Radiation Report

ADC3664-SEP 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 ADC3664-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 up to 10^5 ions / (cm^2 × s) and fluence between 10^5 ions / cm^2 and 10^7 ions / cm^2 were used per run. The results demonstrated that the ADC3664-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.

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Trademarks

1 Introduction

The ADC3664-SEP is a low latency, low noise, and ultra low power, 14-bit, 125MSPS, high-speed dual channel ADC. Designed for best noise performance, the device delivers a noise spectral density of – 156.9dBFS/Hz combined with excellent linearity and dynamic range. The ADC3664-SEP offers DC precision together with IF sampling support to enable the design of a wide range of applications. The low latency architecture (as low as 1 clock cycle latency) and high sample rate also enable high speed control loops. The ADC consumes only 100mW/ch at 125MSPS and the power consumption scales well with sampling rate.

The device uses a serial LVDS (SLVDS) interface to output the data which minimizes the number of digital interconnects. The device also integrates a digital down converter (DDC) to help reduce the data rate and lower system power consumption. The ADC3664-SEP is pinto-pin compatible with a family of 16-bit resolution ADCs.

Table 1-1. Overview Information

Description (1)	Device Information
Generic Part Number	ADC3664-SEP
Orderable Part Number	ADC3664-SEP
Device Function	Low-Noise Dual 14-Bit 125MSPS ADC
Device Package	40-pin VQFN RSB (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 ADC3664-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 ADC3664-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, 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 ADC3664-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 Pr.

The ADC3664-SEP was characterized for SETs at fluxes up to 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 ADC3664-SEP is SEFI-free (no power-cycle events).

3 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 up 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%.

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 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.

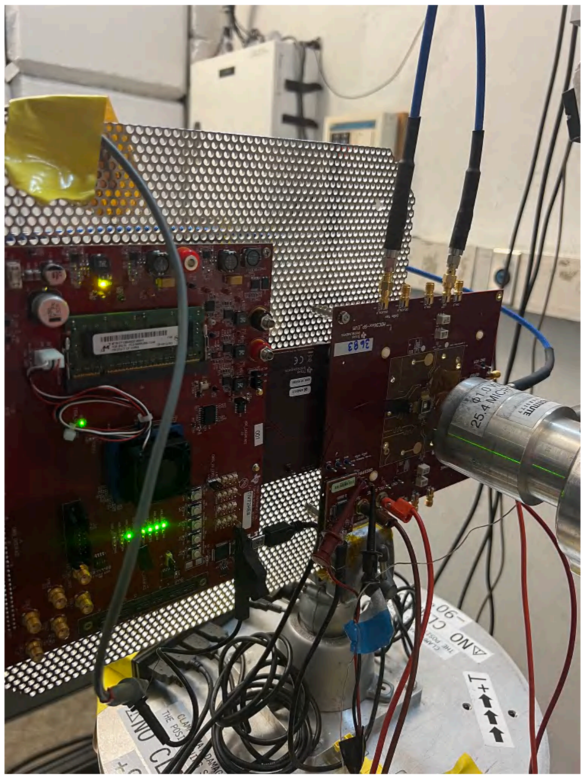

Figure 3-1. Photograph of the ADC3683-SP Evaluation Board Mounted in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron Institute

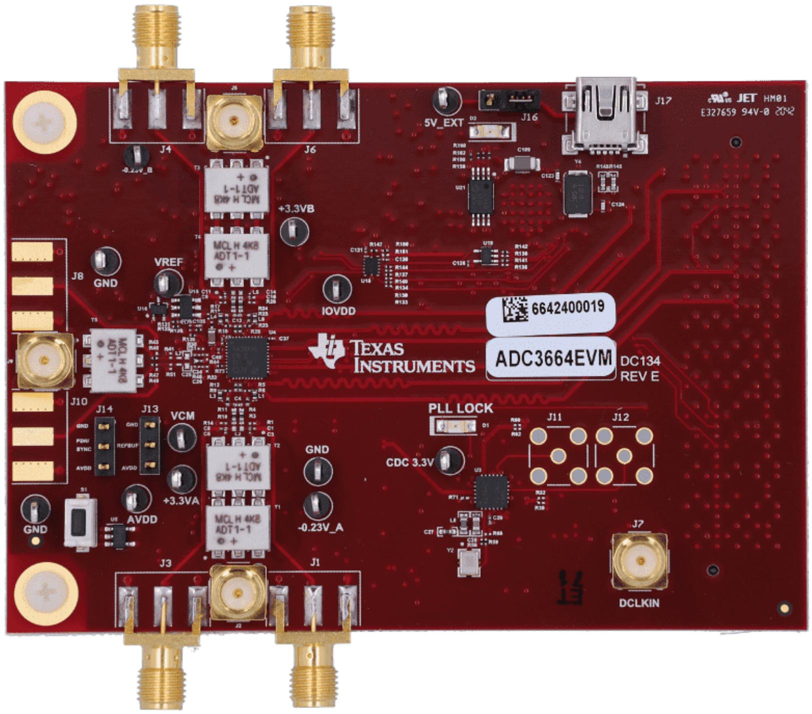

Figure 3-2. Image of ADC3664EVM

4 Depth, Range, and LET_{EFF} Calculation

The ADC3664-SEP 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 ADC3664-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 that was provided by the Texas A&M University Cyclotron Institute and based on the latest SRIM-2013models (4, 5). 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 ADC3664-SEP device solder down on an ADC3664EVM. For the SEL, the device was powered up to a voltage of 1.9V at approximately 125°C. For the SET characterization, the ADC3664-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, 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 7.1 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 5-1 shows a block diagram of the setup used for SEE testing of the ADC3664-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 ADC3664-SEP

Name	Equipment Used	Value set
AVDD	KeySight E36311	1.8V
IOVDD	KeySight E36311	1.8V
DCLKIN	R&S SML01 Sig Gen	350MHz
Channel A	R&S SGS100A	5MHz
CLK	R&S SGS100A	100MHz

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 ADC3664-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. (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.

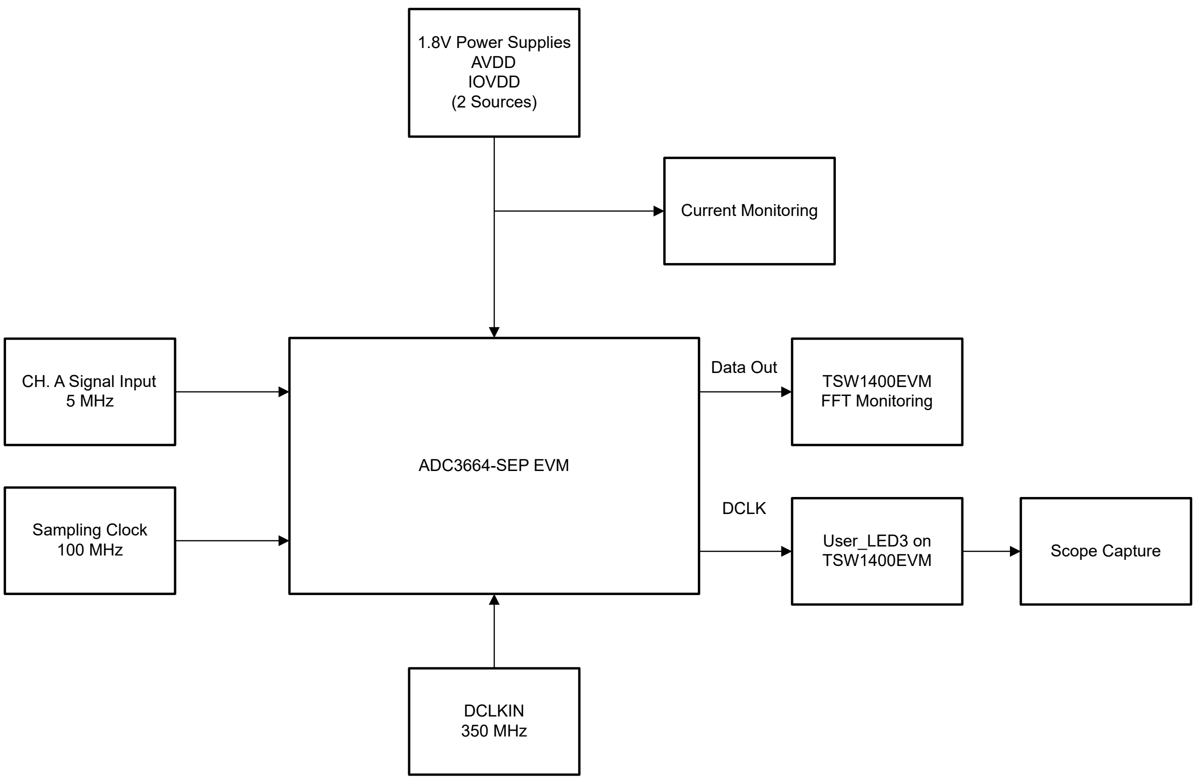

Figure 5-1. Block Diagram of SEE Test Setup With the ADC3664-SEP

6 Destructive Single-Event Effects (DSEE)

6.1 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 Silver (^{109}Ag) ion with an angle-of-incedence of 0° 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 ADC3664-SEP is SEL-free. Table 6-1 shows the SEL test conditions and results. Figure 6-1 shows a typical plot of current versus time for an SEL testing.

Table 6-1. Summary of ADC3664-SEP SEL Test Condition and Results

Run Number	Temperature	Unit #	LET_{EFF} (MeV × cm^2/mg)	Flux (ions × cm^2/s)	Fluence (ions × cm^2)	AVDD/IOVDD (V)
1	125°C	103	51.12	1.00 × 10^5	1.00 × 10^7	1.9
2	125°C	104	51.12	1.00 × 10^5	1.50 × 10^7	1.9
14	125°C	127	51.12	1.00 × 10^5	1.00 × 10^7	1.9

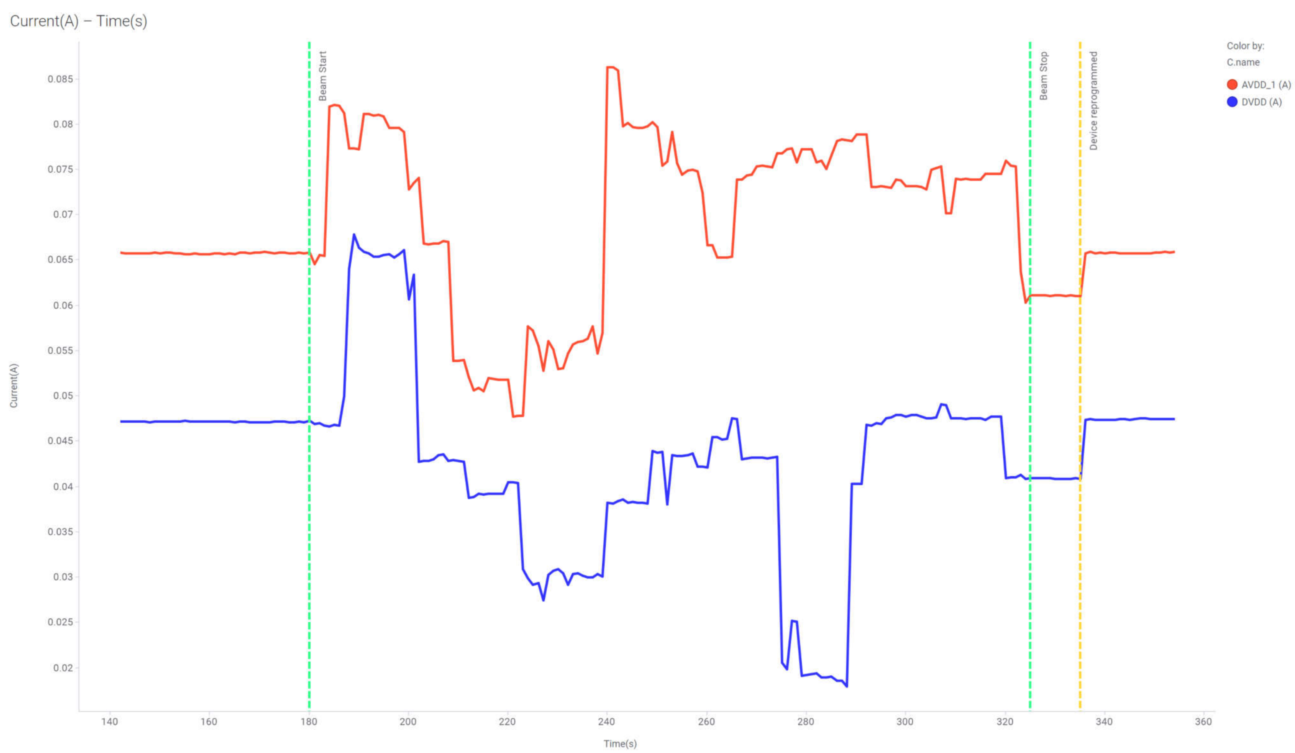

Figure 6-1. Current Versus Time for ADC3664-SEP at T = 125°C

7 Single-Event Transients (SET)

7.1 Single Event Transients

SETs are defined as heavy-ion-induced transients upsets on the DCLK of the ADC3664-SEP. 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. An example of what we considered an "single" event is shown 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 ADC3664-SEP SET Test Conditions and Results

Run Number	Unit Number	Temp	Ion	Angle	LET_{EFF} (MeV.cm^2/mg)	Flux (ions·cm^2/s)	Fluence (ions·cm^2)	Count DCLK Events	Cross-Section based on 95% confidence Interval
15	127	Room	^{109}Ag	0	51.12	1.00×10^5	1.00×10^7	198	3.22×10^{-6}
16	127	Room		0	51.12	1.00×10^5	1.00×10^7	1	
17	127	Room		0	51.12	1.00×10^5	2.60×10^7	1	
18	127	Room		0	51.12	1.00×10^5	2.60×10^7	2	

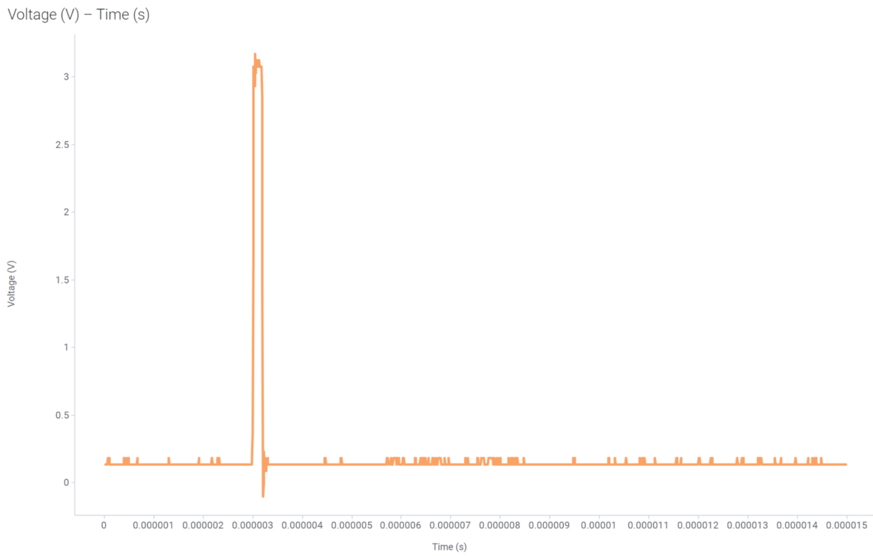

Figure 7-1. Example #1 of a Single Event Seen During SET Run

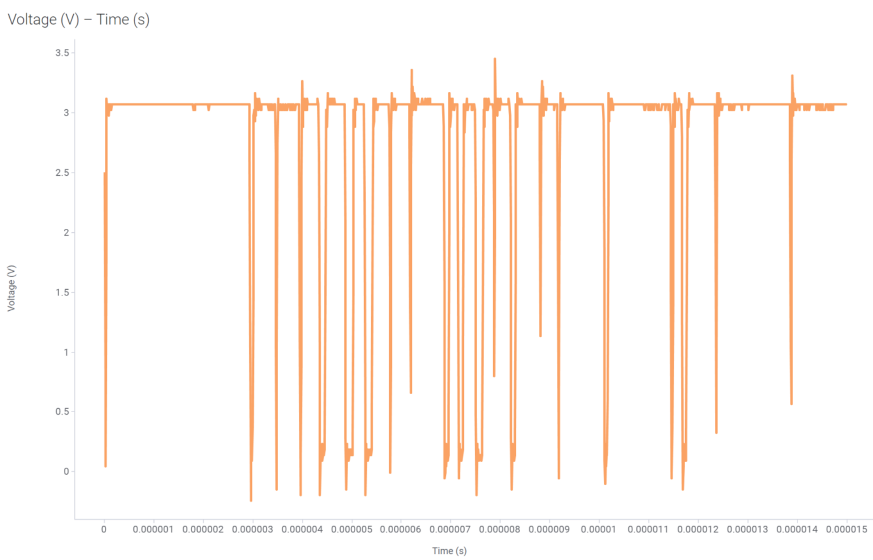

Figure 7-2. Example #2 of a Single Event Seen During SET Run

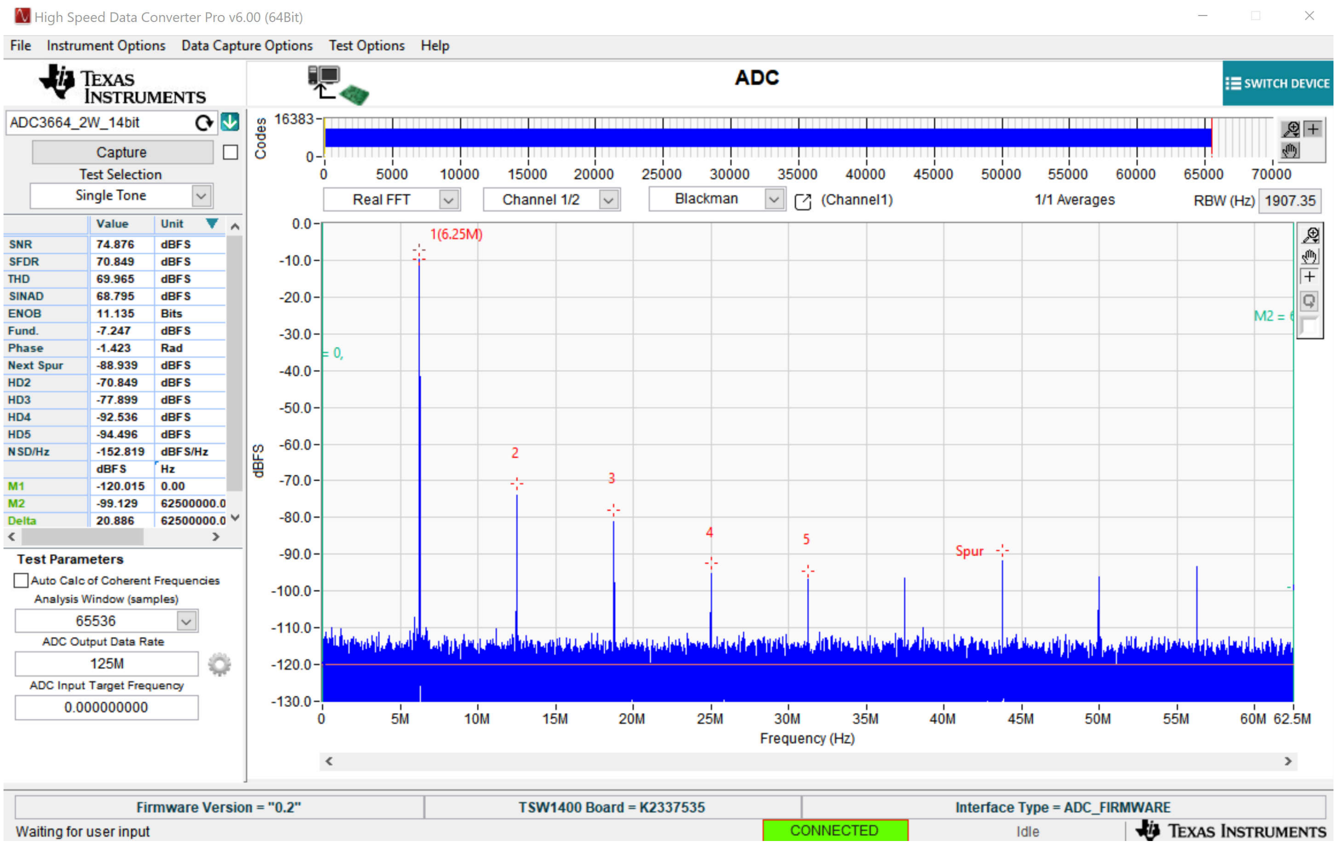

Figure 7-3. FFT Capture of Nominal Operating Conditions

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 ADC3664-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 ADC3664-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.

9 References

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