Radiation Report

ADC3683-SP Single Event Effects Report

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the ADC3683-SP. Heavy-ions with LET_{EFF} (Effective Linear Energy Transfer) of up to 79MeV × 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-SP 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 79MeV × cm^2/ mg. See Section 8 for more details.

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1 Introduction

The ADC3683-SP 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 -160 dBFS/Hz combined with excellent linearity and dynamic range. The ADC3683-SP offers DC precision together with IF sampling support, making the device applicable 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- SP. The ADC3683-SP comes in a 64-pin HBP CFP package (10.9mm × 10.9mm) and supports a temperature range from -55 to +105°C.

Table 1-1. Overview Information

Description (1)	Device Information
Generic Part Number	ADC3683-SP
Orderable Part Number	5962F2320401VXC
Device Function	Low-Noise Dual 18-Bit 65MSPS ADC
Device Package	64-pin HBP CFP (10.9mm × 10.9mm)
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-SP 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-SP, 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, which induces 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-SP 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} = 79MeV × 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 Pr.

The ADC3683-SP 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-SP is SEFI-free (no power-cycle events). For more details, see Single-Event Transients (SET).

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3 Device and Test Board Information

The ADC3683-SP is packaged in a 64-pin QFP (TI package code HBP) ceramic package as shown in Figure 3-1. An ADC3683EVMCVAL ceramic device evaluation board was used to evaluate the performance and characteristics of the ADC3683-SP under heavy-ions.

Figure 3-2 shows the top view of the evaluation board used for the radiation testing. For more detail on the EVM used for testing, see *ADC36XXEVMCVAL User's Guide*.

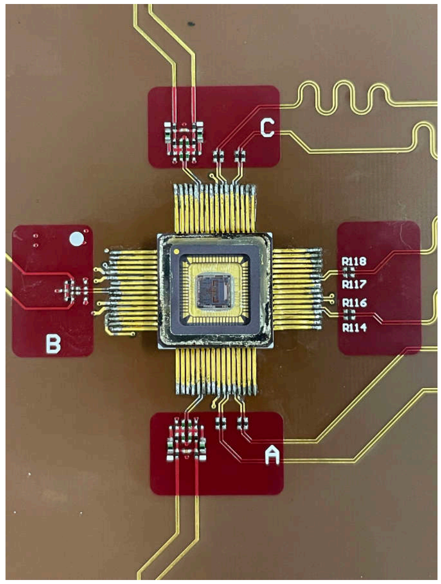

Figure 3-1. Photograph of Delidded ADC3683-SP

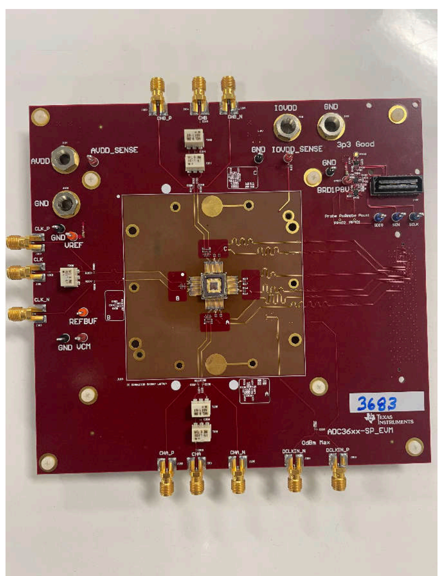

Figure 3-2. ADC3683-SP Board (Top View)

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4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product 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 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 our runs. Ion uniformity for these experiments was between 94 and 98%. See Table 8-1 for more details on the ions used and results of the runs.

Figure 4-1 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 40mm 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.

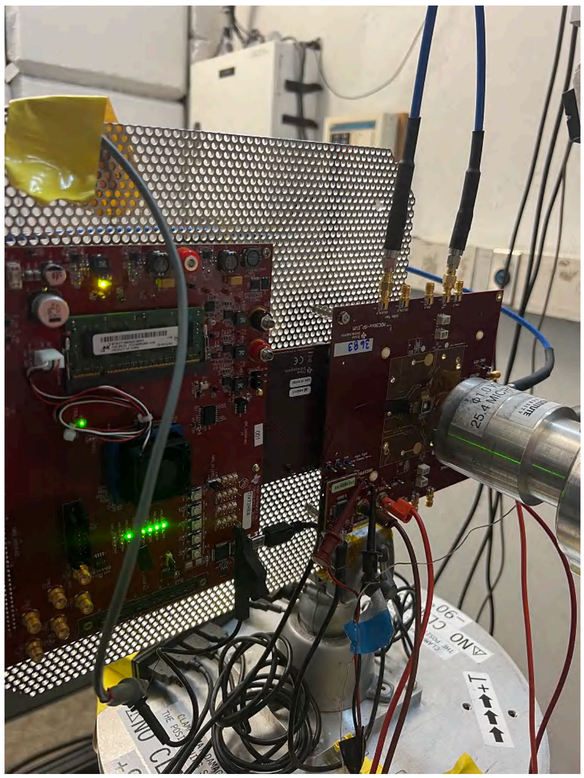

Figure 4-1. Photograph of the ADC3683-SP Evaluation Board Mounted in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron Institute

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5 Depth, Range, and LET_{EFF} Calculation

The ADC3683-SP is fabricated in the TI CMOS C021(C021, 65nm process with a Back-End-Of-Line (BEOL) stack consisting of eight levels 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-SP, 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 that was provided by the Texas A&M University Cyclotron Institute and based on the latest SRIM-2013models (4, 5). Table 5-1 lists the results.

Table 5-1. Ion LET_{EFF} Depth and Range in Silicon

Ion Type	Angle of Incidence (°)	$Range_{EFF}$ in Silicon (µm)	LET_{EFF} (MeV × cm^2/mg)
^{165}Ho	0	78.4	78.36
^{141}Pr	30	68.1	78.67
^{141}Pr	0	81.9	67.45
^{109}Ag	30	63.5	59.82
^{109}Ag	0	76.6	51.12
^{63}Cu	0	102	21.44

6 Test Setup and Procedures

SEE testing was performed on an ADC3683-SP device solder down on an ADC3683-SP 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-SP was tested at room temperature at approximately 25°C operating under nominal conditions for power supplies. Three power supplies were used to power AVDD, IOVDD, and the EVM board supply respectively, each using 1.8V.

For SEU events, we monitored the DCLK output signal; DCLK being the clock signal we supply 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 . See Section 8.1 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 6-1 shows a block diagram of the setup used for SEE testing of the ADC3683-SP. Table 6-1 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.

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Table 6-1. Equipment Set and Parameters Used for SEE Testing the ADC3683-SP

Name	Equipment Used	Value set
AVDD	KeySight E36311	1.8V
IOVDD	KeySight E36311	1.8V
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-SP 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. (This was 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, the AVDD and IOVDD currents were monitored at all times.

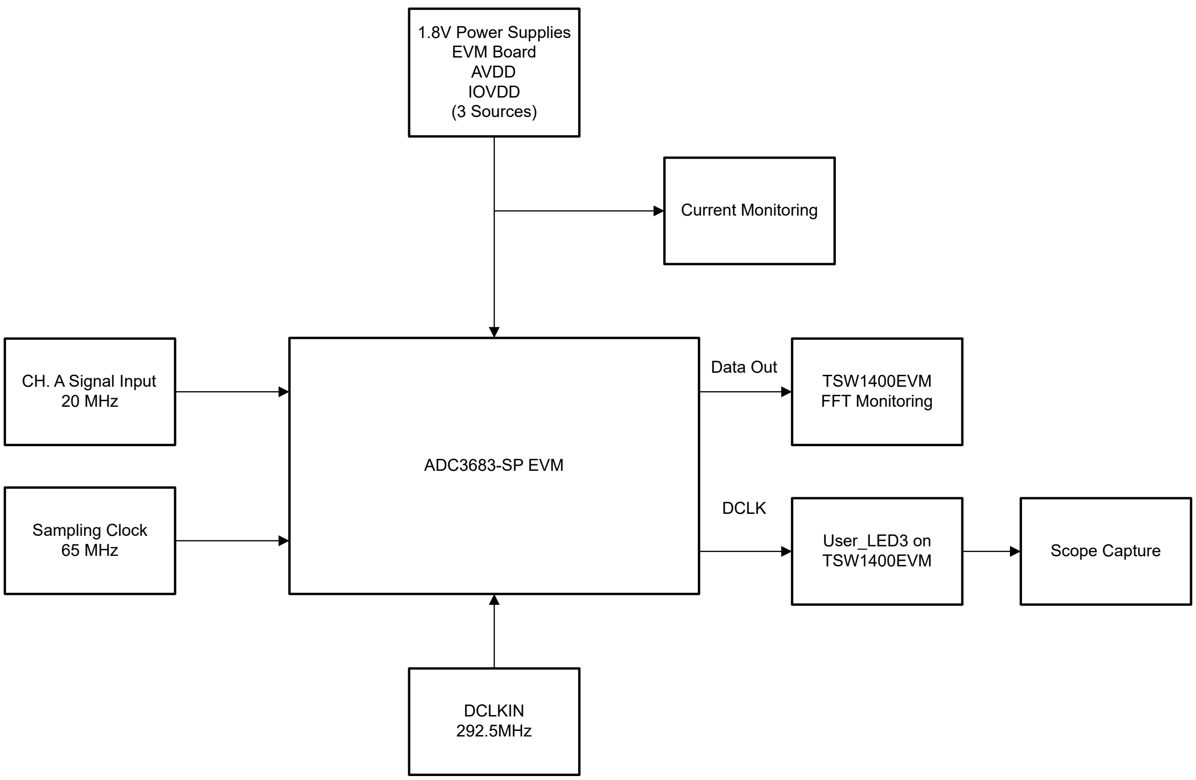

Figure 6-1. Block Diagram of SEE Test Setup With the ADC3683-SP

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7 Destructive Single-Event Effects (DSEE)

7.1 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 Praseodymium (^{141}Pr) ion with an angle-of-incedence of 30° for an LET_{EFF} = 79MeV×cm^2/ mgm. Flux of 10^5 ions / cm^2× s and a fluence of 10^7 ions/cm^2 were used for the three runs. Run duration to achieve this fluence was less than two minutes. 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-SP is SEL-free. Table 7-1 shows the SEL test conditions and results. Figure 7-1 shows a typical plot of current versus time for an SEL testing.

Table 7-1. Summary of ADC3683-SP 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 temperature, approximately 25°C	51.12	1.85×10^4	1.00×10^7	1.9
2	125°C	51.12	1.80×10^4	1.00×10^7	1.9
3	125°C	78.67	1.53×10^4	1.00×10^7	1.9
4	125°C	78.67	1.62×10^4	1.00×10^7	1.9
5	125°C	78.67	1.00×10^5	1.00×10^7	1.85
6	125°C	78.67	1.00×10^5	1.00×10^7	1.85
7	125°C	78.67	1.00×10^5	1.00×10^7	1.9
8	125°C	78.36	1.00×10^5	1.50×10^7	1.9

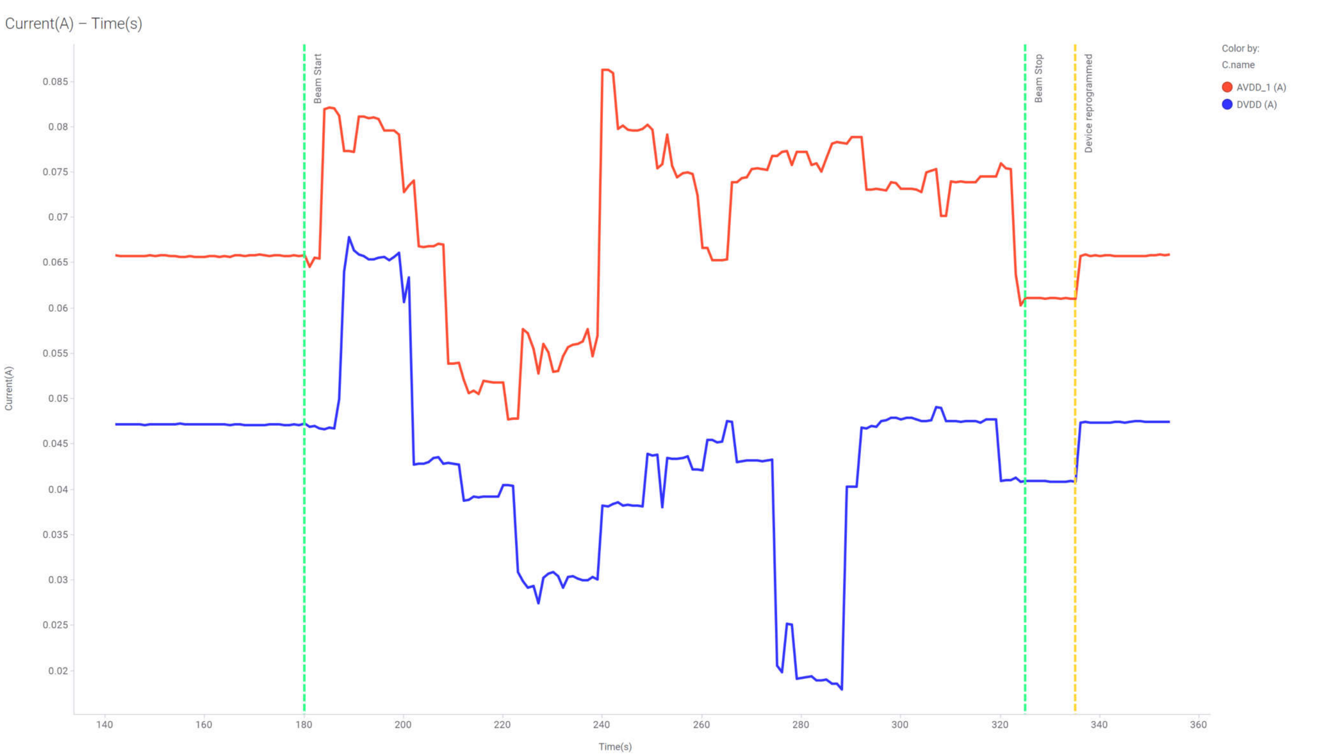

Figure 7-1. Current Versus Time for ADC3683-SP at T = 125°C

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8 Single-Event Transients (SET)

8.1 Single Event Transients

SETs are defined as heavy-ion-induced transients upsets on the DCLK of the ADC3683-SP. SET testing was performed at room temperature with 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 goes high upon because 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).

The scope was programmed to record 20% of the data before (pre-) the trigger happened. Events were seen on DCLK. The results were analyzed and categorized into *short* and *long* events based on DCLK recovery time. A short event is defined by a transient, which lasted less than 500ns while a long event lasts more than 500ns. An example of the events are shown Figure 8-2 and Figure 8-1. Table 8-1 lists the SET test condition and results for all the data.

Table 8-1. Summary of ADC3683-SP SET Test Conditions and Results

Run Number	Run Type	Unit Number	Temp	Ion	Angle	LET_{EFF} (MeV.cm^2 /mg)	Flux (ions·cm^2 /s)	Fluence (ions·cm^2)	Count DCLK Events	Count of Short Events	Count of Long Events
1	SEU	1	Room	^{141}Pr	30	78.67	1.00×10^4	1.00×10^6	14	8	6
2	SEU	1	Room	^{141}Pr	30	78.67	1.00×10^2	1.00×10^5	1	0	1
3	SEU	1	Room	^{141}Pr	0	67.45	1.00×10^4	1.00×10^6	8	5	3
4	SEU	1	Room	^{141}Pr	0	67.45	1.00×10^2	1.00×10^5	1	1	0
5	SEU	1	Room	^{109}Ag	30	59.82	1.00×10^5	1.00×10^7	114	82	32
6	SEU	1	Room	^{109}Ag	30	59.82	1.00×10^4	1.00×10^6	7	6	1
7	SEU	1	Room	^{109}Ag	30	59.82	1.00×10^2	1.00×10^5	1	0	1
8	SEU	1	Room	^{109}Ag	0	51.12	1.00×10^2	1.00×10^5	1	1	0
9	SEU	1	Room	^{109}Ag	0	51.12	1.00×10^4	1.00×10^6	6	4	2
10	SEU	1	Room	^{63}Cu	0	21.44	1.00×10^2	1.00×10^5	3	1	2
11	SEU	1	Room	^{63}Cu	0	21.44	1.00×10^4	1.00×10^6	5	5	0
12	SEU	1	Room	^{63}Cu	0	21.44	1.00×10^5	1.00×10^7	50	43	7

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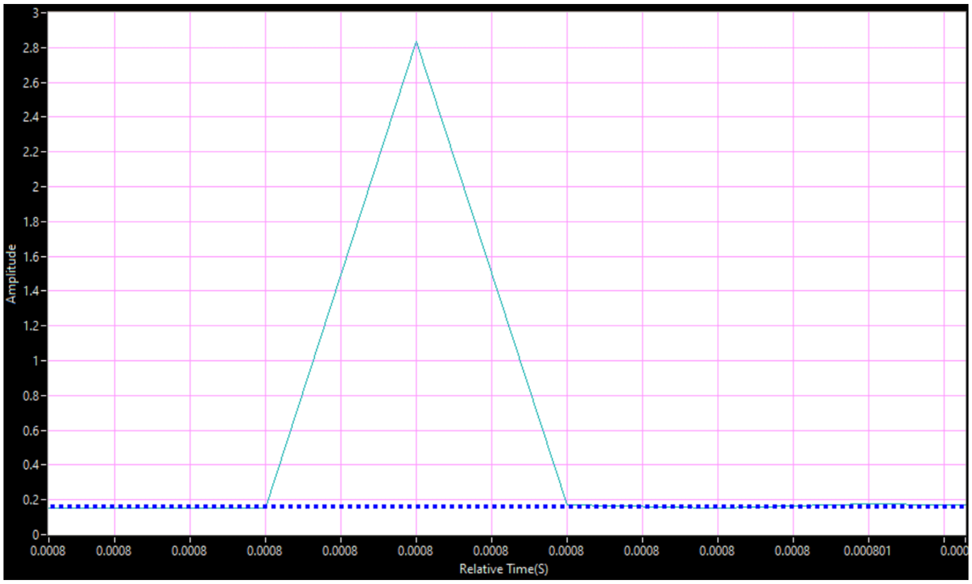

Figure 8-1. Example of a Short Event from Run 12

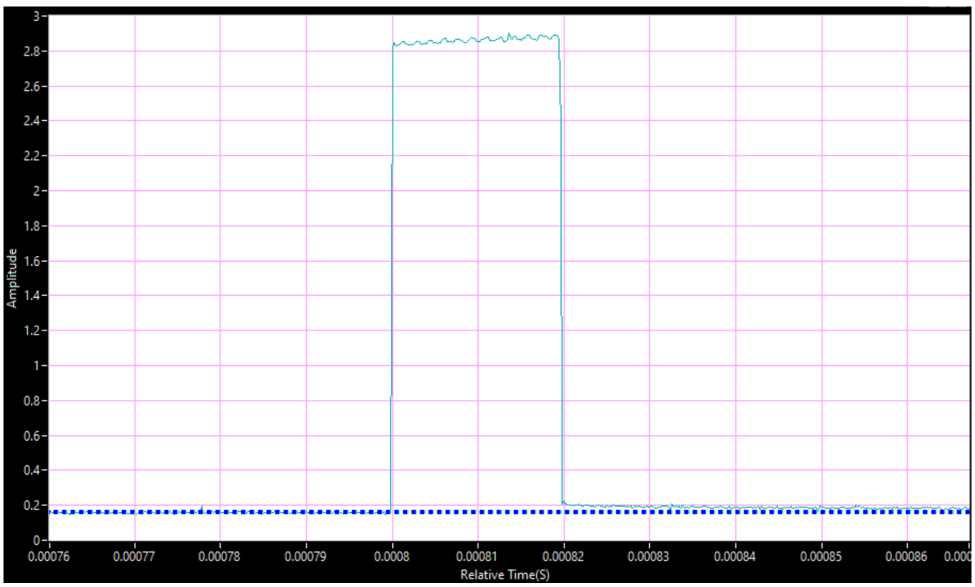

Figure 8-2. Example of a Long Event from Run 12

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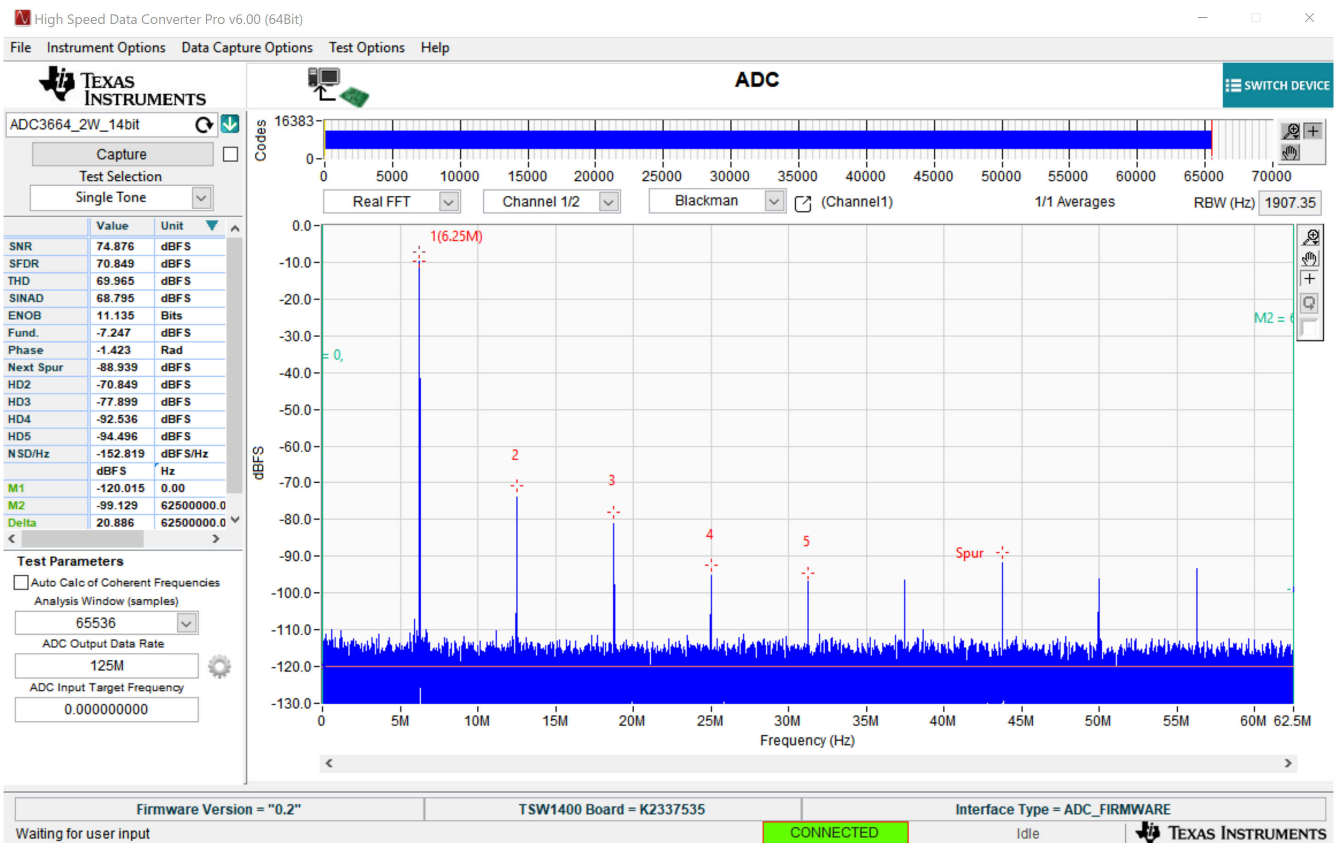

Figure 8-3. FFT Capture of Nominal Operating Conditions

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9 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 1 MeV × 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, we use 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 for SEUs and SEFIs are listed in Table 9-1 and Table 9-3. Figure 9-1 and Figure 9-3 show the cross sections versus LET_{EFF} .

Table 9-1. 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	2.25×10^{-5}	1.67×10^{-5}	6.95×10^{2}	1.64×10^{2}
GEO			1.42×10^{-4}	5.93×10^{3}	1.92×10^{1}

Table 9-2. 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)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	1	1.43×10^{-5}	1.74×10^{-5}	7.25×10^{2}	1.57×10^{2}
GEO			1.50×10^{-4}	6.25×10^{3}	1.83×10^{1}

Table 9-3. 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	1.31×10^{-5}	2.46×10^{-6}	1.03×10^{2}	1.11×10^{3}
GEO			2.04×10^{-5}	8.51×10^{2}	1.34×10^{2}

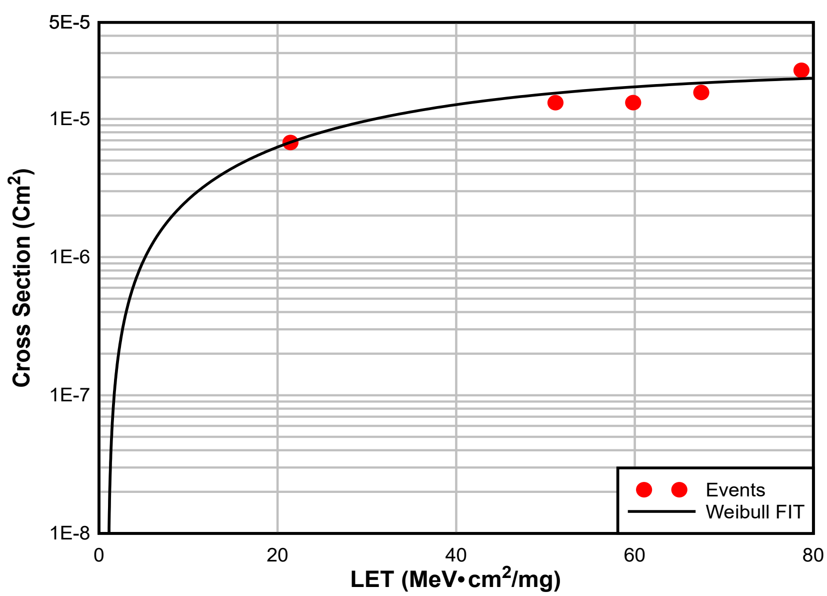

Figure 9-1. Cross Section Plot for All Events

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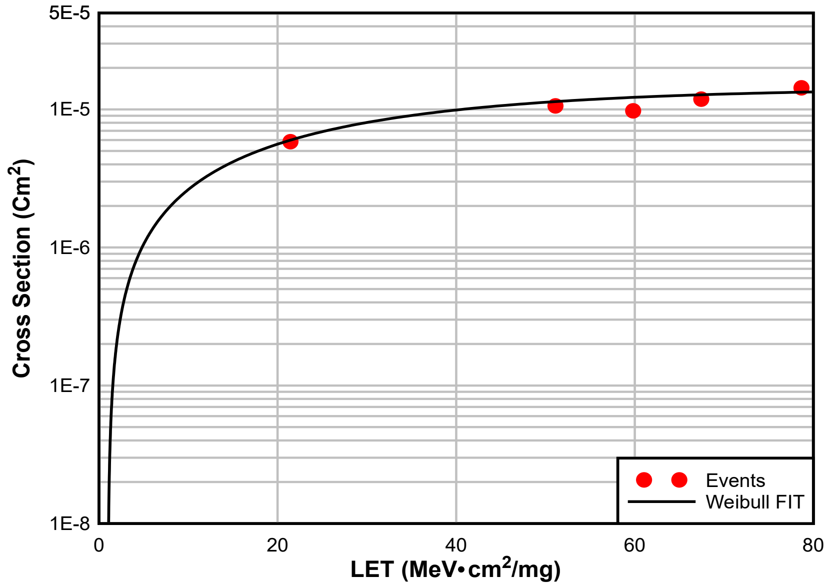

Figure 9-2. Cross Section for Short Events

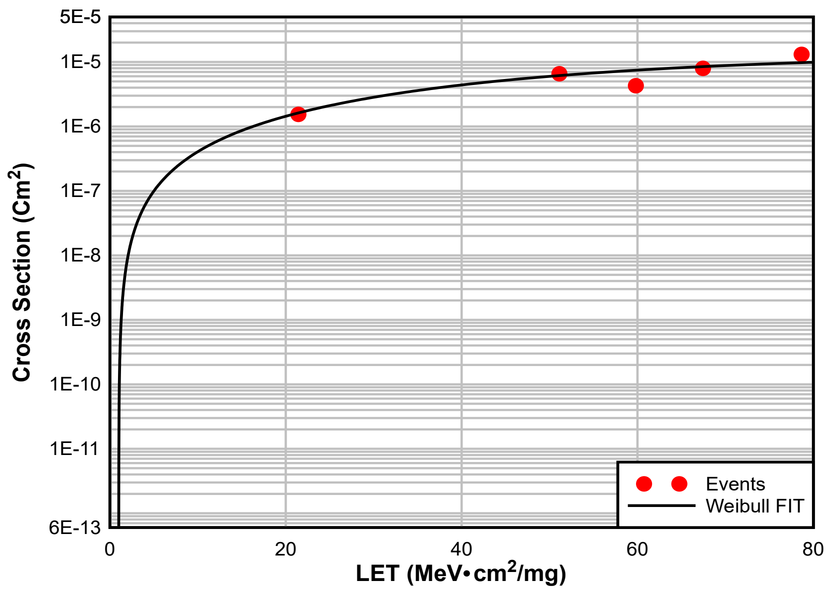

Figure 9-3. Cross Section for Long Events

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10 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-SP. Heavy-ions with LET_{EFF} up to 79MeV × 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-SP is SEL and SEFI free up to LET_{EFF} = 79MeV × cm^2/ mg. The device is characterized for SETs up to LET_{EFF} = 79MeV × cm^2/ mg. CREME96-based worst-week event-rate calculations for LEO (ISS) and GEO orbits are presented for reference.

11 References

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12 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (July 2024) to Revision A (November 2024) **Page**

- Added Ho as an ION used in beam runs to *Ion LET_{EFF} Depth and Range in Silicon* table.............................. 7
- Added SEL run #8, using Ho and going up to 1p5E7 fluence...9
- Replaced old SEL current plot with an updated plot.. 9
- Added an FFT capture of nominal operating conditions...10
- Updated the onset LET...13
- Event rate calculations for *total, short, long* have been re-calculated, plots updated......................................13

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