

ADC168M102R-SP Single-Event Effects (SEE) Radiation Report



Abstract

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the ADC168M102R-SP. Heavy-ions with LET_{EFF} of 48, 65, and 75 MeV $\times$ cm²/mg were used to irradiate four production devices. Flux of 1×10^5 ions $\times$ cm²/s and fluence of 1×10^7 ions/cm² per run were used for the characterization. The results demonstrated that the ADC168M102R-SP is SEL-free up to 75 MeV $\times$ cm²/mg at $T = 125^\circ\text{C}$. SET performance for output $\geq |5\%|$ from the established baseline are presented and discussed.

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1 Introduction

The ADC168M102R-SP is a dual, 16-bit, 1MSPS analog-to-digital converter (ADC). This ADC has eight pseudo- or four fully differential input channels grouped into two pairs for simultaneous signal acquisition. The analog inputs are maintained differentially to the input of the ADC. Use the input multiplexer in either pseudo-differential mode or fully differential mode. Pseudo-differential mode supports up to four channels per ADC (4×2), and fully differential mode converts up to two inputs per ADC (2×2).

The ADC168M102R-SP offers two programmable reference outputs, flexible supply voltage ranges, a programmable auto-sequencer, and several power-down features. The device also includes data storage up to four conversion results per channel.

The device is offered in a 32-pin plastic package. General device information and test conditions are listed in the overview information table. For more detailed technical specifications, user guides, and application notes please go to [device product page](#).

Table 1-1. Overview Information

DESCRIPTION	DEVICE INFORMATION
TI part number	ADC168M102R-SP
Orderable Part Number	5962R2521601PXE
VID/SMD Number	5962-25216
Device function	Analog-to-digital Converter
Technology	HPA07
Exposure facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University And Facility for Rare Isotope Beams, K500 Cyclotron (KSEE), Michigan State University (19.5MeV/nucleon)
Heavy ion fluence per run	$1 \times 10^6 - 1 \times 10^7$ ions/cm ²
Irradiation temperature	25°C (for SET testing), and 125°C (for SEL testing)

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2 Single-Event Effects (SEE)

The primary concern for the ADC168M102R-SP is the robustness against the destructive single-event effect (DSEE) single-event latch-up (SEL).

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) between power and ground that persists (is “latched”) until power is removed, the device is reset, or until the device is destroyed by the high-current state. The ADC168M102R-SP was tested for SEL at the maximum recommended operating conditions of AVDD = 5.5V, DVDD = 3.6V. Output of the SDO pins were monitored to confirm operation during SEL testing and to count variations of +/- 5% from a baseline during SET testing. During testing of the four devices, the ADC168M102R-SP did not exhibit any SEL with heavy-ions with $LET_{EFF} = 75\text{MeV}\times\text{cm}^2/\text{mg}$ at flux $\approx 10^5$ ions $\times\text{cm}^2/\text{s}$, fluence of $\approx 10^7$ ions/ cm^2 , and a die temperature of 125°C.

The ADC168M102R-SP was characterized for SET at flux of 1×10^5 ions $\times\text{cm}^2/\text{s}$, fluences of 1×10^7 ions/ cm^2 , and room temperature. The device was characterized at V_{IN} of 2.7V. Heavy-ions with LET_{EFF} of 48, 65, and $75\text{MeV}\times\text{cm}^2/\text{mg}$ were used to characterize the transient performance. To see the SET results of the ADC168M102R-SP, please refer to Single-Event Transients (SET).

3 Device and Test Board Information

The ADC168M102R-SP is packaged in a 32-pin VQFN plastic package as shown in Figure 3-1. The TPS7H1111-SP evaluation module was used to evaluate the performance and characteristics of the TPS7H1111-SP under heavy ion radiation. The ADC168M102REVM-PDK is shown in Figure 3-2. The schematic is shown in Figure 3-2.

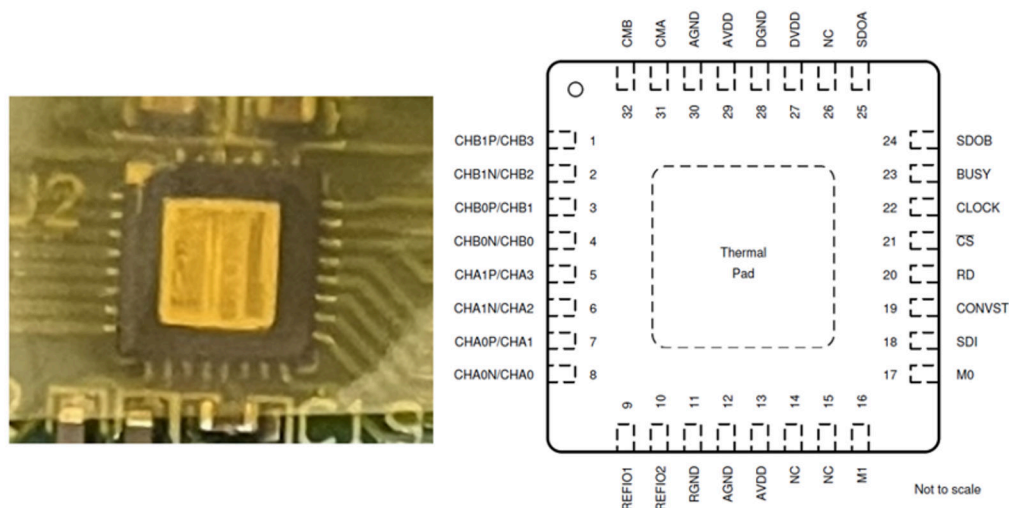


Figure 3-1. Photograph of Decapped ADC168M102R-SP [Left] and Pinout Diagram [Right]



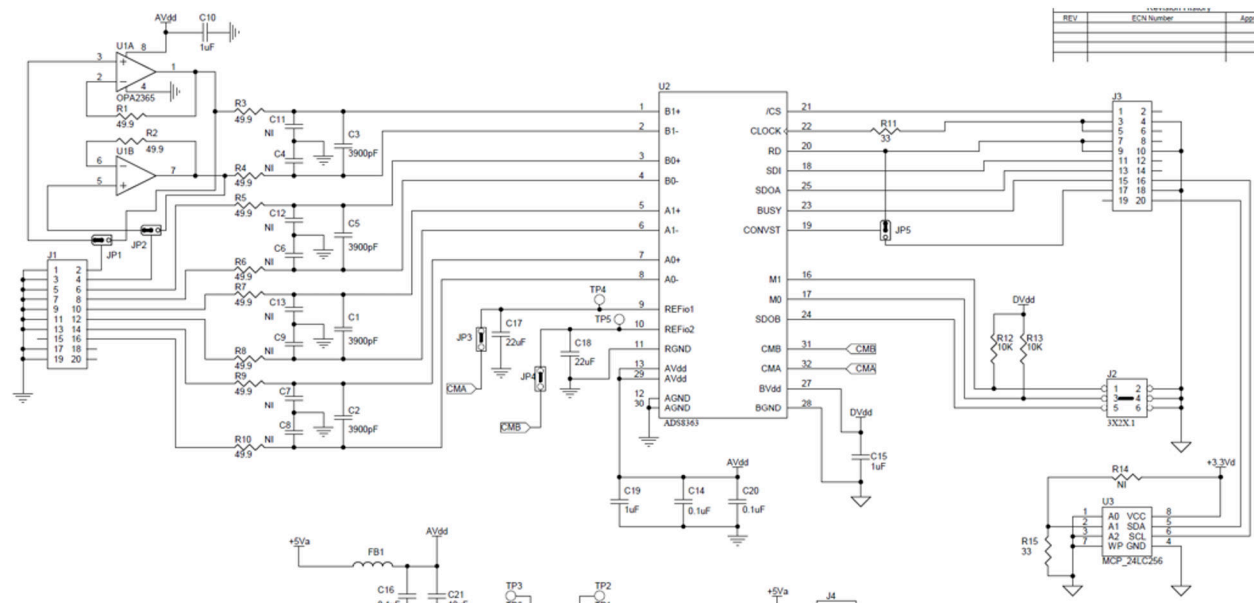


Figure 3-3. ADC168M102R-SP EVM Schematic

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by:

- Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a K500 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 1-in diameter circular cross-sectional area for the in-air station. Uniformity is achieved by magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of 1×10^5 ions/cm² · s was used to provide heavy-ion fluences of $1 \times 10^6 - 1 \times 10^7$ ions/cm². The TAMU facility uses a beam port that has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 40 mm for all runs.
- Michigan State University (MSU) Facility for Rare Isotope Beams (FRIB) using a K500 superconducting cyclotron (KSEE) and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity as the beam is collimated to a maximum of 40mm × 40mm square cross-sectional area for the in-air and vacuum scintillators. Uniformity is achieved by scattering on a Cu foil and then performing magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of 1×10^5 ions/cm² · s was used to provide heavy-ion fluences of $1 \times 10^6 - 1 \times 10^7$ ions/cm². The KSEE facility uses a beam port that has a 3-mil polyethylene naphthalate (PEN) window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.

For the experiments conducted on this report, there were three ions used, ¹⁶⁹Tm, ¹⁴¹Pr and ¹⁰⁹Ag. ¹⁶⁹Tm was used to obtain LET_{EFF} of 75MeV×cm²/mg. ¹⁰⁹Ag was used to obtain LET_{EFF} of 48MeV×cm²/mg. ¹⁴¹Pr was used to obtain LET_{EFF} of 65 and 75MeV×cm²/mg. The total kinetic energies for each of the ions were:

- ¹⁶⁹Tm = 3.295GeV (19.5MeV/nucleon)
 - Ion uniformity for these experiments was ≈90.5%
- ¹⁴¹Pr = 2.114GeV (15MeV/nucleon)
 - Ion uniformity for these experiments was 88 to 97%
- ¹⁰⁹Ag = 1.634GeV (15MeV/nucleon)
 - Ion uniformity for these experiments was 88 to 97%

Figure 4-1 shows the ADC168M102R-SP EVM in front of the beam line at the MSU facility.

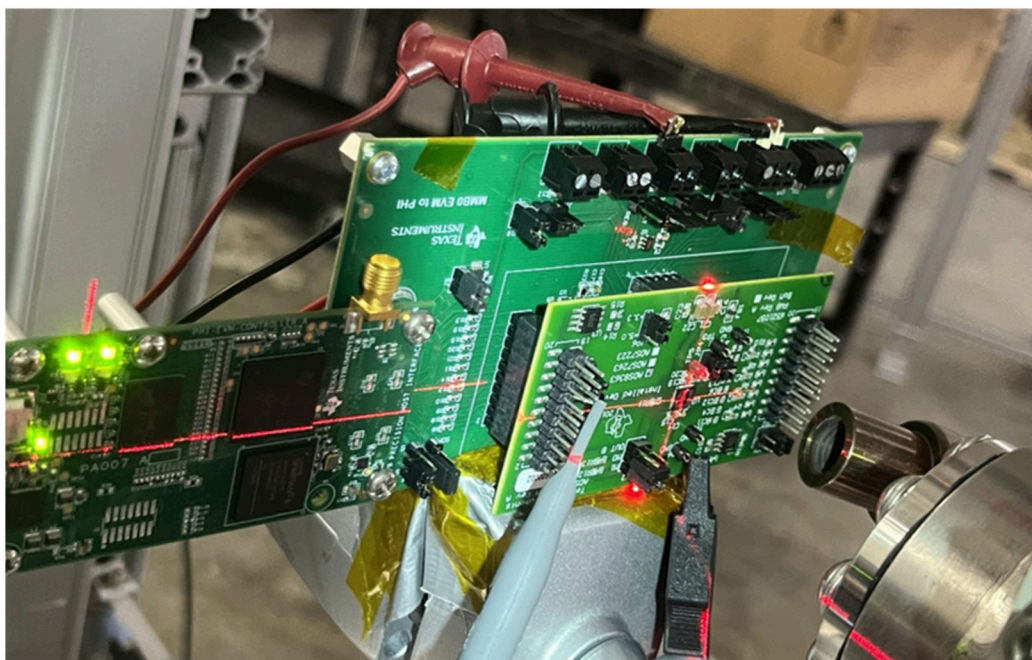


Figure 4-1. ADC168M102R-SP EVM in Front of the Heavy-Ion Beam Exit Port at MSU

5 LET_{EFF} and Range Calculation

Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the ADC168M102R-SP, the effective LET (LET_{EFF}) at the surface of the silicon substrate and the range was determined with:

- SEUSS 2024 software (provided by TAMU and based on the latest SRIM-2013 [7] models)
- MSU Stack-Up Calculator (provided by MSU FRIB and based on the latest SRIM-2013 [7] models)

The results are shown in [Table 5-1](#).

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

Facility	Beam Energy (MeV/nucleon)	Ion Type	Degrader Steps (#)	Degrader Angle (°)	Copper Foil Width(μm)	Beam Port Window	Air Gap (mm)	Angle of Incidence	LET _{EFF} (MeV×cm ² /mg)	Range in Silicon(μm)
TAMU	15	¹⁰⁹ Ag	0	0	-	1-mil Aramica	40	0	48	130
TAMU	15	¹⁴¹ Pr	0	0	-	1-mil Aramica	40	0	65	117
TAMU	15	¹⁴¹ Pr	0	0	-	1-mil Aramica	40	30	75	117
KSEE	19.5	¹⁶⁹ Tm	-	-	5	3-mil PEN	40	0	75	90

6 Test Setup and Procedures

There were four input supplies used to power the ADC168M102R-SP which provided V_{IN}, V_{REF}, AVDD and DVDD.

For SEL testing, continuous device output was monitored using device-specific GUI software. The primary signal monitored on the EVM during SET testing was SDO for which an external Tektronix MSO was set to trigger on a 5% pulse width variation from a baseline value measured at the beginning of each SET run.

Power supply 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 via an MXI controller and NI PXIe-8381 remote control module.

Table 6-1 shows the connections, limits, and compliance values used during the testing. Figure 6-1 shows a block diagram of the setup used for SEE testing of the ADC168M102R-SP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the ADC168M102R-SP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
VIN	NI-PXle 4139-1(CH # 1)	$\pm 60\text{V}$, 3A	3A	5.5 V
VREF	NI-PXle 4139-2(CH # 1)	$\pm 60\text{V}$, 3A	3A	2.5 V
AVDD	E36311A (CH # 1)	5V,5A	0.1A	2.7 to 5.5 V
DVDD	E36311A (CH # 2)	5V,5A	0.1A	2.3 to 3.6 V
SDOA	Tektronix MSO58B	1GHz, 6.25GS/s	62.5M record length	+/- 5% Width Trigger

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to ensure that the test system was stable under all bias and load conditions prior to being taken to the test facilities. During the heavy-ion testing, the LabVIEW control program powered up the ADC168M102R-SP device and set the external sourcing and monitoring functions of the external equipment. After functionality and stability was 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 output signals were continuously monitored by the external GUI for SEL and by the Tektronix MSO for SET testing. When the output exceeded the pre-defined 5% width trigger, a data capture was initiated and a transient was counted. No sudden increases in current were observed (outside of normal fluctuations) on any of the test runs and indicated that no SEL events occurred during any of the tests.

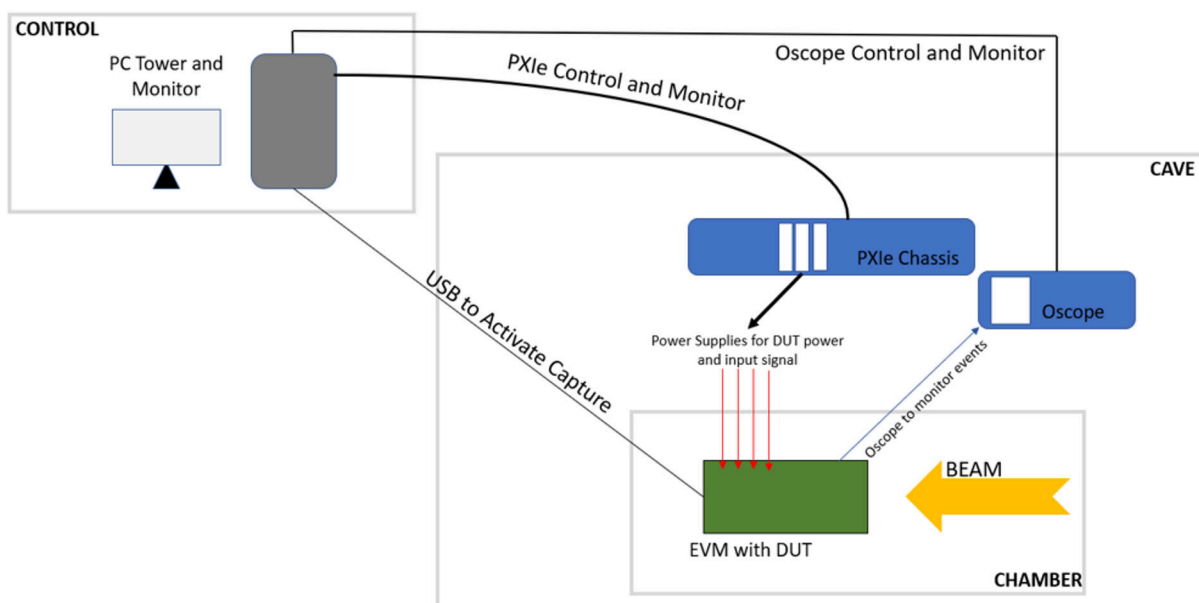


Figure 6-1. Block Diagram of the SEE Test Setup for the ADC168M102R-SP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

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)). The temperature of the die was constantly monitored during testing at TAMU through an IR camera integrated into the control loop to create closed-loop temperature control. The die temperature was verified using a standalone FLIR thermal camera prior to exposure to heavy ions at KSEE.

The species used for SEL testing was ^{169}Tm at 19.6MeV/nucleon. Ion LET_{EFF} and Range in Silicon). Flux of approximately 1×10^5 ions $\times$ cm ^{2} /s and a fluence of approximately 1×10^7 ions/cm ^{2} per run was used. Run duration to achieve this fluence was approximately two minutes. The three devices were powered up and exposed to the heavy-ions using the maximum recommended operating voltages of AVDD = 5.5V, DVDD = 3.6V, and input of $V_{\text{IN}} = 5.5\text{V}$. No SEL events were observed, indicating that the ADC168M102R-SP is SEL-free up to 75MeV $\times$ cm ^{2} /mg. Table 7-1 shows the SEL test conditions and results. Figure 7-1 and Figure 7-2 show plots of the current versus time for run # 6.

Table 7-1. Summary of ADC168M102R-SP SEL Test Condition and Results

Run #	Unit #	Facility	Ion	LET_{EFF} (MeV $\times$ c m ^{2} /mg)	Flux (ions $\times$ cm ^{2} / mg)	Fluence (# ions)	AVDD	DVDD	V_{IN}	SEL (# Events)
4	1	MSU	^{169}Tm	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0
5	1	MSU	^{169}Tm	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0
6	1	MSU	^{169}Tm	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0
29	2	TAMU	^{141}Pr	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0
30	2	TAMU	^{141}Pr	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0
31	2	TAMU	^{141}Pr	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0
32	3	TAMU	^{141}Pr	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0
33	3	TAMU	^{141}Pr	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0
34	3	TAMU	^{141}Pr	75	1.00×10^5	1×10^7	5.5	3.6	5.5	0

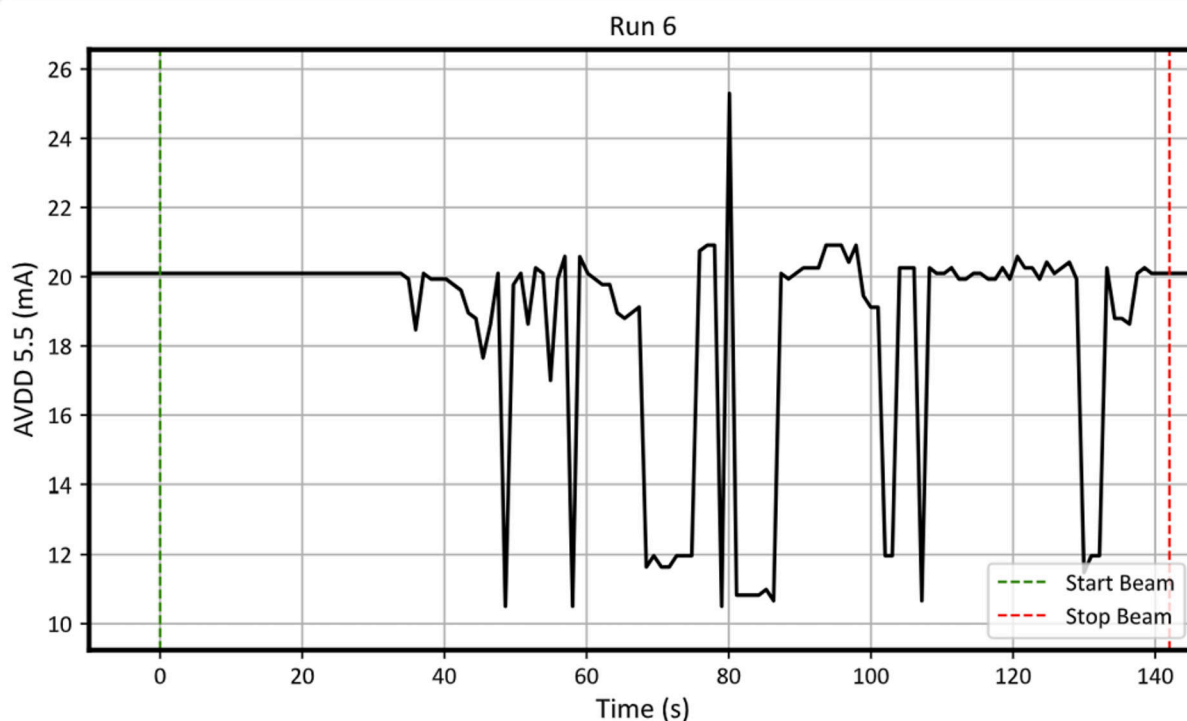


Figure 7-1. AVDD Current versus Time for Run # 6 of the ADC168M102R-SP at T = 125°C

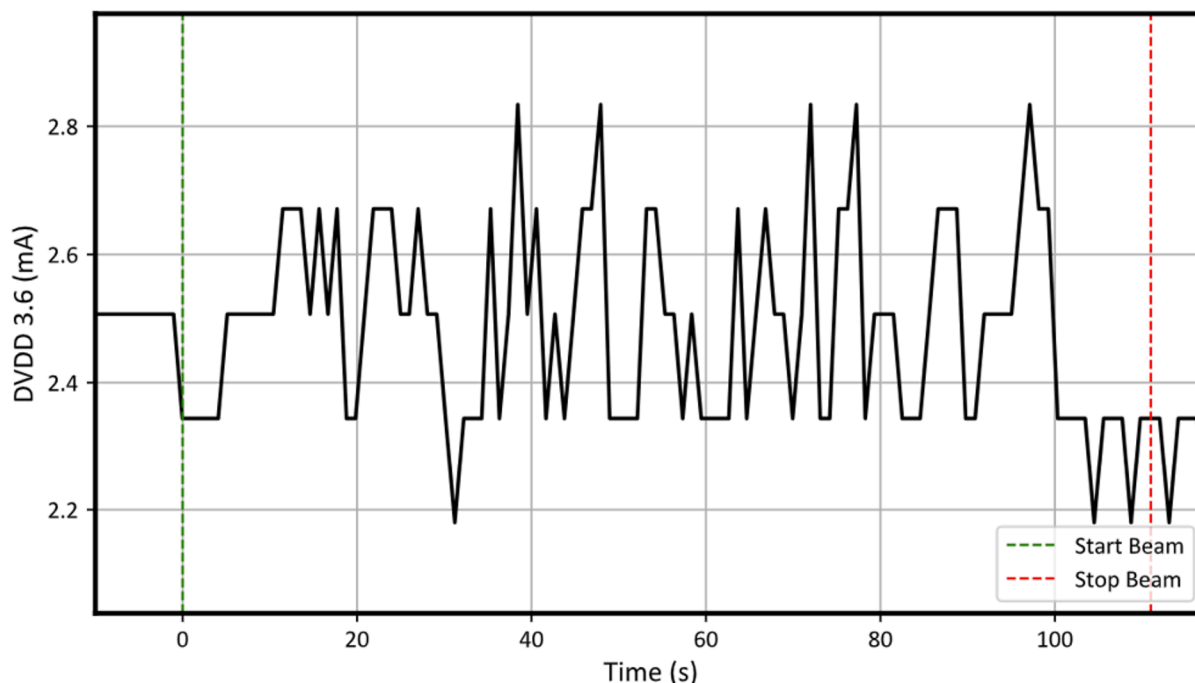


Figure 7-2. DVDD Current versus Time for Run # 6 of the ADC168M102R-SP at T = 125°C

8 Single-Event Transients (SET)

SET are defined as heavy-ion-induced transient upsets in the device output of the ADC168M102R-SP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for SET testing were ^{109}Ag and ^{141}Pr at 15MeV/nucleon. Ion LET_{EFF} and Range in Silicon) for LET_{EFF} of 43, 65, and 75 MeV $\times\text{cm}^2/\text{mg}$. Flux of 1×10^5 ions $\times\text{cm}^2/\text{s}$ and a fluence of 1×10^7 ions $\times\text{cm}^2/\text{s}$ per run were used for the SET's characterization discussed in this chapter. Waveform size, sample rate, trigger type, value, and signal for all scopes used is presented on [Table 8-1](#).

Table 8-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
MSO58B	SDO	Pulse Width	$\pm 5\%$	1.25M	6.25GS/s

SET study was performed at Texas A&M University Cyclotron Institute (TAMU). For SET setup, the EVM along with capture card was used as shown in [Figure 8-1](#). The capture card is connected to PC for through a GUI.



Figure 8-1. EVM Setup Under Beam at TAMU

The GUI is used to configure capture parameters, initiate a soft device reset, and for writing default register reconfiguration to the device without interrupting power supply.

For SET test, device was programmed to have continuous capture for 64K samples at a time. Output duty cycle varies according to the input voltage. Oscilloscope was used to monitor the waveform and duty cycle change was used to capture the transient fails. An example of typical full-scale output on SDO is shown in [Figure 8-2](#).

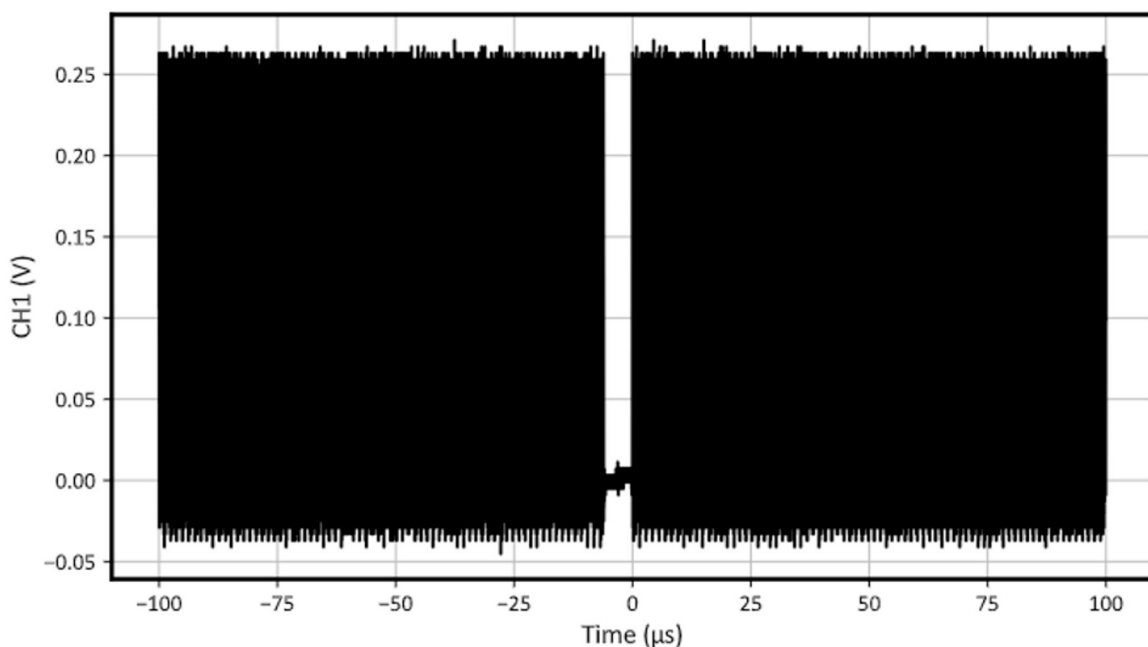


Figure 8-2. Typical Full-scale SDO output

Note that the typical full-scale output contains an extended LOW period at the end of every cycle (centered in each figure). This period is consistent pre-beam and during exposure and is due to modifying the GUI software for continuous looping. This consistently occurring period is discarded from all event counts.

Minimum recommended operating voltage of 2.7V for AVDD and 2.3V for DVDD was supplied from NI PXIe chassis cards as well as an external reference voltage of 2.5V per device spec and full-scale input matching AVDD level. The digital output channel (SDO) was monitored, and triggered events were recorded using an external oscilloscope.

An ion flux of 10^5 ions/sec-cm² was used to reach a Fluence of 10^7 ions/cm² for each run. Ion beam of ¹⁰⁹Ag was used with incident angle which resulted in LET_{EFF} of 48MeV×cm²/mg, ion beam of ¹⁴¹Pr was used with incident angle which resulted in LET_{EFF} of 65MeV×cm²/mg, and ion beam of ¹⁴¹Pr was used with 30° angle which resulted in LET_{EFF} of 75MeV×cm²/mg.

Two forms of SET were characterized during the runs. A one-time variance from baseline which resumed functioning in the next clock cycle was characterized as SET1. A variance which did not recover until after multiple clock cycles was characterized as SET2. SET2 recovery would either recover within multiple clock cycles, need a soft device reset, or a combination of soft device reset and default register re-configuration before recovery.

Examples of typical SET1 events are shown and marked in [Figure 8-3](#) . An example of a typical SET2 event is shown in [Figure 8-4](#).

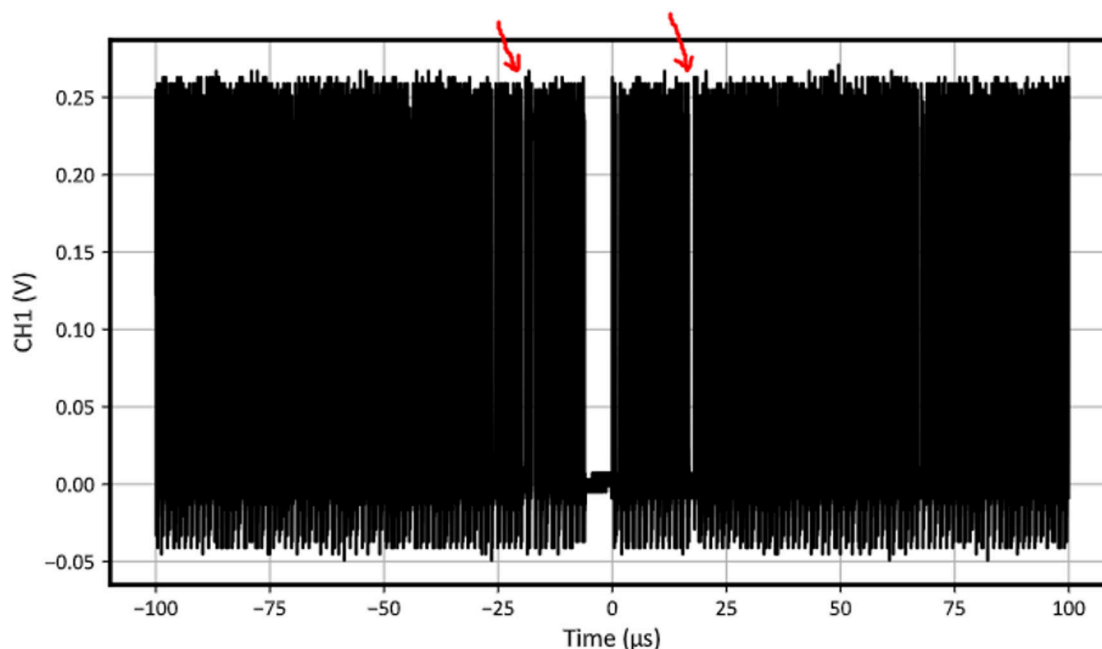


Figure 8-3. Typical Observed SET1 Events

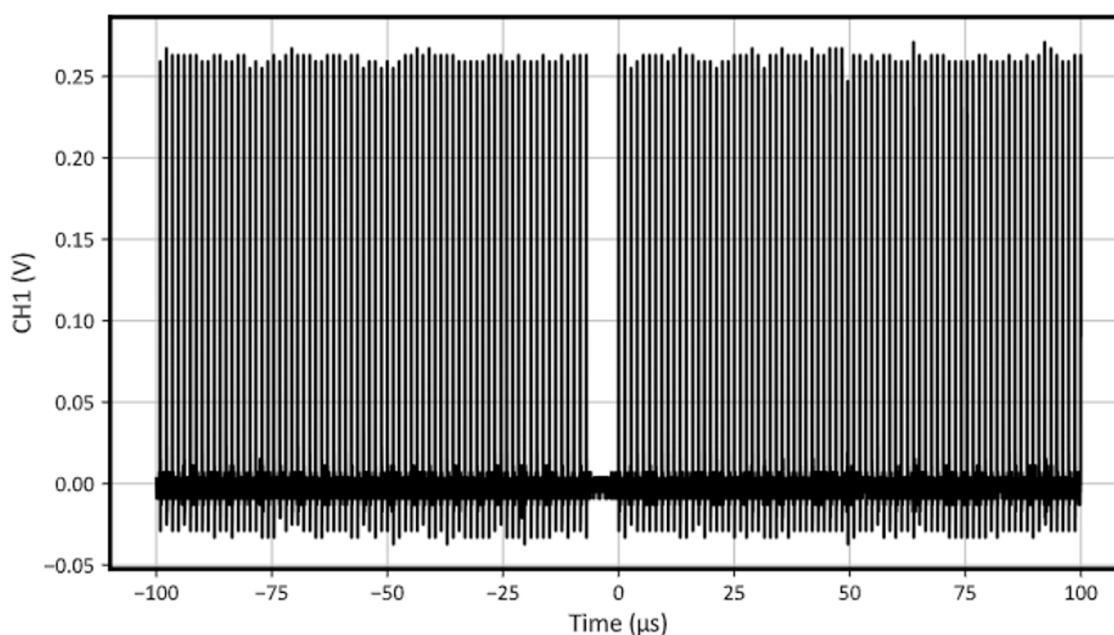


Figure 8-4. Typical Observed SET2 Events

A total of three runs at each LET_{EFF} was performed to characterize the SET cross sections at 48, 65, and 75 $MeV \times cm^2/mg$. A summary of data collection runs is shown in [Table 8-2](#). The mean calculated cross sections are shown in [Table 8-3](#).

Table 8-2. Summary of ADC168M102R-SP SET Runs and Test Conditions

Run #	Unit #	Facility	Ion	Angle	LET_{EFF} ($MeV \times cm^2/mg$)	Flux ($ions \times cm^2/mg$)	Fluence (# ions)	AVDD	DVDD	V_{IN}
26	1	TAMU	^{109}Ag	0	48	1.00×10^5	1×10^7	2.7	2.3	2.7
28	1	TAMU	^{109}Ag	0	48	1.00×10^5	1×10^7	2.7	2.3	2.7
29	1	TAMU	^{109}Ag	0	48	1.00×10^5	1×10^7	2.7	2.3	2.7
30	1	TAMU	^{141}Pr	0	65	1.00×10^5	1×10^7	2.7	2.3	2.7

Table 8-2. Summary of ADC168M102R-SP SET Runs and Test Conditions (continued)

Run #	Unit #	Facility	Ion	Angle	LET _{EFF} (MeV×cm ² /mg)	Flux (ions×cm ² /mg)	Fluence (# ions)	AVDD	DVDD	V _{IN}
31	1	TAMU	¹⁴¹ Pr	0	65	1.00 × 10 ⁵	1 × 10 ⁷	2.7	2.3	2.7
32	2	TAMU	¹⁴¹ Pr	30	75	1.00 × 10 ⁵	1.00 × 10 ⁷	2.7	2.3	2.7
33	2	TAMU	¹⁴¹ Pr	30	75	1.00 × 10 ⁵	1 × 10 ⁷	2.7	2.3	2.7
34	2	TAMU	¹⁴¹ Pr	30	75	1.00 × 10 ⁵	1 × 10 ⁷	2.7	2.3	2.7
35	2	TAMU	¹⁴¹ Pr	0	65	1.00 × 10 ⁵	1 × 10 ⁷	2.7	2.3	2.7

Table 8-3. Calculated Cross Sections

LET _{EFF} (MeV × cm ² /mg)	Total Fluence (# ions × cm ²)	Total # of Upsets	LB X _{SECTION} (cm ² /device)	MEANX _{SECTION} (cm ² /device)	UB X _{SECTION} (cm ² /device)	UB Error	LB Error
48	3.00E+07	48	1.18E-06	1.60E-06	2.12E-06	5.21E-07	4.20E-07
65	3.00E+07	82	2.17E-06	2.73E-06	3.39E-06	6.59E-07	5.59E-07
75	3.00E+07	150	4.23E-06	5.00E-06	5.87E-06	8.67E-07	7.68E-07

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 ADC168M102R-SP dual, 16-bit, 1MSPS analog-to-digital converter (ADC). Heavy-ions with LET_{EFF} = 48, 65 and 75MeV×cm²/mg were used for the SEE characterization campaign. Flux of ≈10⁵ ions/cm² ·s and fluence of ≈10⁷ ions/cm² per run were used for the characterization. The SEE results demonstrated that the ADC168M102R-SP is free of destructive SEL at LET_{EFF} = 75MeVcm²/mg and across the full electrical specifications. Transients at LET_{EFF} = 48 to 75MeV×cm² /mg on SDO are presented and discussed.

10 References

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