Reliability Report

ADC3683-SEP Single Event Effects (SEE) Report

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the ADC3683-SEP. Heavy-ions with LET_{EFF} (Effective Linear Energy Transfer) of up to 51MeV × cm^2/ mg were used to irradiate the device. Tests were run across a range of flux and fluences for the characterization. Flux was between 10^2 ions / (cm^2× s) and 10^5 ions / (cm^2× s) and fluence between 10^5 ions / cm^2 and 10^7 ions / cm^2 per run. The results demonstrated that the ADC3683-SEP is single event latch-up free at T = 125°C. Single event upsets are characterized at 25°C and no functional interrupts (power-cycle events) were seen up to 51MeV × cm^2/ mg. See Section 7 for more details.

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1 Introduction

The ADC3683-SEP is a low noise, ultra-low power 18 bit 65 MSPS high-speed dual channel ADC. Designed for lowest noise performance, the device delivers a noise spectral density of -160dBFS/Hz combined with excellent linearity and dynamic range. The ADC3683-SEP offers DC precision together with IF sampling support making it designed for a wide range of applications. High-speed control loops benefit from the short latency as low as only one clock cycle. The ADC consumes only 94mW/ch at 65MSPS and the power consumption scales well with lower sampling rates.

The device uses a serial LVDS (SLVDS) interface to output the data which minimizes the number of digital interconnects. The device supports two-lane, one-lane and half-lane options. The device is a pin-to-pin compatible with the 14 bit, 125MSPS ADC3664- SEP. The ADC3683-SEP comes in a 40-pin RSB VQFN package (5 × 5mm) and supports an extended temperature range from -55 to +105°C.

Description[1]	Device Information
Generic Part Number	ADC3683-SEP
Orderable Part Number	ADC3683RSBTSEP
Device Function	Low-noise dual 18-bit 65-MSPS ADC
Device Package	40-Pin RSB VQFN (5 × 5mm)
Technology	TI C021 65nm CMOS
Exposure Facility	Radiation Effects Facility Cyclotron Institute, Texas A&M University (15MeV/Nucleon)
Heavy Ion Fluence per Run	Up to 1 × 10^7 ions/cm^2
Irradiation Temperature	25°C (for SET testing) and 125°C (for SEL testing)

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2 Single-Event Effects

The primary concern of interest for the ADC3683-SEP is the robustness against Single-Event Latch-up (SEL) and Single -Event Functional Interrupt (SEFI)

In CMOS technologies, such as the TI 65nm CMOS (C021) process used on the ADC3683-SEP, the 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) [1, 2]. 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). This current between power and ground persists or is latched until power is removed, the device is reset, or until the device is destroyed by the high-current state. The ADC3683-SEP was tested for SEL at above the maximum recommended voltage at 1.9V. The device exhibits no SEL with heavy-ions up to LET_{EFF} = 51 MeV × cm^2/ mg at flux approximately 10^5 ions / cm^2× s, fluence of approximately 10^7 ions / cm^2, and a die temperature of 125°C, using Ag.

The ADC3683-SEP was characterized for SETs at fluxes between 10^2 ions / cm^2 × s and 10^5 ions / cm^2 × s and with a fluence between 10^5 ions / $cm^2$and 10^7 ions / cm^2 per run, at room temperature. The ADC3683-SEP is SEFI-free (no power-cycle events). For more details, see *Single-Event Transients (SET)*.

3 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 using a superconducting cyclotron and an advanced Electron Cyclotron Resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 1in 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 this characterization, ion flux of 10^2 ions / $cm^2 \times$ s to 10^5 ions / $cm^2 \times$ s were used to provide heavy-ion fluences of up to 10^7 ions / cm^2 for runs. Ion uniformity for these experiments was between 94 and 98%. See Table 7-1 for more details on the ions used and results of the runs.

Figure 3-1 shows the test board used for the experiments at the TAMU facility. Although not visible in this photo, the beam port has a 1mil Aramica window to allow in-air testing while maintaining the vacuum within the accelerator with only minor ion energy loss. A 40-mm in-air gap between the device and the ion beam port window was maintained at these distances for all runs respective to the ion that was tested.

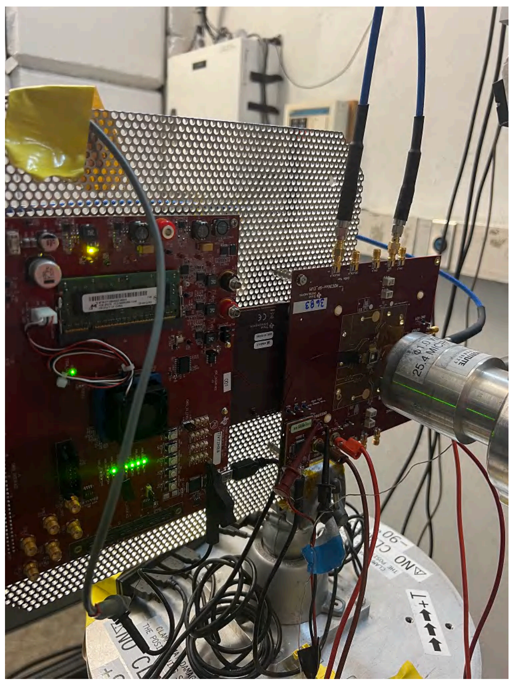

Figure 3-1. Photo of ADC36xx Evaluation Board Mounted in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron Facility

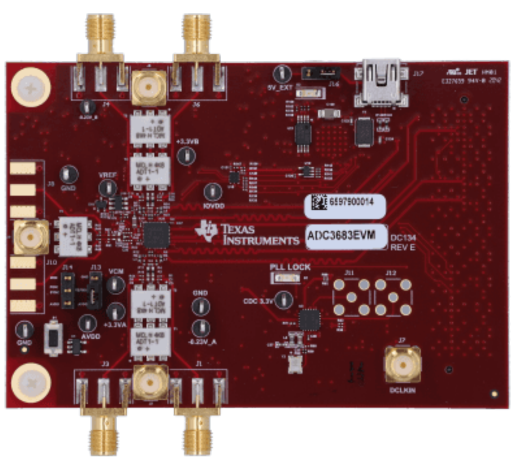

Figure 3-2. Image of ADC3683EVM

4 Depth, Range, and LET_{EFF} Calculations

The ADC3683-SEP is fabricated in the TI CMOS C021(C021, 65-nm process with a Back-End-Of-Line (BEOL) stack consisting of eight layers of standard thickness aluminum metal. The total stack height from the surface of the passivation to the silicon surface is 20.7µm based on nominal layer thickness. Accounting for energy loss through the 1mil thick Aramica beam port window, the 40mm air gap and the BEOL stack over the ADC3683-SEP, the effective LET (LET_{EFF}) at the surface of the silicon substrate, the depth, and the ion range was determined with the SEUSS 2020 Software [4] (provided by the Texas A&M Cyclotron Institute and based on the latest SRIM-2013 models). Table 4-1 lists the results.

Table 4-1. Ion LET EFF Depth and Range in Silicon

Ion Type	Angle of Incidence (°)	$Range_{EFF}$ in Silicon (µm)	LET_{EFF} (MeV × cm^2/ mg)
^{109}Ag	0	76.6	51.12

5 Test Setup and Procedures

SEE testing was performed on an ADC3683-SEP device solder down on an ADC3683-SEP EVM. For the SEL, the device was powered up to a voltage of 1.9V at approximately 125°C. For the SET characterization, the ADC3683-SEP was tested at room temperature at approximately 25°C operating under nominal conditions for power supplies. Two power supplies were used to power AVDD and IOVDD, each using 1.8V.

For SEU events, the DCLK output signal was monitored, with DCLK being the clock signal supplied to the FPGA. When the DCLK signal experiences an upset, the data on the data lines is not valid. As DCLK by default is always toggling and outputting a constant and continuous signal, when there is a significant deviation from normal, an event has occurred. To monitor DCLK events, a National Instruments™ (NI) PXIe-5172 scope card connected to USER_LED3 on the TSW1400EVM was used, which goes high when a valid clock from the ADC is not received, which is defined as an event occurring.

The scope was configured to capture events using a rising edge trigger. AVDD and IOVDD currents were also monitored during SEU testing. However, the currents were not used in determining whether an event has occurred. Events were observed and are characterized in Table 5-1. See Section 7 for more details.

All equipment was controlled and monitored using a custom-developed LabVIEW™ program (PXI-RadTest) running on a HP-Z4® desktop computer. The computer communicates with the PXI chassis through an MXIExpress cable and a NI PXIe-8381 remote control module. Figure 5-1 shows a block diagram of the setup used for SEE testing of the ADC3683-SEP. Table 5-1 lists the connections, limits, and compliance values used during the testing. During the SEL testing, the device was heated to 125°C by using a Closed-Loop PID controlled heat gun (MISTRAL 6 System 120V, 2400W). For SEU testing, the device was tested at room temperature. No cooling or heating was applied to the DUT. Die temperature was verified using a FLIR IR-camera prior to the SEE test campaign.

Table 5-1. Equipment Set and Parameters Used for SEE Testing the ADC3683-SEP

Name	Equipment Used	Value Set
AVDD	KeySight E36311	1.9V
IOVDD	KeySight E36311	1.9V
EVM Board Supply	KeySight E36311	1.8V
DCLKIN	R&S SML01 Sig Gen	292.5MHz
Channel A	R&S SGS100A	20MHz
CLK	R&S SGS100A	65MHz

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to make sure that the test system was stable under all bias and load conditions prior to being taken to the TAMU facility. During the heavy-ion testing, the LabVIEW control program powered up the ADC3683-SEP device and set the external sourcing and monitoring functions of the external equipment. After functionality and stability had been confirmed, the beam shutter was opened to expose the device to the heavy-ion beam. The shutter remained open until the target fluence was achieved (determined by external detectors and counters). During irradiation, the NI scope cards continuously monitored the signals. When the DCLK voltage changes from low to high (using a positive edge trigger), a data capture was initiated. In addition to monitoring the DCLK signal, AVDD and IOVDD current were monitored at all times.

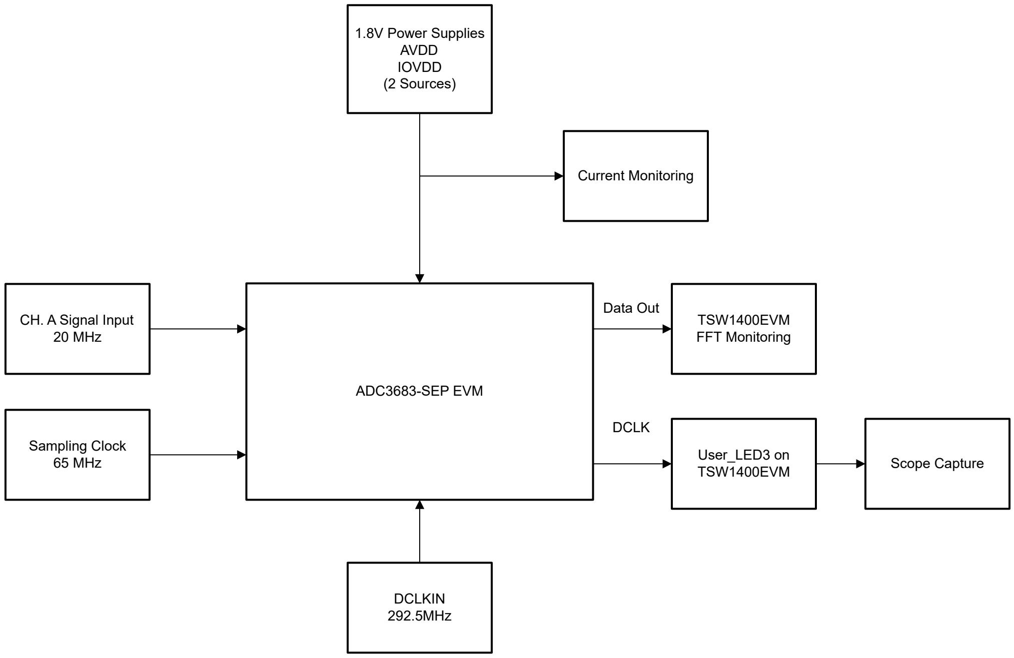

Figure 5-1. Block Diagram of SEE Test Setup With the ADC3683-SEP

6 Destructive Single-Event Effects (DSEE)

Single-Event Latch-Up (SEL) Results

During SEL characterization, the device was heated using forced hot air, maintaining the DUT temperature at 125°C. The die temperature was monitored prior to radiation using a FLIR IR-camera.

The species used for the SEL testing was Silver (^{109}Ag) ion with an angle-of-incidence of 0° for an LET_{EFF} = 51.12MeV × cm^2/ mgm. Flux of 10^5 ions / cm^2× s and a fluence of 10^7 ions / cm^2 were used. The device was powered up and exposed to the heavy-ions using voltages up to 1.9V, with 1.85V being the maximum recommended operating voltage. No SEL events were observed during all three runs, indicating that the ADC3683-SEP is SEL-free. Table 6-1 lists the SEL test conditions and results. Figure 6-1 shows a typical plot of current versus time for SEL testing.

Table 6-1. Summary of ADC3683-SEP SEL Test Condition and Results

Run Number	Temperature	LET_{EFF} (MeV × cm^2/mg)	Flux (ions × cm^2/s)	Fluence (ions × cm^2)	AVDD/IOVDD (V)
1	Room, approximately 25°C	51.12	1.85×10^4	1×10^7	1.9
2	125°C	51.12	1.8×10^4	1×10^7	1.9
3	125°C	51.12	1×10^5	1×10^7	1.9
4	125°C	51.12	1×10^5	1×10^7	1.9

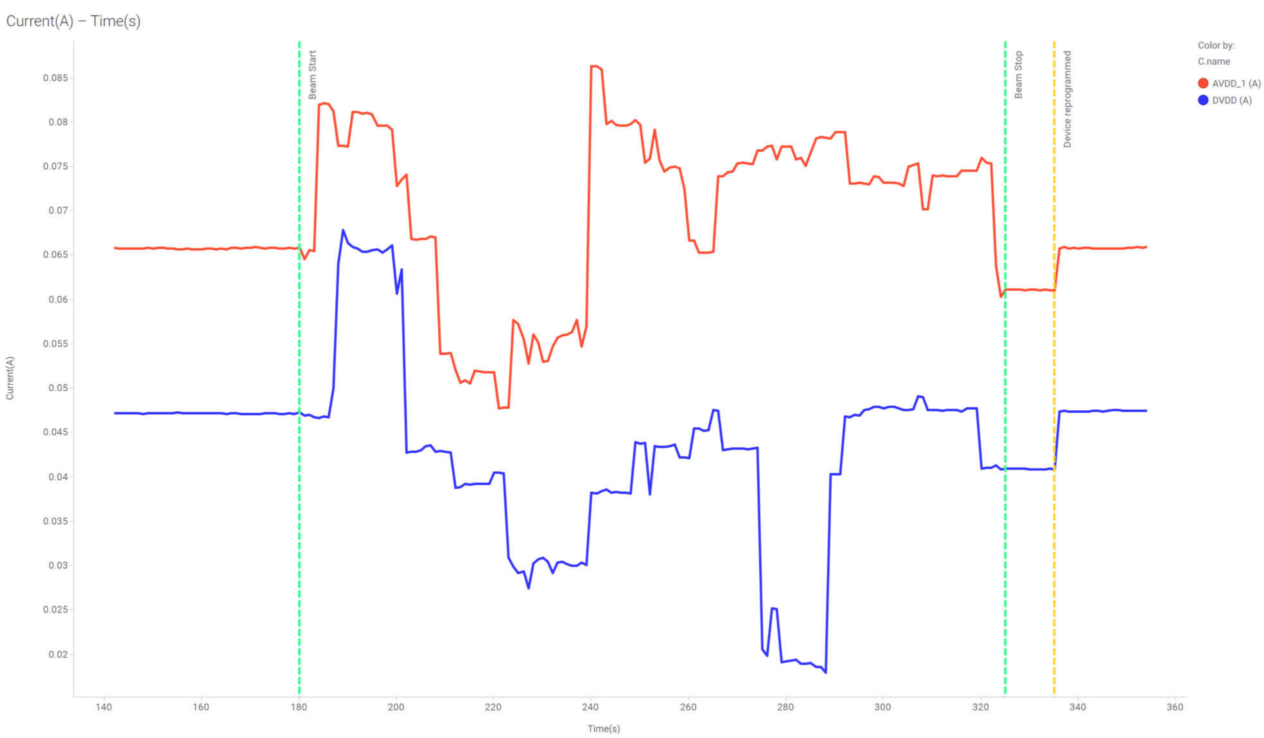

Figure 6-1. Current vs Time for ADC3683-SEP at T = 125°C

7 Single-Event Transients (SET)

Single Event Transients

SETs are defined as heavy-ion-induced transients upsets on the DCLK of the ADC3683-SEP. SET testing was performed at room temperature (no external temperature control applied). DCLK SEUs were characterized using a positive edge trigger. The devices were characterized with input voltages AVDD/IOVDD = 1.85V. To capture the event, the NI-PXI-5172 Scope Card was continuously monitoring the DCLK. The DCLK was monitored by using USER_LED3 that is located on the TSW1400EVM. The scope was attached to the LED which would go high upon seeing that the FPGA was not receiving a valid clock signal. The scope triggering from DCLK was programmed to record 20K samples with a sample rate of 5M samples per second (S/s) in case of an event (trigger). Scope was programmed to record 20% of the data before (pre) the trigger happened. Events were seen on DCLK and are characterized below. Table 7-1 lists the SET test conditions and results for all the data. The Results were analyzed and broken down into *short* and *long* events based on time taken for the DCLK to recover. A short event is defined by a transient which lasted less than 500ns while a long event lasts greater than 500ns. An example of such events can be seen in Figure 7-1 and Figure 7-2. Table 7-1 lists the SET test condition and results for all the data.

Table 7-1. Summary of ADC3683-SEP SET Test Condition and Results

Run Number	Run Type	Unit Number	Temperature	Ion	Angle	LET_{EFF} (MeV × cm²/ mg)	Flux (ions × cm²/ s)	Fluence (ions × cm²)	Count DCLK Events	Count of Short Events	Count of Long Events
8	SEU	1	Room	^{109}Ag	0	51.12	1×10^2	1×10^5	1	1	0
9	SEU	1	Room	^{109}Ag	0	51.12	1×10^4	1×10^6	6	4	2
10	SEU	1	Room	^{63}Cu	0	21.44	1×10^2	1×10^5	3	1	2
11	SEU	1	Room	^{63}Cu	0	21.44	1×10^4	1×10^6	5	5	0
12	SEU	1	Room	^{63}Cu	0	21.44	1×10^5	1×10^7	50	43	7

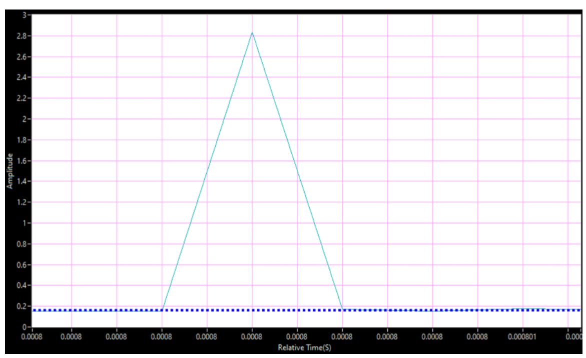

Figure 7-1. Example of a Short Event from Run 5

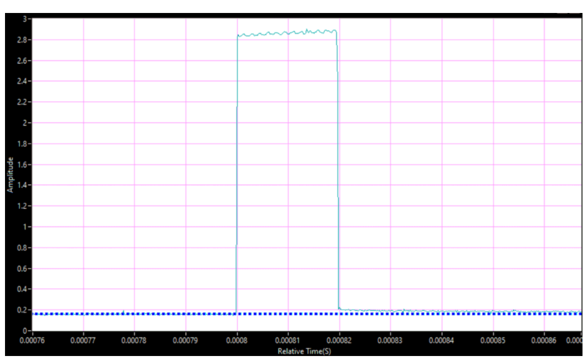

Figure 7-2. Example of a Long Event from Run 5

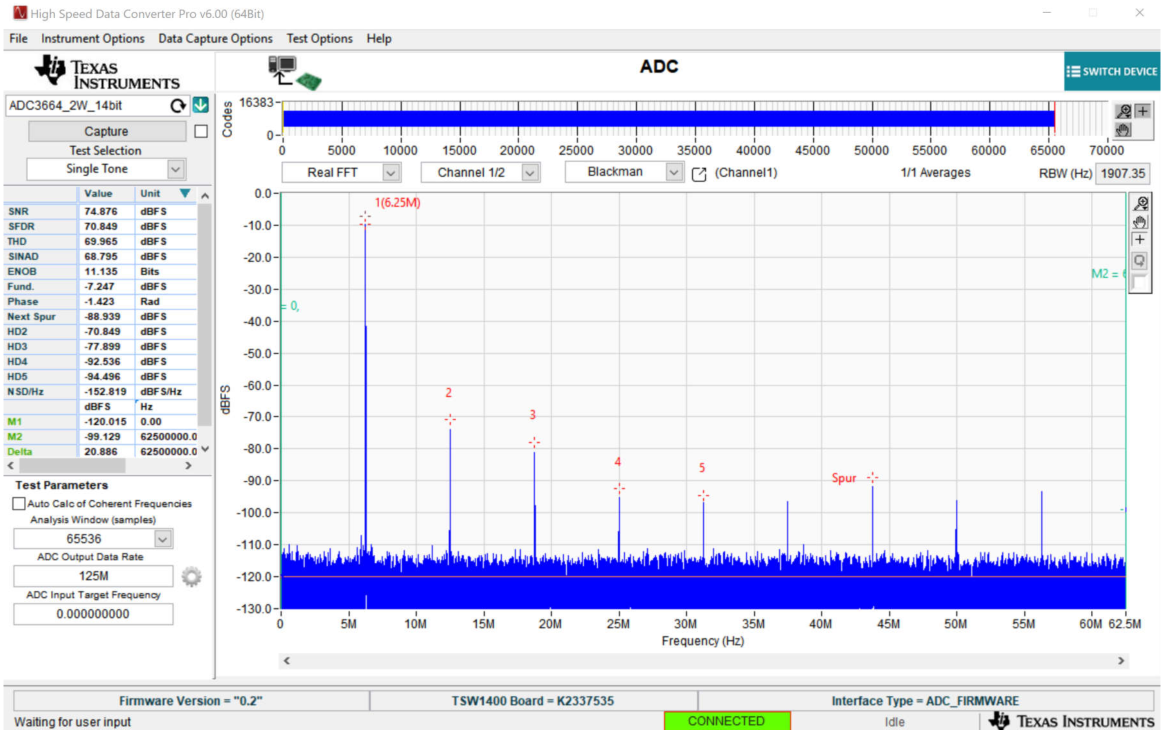

Figure 7-3. FFT Capture of Nominal Operating Conditions

8 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations and simplified SEE cross sections according to methods shown in *Heavy Ion Orbital Environment Single-Event Effects Estimations*.

For calculation purposes, an onset LET of 1MeV × cm^2 / mg is used. The device was not tested at this LET but based on testing of similar products of the same process (C021), this as a conservative starting point. The onset can possibly be higher.

A minimum shielding configuration of 100mils (2.54mm) of aluminum, and *worst-week* solar activity (this is similar to a 99% upper bound for the environment) is assumed. Using the 95% upper-bounds for the SEL and SET, the event rates and Weibull plots for SETs are listed below.

Table 8-1. SET Event Rate Calculations of Total Events for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/ mg)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	1	1.31×10^{-5}	1.47×10^{-5}	6.12×10^{2}	1.86×10^{2}
GEO			1.25×10^{-4}	5.22×10^{3}	2.19×10^{1}

Table 8-2. SET Event Rate Calculations of Short Events for Worst-Week LEO and GEO Orbit

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	σSAT (cm^2)	Event Rate (/day)		
LEO (ISS)	1	1.06×10^{-5}	1.57×10^{-5}	6.56×10^{2}	1.74×10^{2}
GEO			1.35×10^{-4}	5.62×10^{3}	2.03×10^{1}

Table 8-3. SET Event Rate Calculations of Long Events for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	1	6.57×10^{-6}	2.77×10^{-6}	1.15×10^{2}	9.90×10^{2}
GEO			2.29×10^{-5}	9.53×10^{2}	1.20×10^{2}

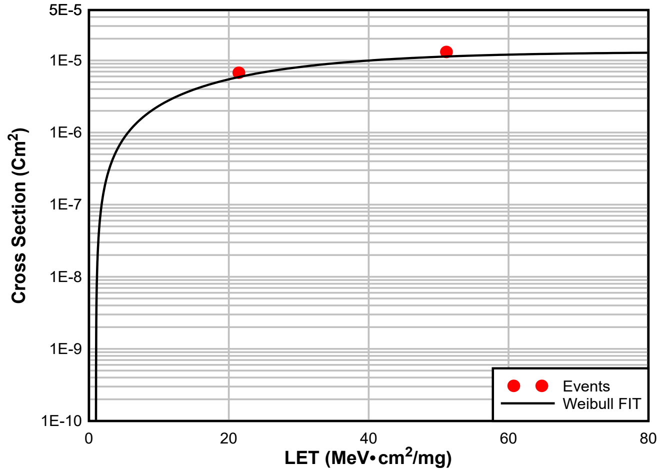

Figure 8-1. Cross Section Plot for Total Events

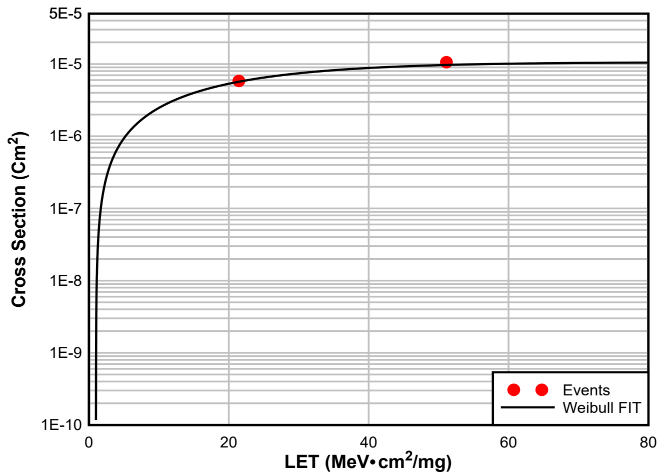

Figure 8-2. Cross Section for Short Events

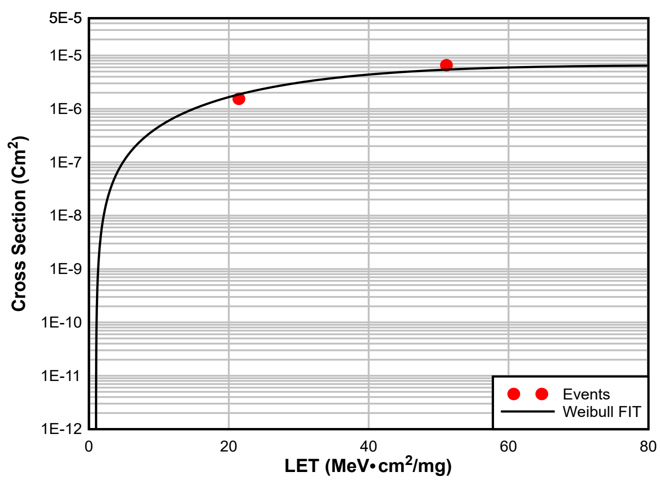

Figure 8-3. Cross Section for Long Events

9 Summary

The purpose of this study was to characterize the effect of heavy-ion irradiation on the Single-Event-Effect (SEE) performance of the ADC3683-SEP. Heavy-ions with LET_{EFF} up to 51MeV × cm^2/ mg were used for the SEE test campaign. Flux of up to 10^5ions / cm^2× s and fluences up to 10^7 ions / cm^2 per run were used for the characterization. The SEE results demonstrated that the ADC3683-SEP is SEL and SEFI free up to LET_{EFF} = 51MeV × cm^2/ mg. The device is characterized for SETs up to LET_{EFF} = 51MeV × cm^2/ mg. CREME96-based worst-week event-rate calculations for LEO (ISS) and GEO orbits are presented for reference.

10 References

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