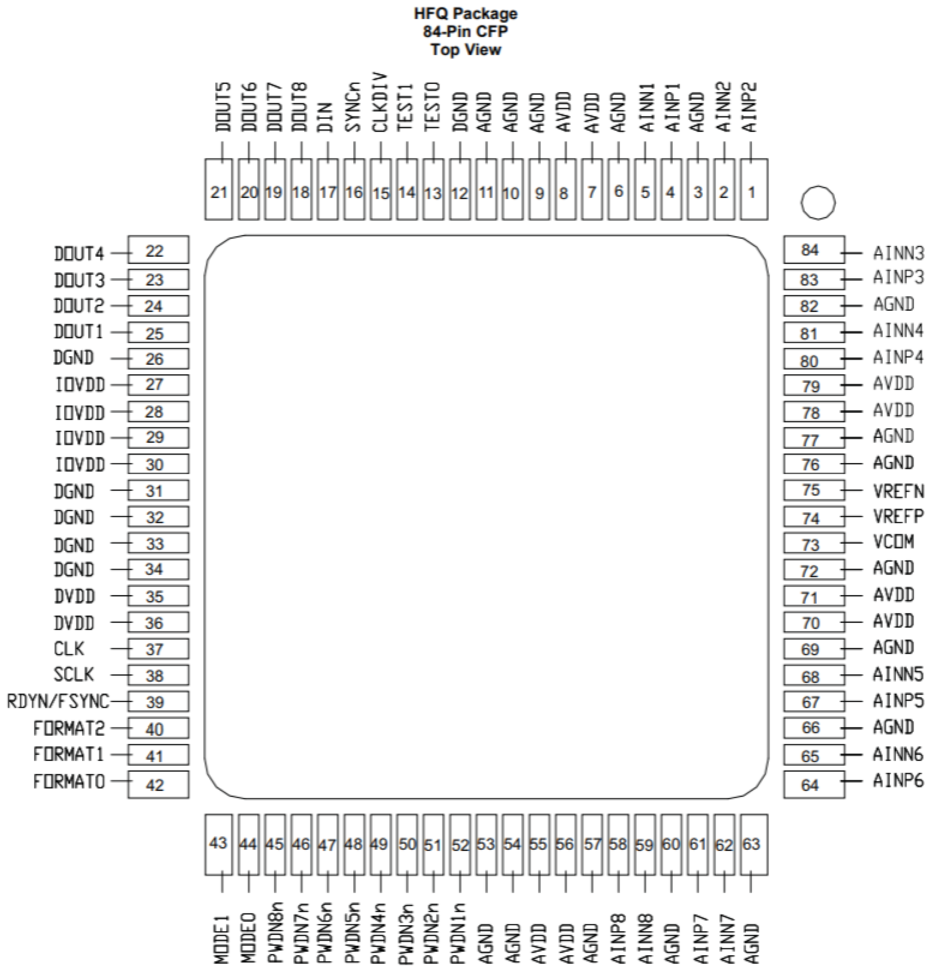


Figure 1. Functional Block Diagram of the ADS1278-SP

3 Test Device and Test Board Information

The ADS1278-SP is packaged in a 84-pin, HFQ shown with pinout shown in Figure 2. The ADS1278-SP evaluation board used for the SEE characterization is shown in Figure 3 and schematics in Figure 4.



NOTE: ADS1278-SP pinout diagram. The package was decap'ed to reveal the die face for all heavy ion testing.

Figure 2. ADS1278-SP Pinout Diagram

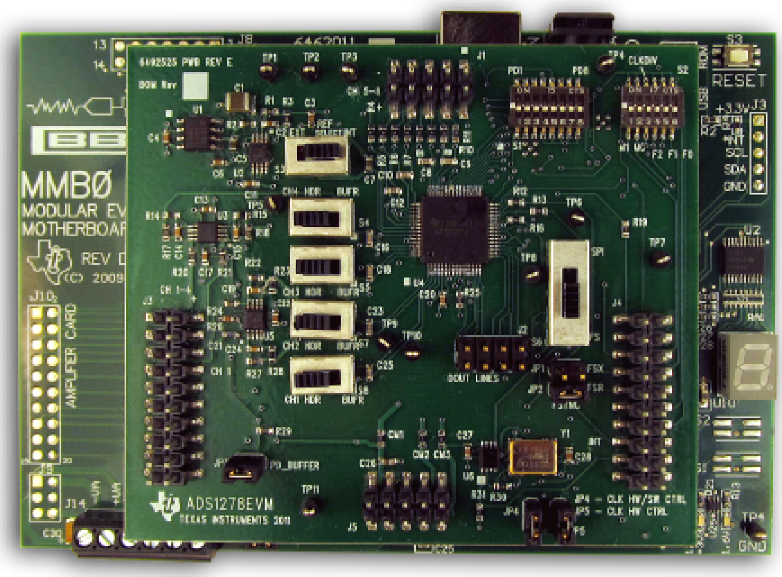


Figure 3. ADS1278EVM-CVAL 24-Bit Analog-to-Digital Converter Evaluation and Demonstration Kit

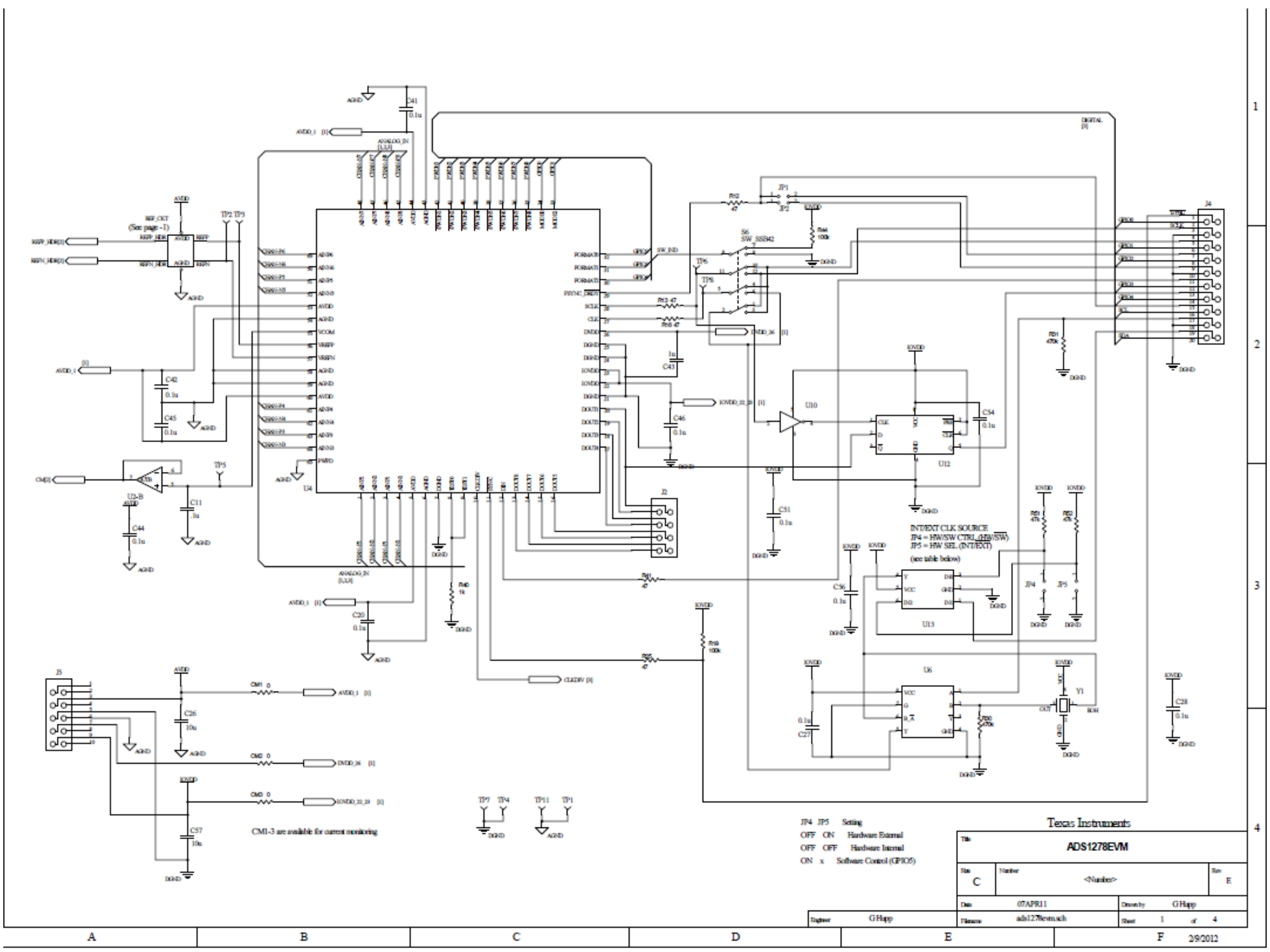


Figure 4. ADS1278EVM-PDK Schematic

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-in 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 as possible to the IC. The species used for the SEL testing was a silver (^{47}Ag) ion with an angle-of-incidence of 45° for an LET_{EFF} = 69.96 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 three supplies of AVDD, IOVDD, and DVDD are supplied externally by-passing the on board regulators at recommended maximum voltage setting of 5.25 V, 3.6 V, and 2.2 V, respectively. Run duration to achieve this fluence was approximately 2 minutes. No SEL events were observed during all four runs shown in Table 2. Figure 5 and Figure 6 show plots of the current vs time.

Table 2. ADS1278-SP SEL Conditions Using ^{47}Ag at an Angle-of-Incidence of 45°

RUN #	DISTANCE (mm)	TEMPERATURE (°C)	ION	ANGLE	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	LET_{EFF} (MeV.cm^2/mg)
18	40	25	Ag	45°	1.00E+05	1.00E+07	69.96
19	40	25	Ag	45°	1.00E+05	1.00E+07	69.96
20	40	125	Ag	45°	1.00E+05	1.00E+07	69.96
21	40	125	Ag	45°	1.00E+05	1.00E+07	69.96

No SEL events were observed, indicating that the ADS1278-SP is SEL-immune at LET_{EFF} = 69.96 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 as:

$\sigma SEL \leq 1.84 \times 10^{-7}$ cm^2 for LET_{EFF} = 69.96 MeV-cm^2/mg and T = 125°C.

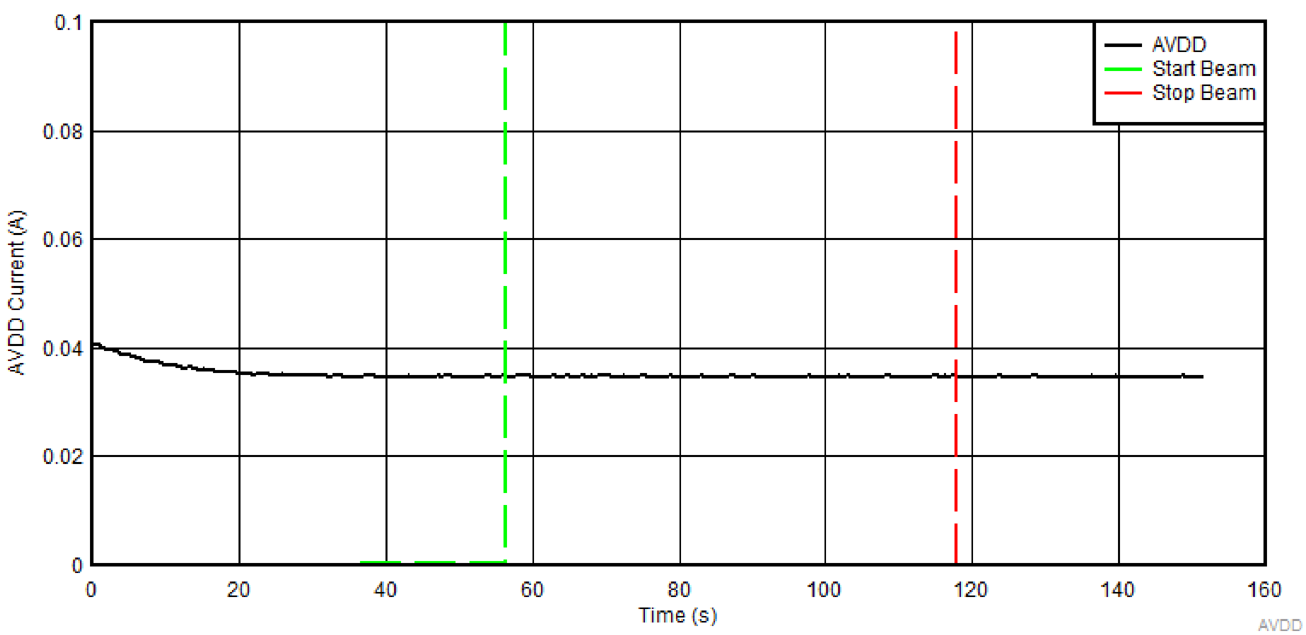


Figure 5. Current vs Time (I vs t) Data for AVDD Current During SEL Run #22

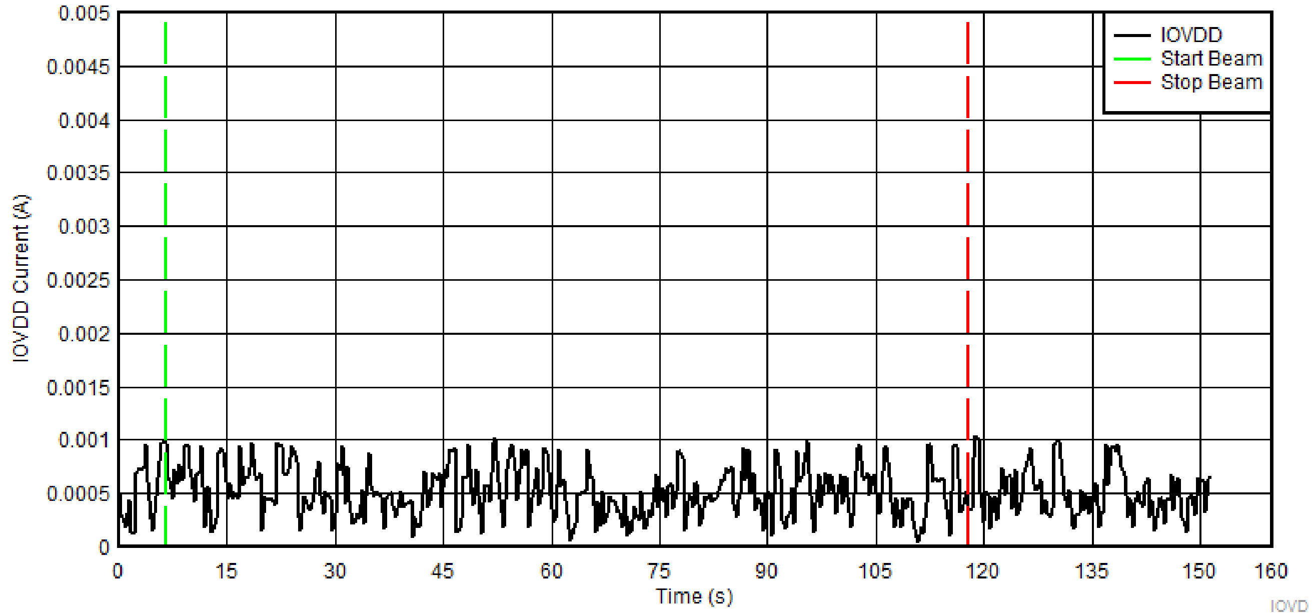


Figure 6. Current vs Time (I vs t) Data for IOVDD Current During SEL Run #22

6 Summary

Radiation effects of Octal, Simultaneous Sampling, 24-Bit Analog-to-Digital Converter ADS1278-SP was studied. This device passed total dose rate of up to 50 krad(Si) and is latch-up immune up to LET_{EFF} = 69.96 MeV-cm^2/mg and T = 125°C.

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, determining the cross-section becomes more difficult since often few, or even, 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 (since 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.

In order 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):

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

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) and *T*, is the test time, and χ^2 is the chi-square distribution evaluated at 100(1 – α / 2) confidence level and where *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*:

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

Where now *MFTF* is mean-fluence-to-failure and *F* is the test fluence, and as before, χ^2 is the chi-square distribution evaluated at 100(1 – α / 2) confidence and where *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*:

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

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

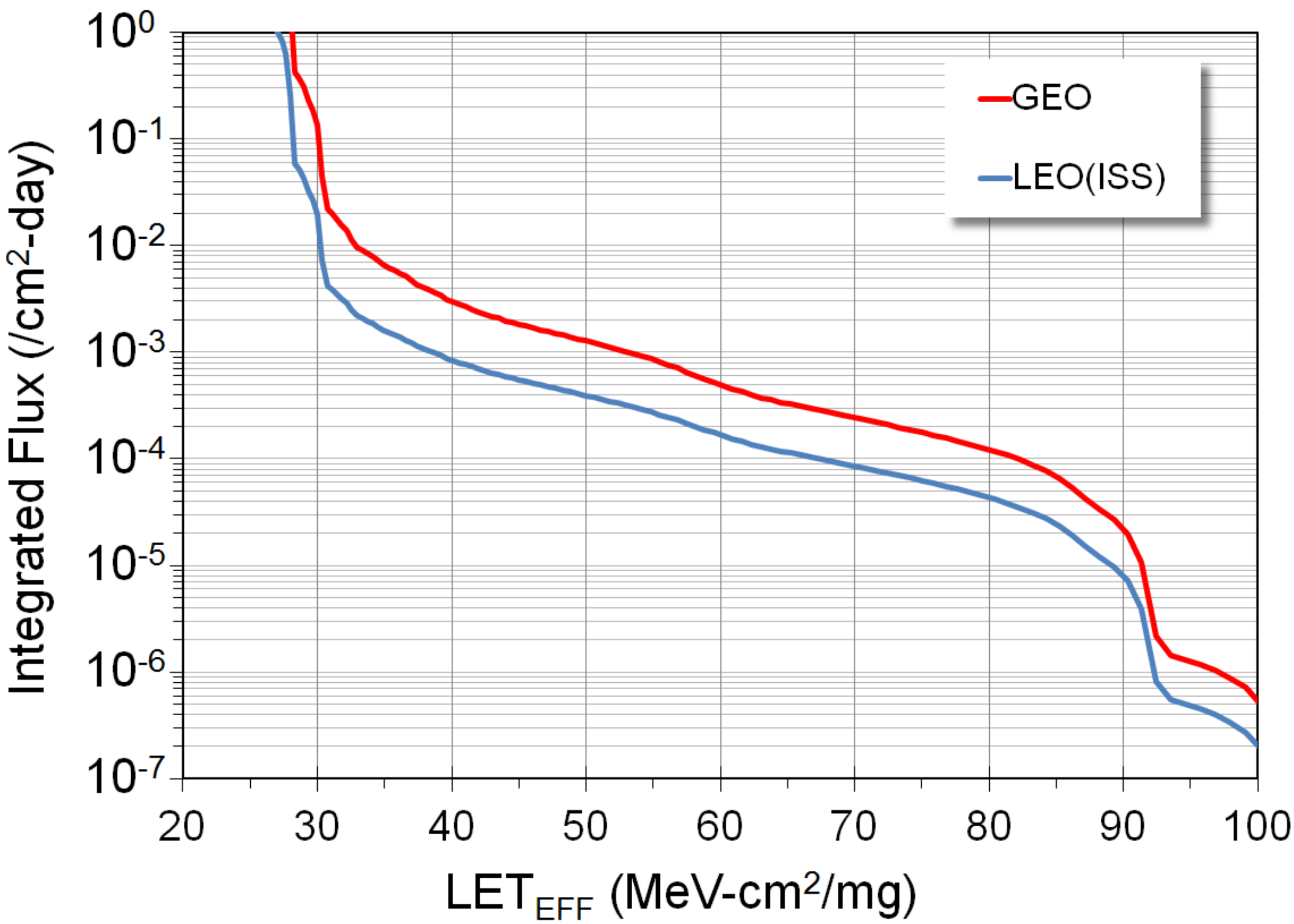
Degrees-of-Freedom (d)	2(d + 1)	χ^2 @ 95%	Calculated Cross Section (cm^2)		
			Upper-Bound @ 95% Confidence	Mean	Average + Standard Deviation
0	2	7.38	3.69E–06	0.00E+00	0.00E+00
1	4	11.14	5.57E–06	1.00E–06	2.00E–06
2	6	14.45	7.22E–06	2.00E–06	3.41E–06
3	8	17.53	8.77E–06	3.00E–06	4.73E–06
4	10	20.48	1.02E–05	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.

Orbital Environment Estimations

In order to calculate on-orbit SEE event rates one needs both the device SEE cross-section and the flux of particles encountered in a particular orbit. Device SEE cross-sections are usually determined experimentally while flux of particles in orbit is calculated using various codes. For the purpose of generating some event rates, a Low-Earth Orbit (LEO) and a Geostationary-Earth Orbit (GEO) were calculated using CREME96. CREME96 code, short for Cosmic Ray Effects on Micro-Electronics is a suite of programs [6][7] that enable estimation of the radiation environment in near-Earth orbits. CREME96 is one several tools available in the aerospace industry to provide accurate space environment calculations. Over the years since its introduction, the CREME models have been compared with on-orbit data and demonstrated their accuracy. In particular, CREME96 incorporates realistic "worst-case" solar particle event models, where fluxes can increase by several orders-of-magnitude over short periods of time.

For the purposes of generating conservative event rates, the worst-week model (based on the biggest solar event lasting a week in the last 45 years) was selected, which has been equated to a 99%-confidence level worst-case event [7][8]. The integrated flux includes protons to heavy ions from solar and galactic sources. A minimal shielding configuration is assumed at 100 mils (2.54 mm) of aluminum. Two orbital environments were estimated, that of the International Space Station (ISS), which is the LEO and the GEO environment. Figure 7 shows the integrated flux (from high LET to low) for these two environments.

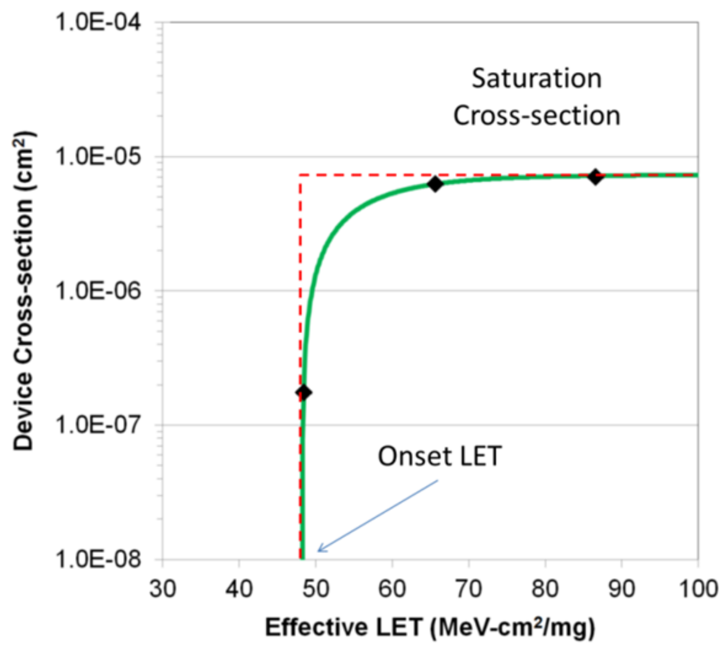


NOTE: LEO(ISS) (blue) and a GEO (red) environment as calculated by CREME96 assuming worst-week and 100 mils (2.54 mm) of aluminum shielding.

NOTE: The y-axis represents flux integrated from higher LET to lower LET. The value of integral flux at any specific LET value is actually the integral of all ion events at that specific LET value to all higher LETs.

Figure 7. Integral Particle Flux vs LET_{EFF}

Using this data, we can extract integral particle fluxes for any arbitrary LET of interest. To simplify the calculation of event rates we assume that all cross section curves are square – meaning that below the onset LET the cross section is identically zero while above the onset LET the cross section is uniformly equal to the saturation cross section. Figure 8 illustrates the approximation, with the green curve being the actual Weibull fit to the data with the "square" approximation shown as the red-dashed line. This allows us to calculate event rates with a single multiplication, the event rate becoming simply the product of the integral flux at the onset LET, and the saturation cross section. Obviously this leads to an overestimation of the event rate since the area under the square approximation is larger than the actual cross section curve – but for the purposes of calculating upper-bound event rate estimates, this modification avoids the need to do the integral over the flux and cross section curves.



NOTE: Weibull Fit (green) is "simplified" with the use of a square approximation (red dashed line).

Figure 8. Device Cross Section vs LET_{EFF}

To demonstrate how the event rates in this report were calculated, assume that we wish to calculate an event rate for a GEO orbit for the device whose cross section is shown in Figure 8. Using the red curve in Figure 7 and the onset LET value obtained from Figure 8 (≈ 47 MeV-cm²/mg) we find the GEO integral flux to be ≈ 1.6×10^{-3} ions/cm²-day. The event rate is the product of the integral flux and the saturation cross section in Figure 8 (≈ 7.5×10^{-6} cm²):

$$GEO\ Event\ Rate = \left(1.6 \times 10^{-3} \frac{ions}{cm^2 \times day}\right) \times \left(7.5 \times 10^{-6} cm^2\right) = 1.2 \times 10^{-8} \frac{events}{day} \quad (4)$$

$$GEO\ Event\ Rate = 5.0 \times 10^{-10} \frac{events}{hr} = 0.5\ FIT \quad (5)$$

$$MTBF = 234,000\ Years! \quad (6)$$

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.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265