SINGLE EVENT EFFECTS TEST REPORT RHP50000-CSL

August 2024

Radiation Test Report	
Product:	RHP50000-CSL
Effective LET:	≤ 47.0 MeV-cm^2/mg
Fluence:	1E7 Ions/cm^2
Facilities:	TAMU
Tested:	August 2024

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SEE Test Report for the RHP50000-CSL – 5V, 12.5A Synchronous Step-Down Silent Switcher

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Braxton Houlden, Nolan Carr

Test Dates:
August 22 - 27, 2024

I. Introduction

The purpose of this test is to determine the Single-Event Effects (SEE) susceptibility of the RHP50000-CSL, synchronous step-down silent switcher. Single Event Latchup (SEL) and Single Event Transient (SET) were verified between August 22 - 27, 2024, at the TAMU heavy ion facility. The I/O voltages and the supply currents were monitored for the device during SEE testing. A specific SEL mitigation circuit was used during t esting

II. Device Under Test

The RHP50000-CSL is a small, low noise, monolithic step-down DC/DC converter capable of providing up to 12.5A of output current from a 2.25V to 5.5V input supply. The device uses silent switcher architecture which minimizes EMI while delivering high efficiency at frequencies up to 5MHz. This device has an adjustable voltage output by configuring the V_{FB} pin. For our tests, the DC3018A evaluation board was used to characterize the RHP50000-CSL with a proprietary SEL mitigation circuit added to the eval board.

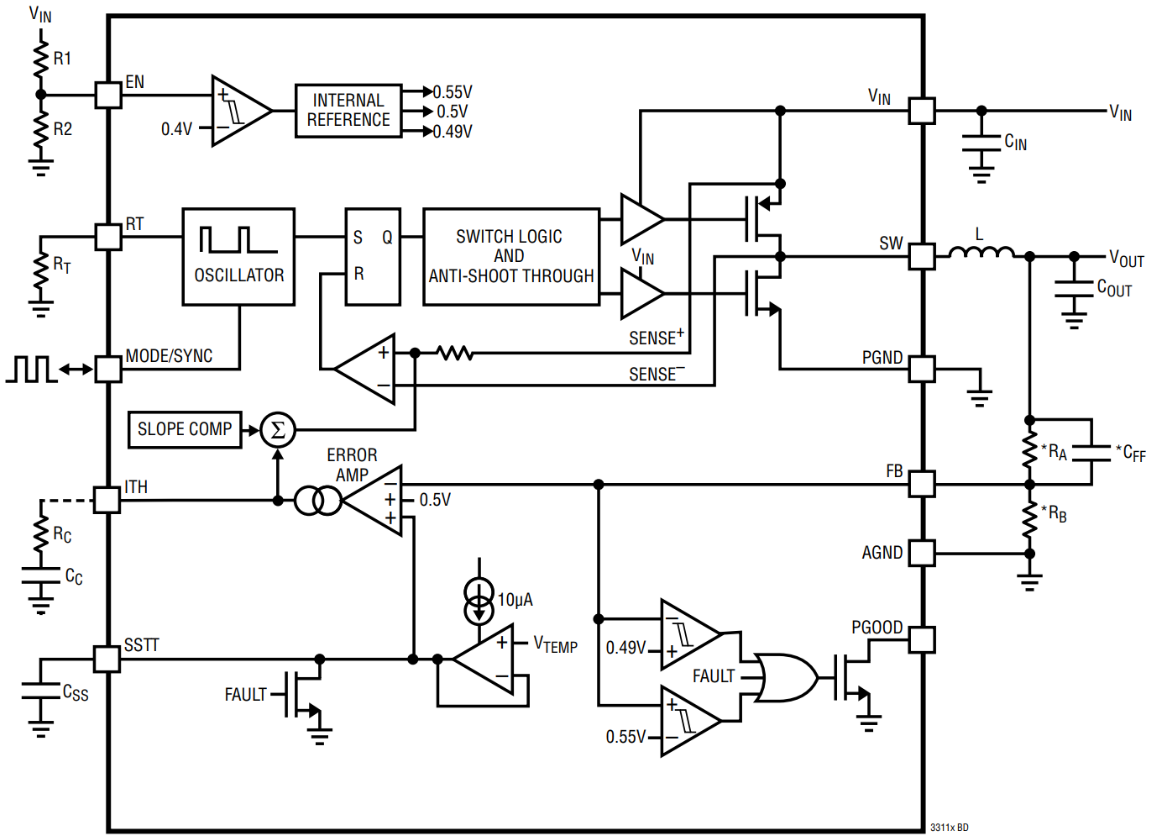


Figure 1. Functional block diagram.

Table 1
Part and test information.

Generic Part Number:	RHP50000-CSL
Date of Test:	August 22 – 27
Manufacturer:	Analog Devices, Inc.
Part Function:	12.5A, Low Voltage Synchronous Step-Down Regulator
Part Technology:	0.35um BCDMOS (flip chip)
Package Style:	18 – Lead LQFN (3mm x 3mm x 0.94mm)
Test Equipment:	Power Supply (Keithley 2230G-30-6), LabVIEW, NI PXI-1095 with PXIe5172 oscilloscope, TCPA300 current amp and TCP312 current probe

III. Test Facilities

The heavy-ion beam testing was carried out at the Texas A&M University Cyclotron Facility. The facility utilizes the K500 cyclotron with a superconducting magnet which generates the magnetic field used to accelerate the ions. The test setup was in an open-air environment.

Facility: Texas A&M University Cyclotron Facility
Cocktail: 15 MeV/nuc
Flux: 1×10^5 cm$^{-2}\cdot$s^{-1}
Fluence: 1×10^7 cm^{-2} (per run)
Ions: Neon, Argon, Copper, Silver, and Krypton

Table 2.
Heavy-ion specie, linear energy transfer (LET).

Ion	Initial LET in air (MeV·cm^2/mg)
Ne	2.6
Ar	8.0
Cu	18.7
Ag	35.7
Kr	40.8

IV. Test Method

A. Test Setup

The devices under test (DUTs) were de-processed to expose the die which was thinned to 80 um. The RHP50000-CSL was configured, as shown in Figure 2, by connecting the power supplies to the V_{IN} port, with an electronic load connected to V_{OUT}, set to constant resistance mode to set the output current to ~10A. The supply current was monitored using a current probe on the input channel. The device's input current, input voltage, power good, voltage track / soft start voltage, and output voltage were recorded using a LabVIEW program on a PXI-1095 chassis.

In some runs, a proprietary SEL hardware mitigation circuit was used to mitigate SEL (indicated with "Hardware" in Tables 3 and 4).

In some runs, a software-enabled power cycle of V_{IN} was used to mitigate SEL whenever the power good signal was observed to decrease by ~50% in magnitude for a duration of ~750 ms (indicated with "Software" in Tables 3 and 4).

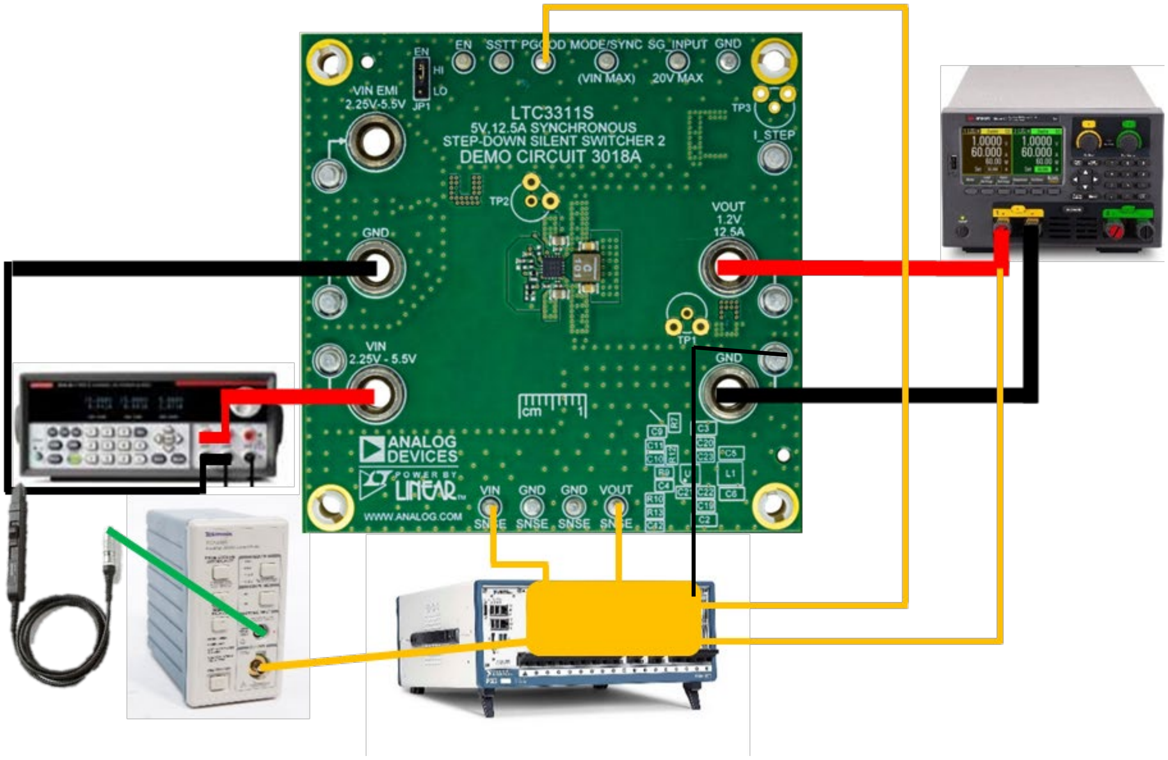


Figure 2. RHP50000-CSL test setup.

B. Irradiation procedure

SEL: Configure the device with the load described in the *Test Setup*. Using a heat gun, the device was heated to 125°C. The supply voltage and current were monitored before, after, and while the ion beam was turned on.

SET: Configure the device with the same parameters as the SEL procedure. The device temperature was at 25°C. The I/O signals were monitored before, after, and while the ion beam was turned on.

C. Test Conditions

Test Temperature:	25°C (SET), 125°C (SEL)
Power Supply(s):	3.0V – 5.3V
Angles of Incidence:	0°, 25°, 30°, 35°, 36°, 42°
Parameters:	Output Load ~10A sink

V. Results

SEL – No latchup or destructive SEE events were observed on the RHP50000-CSL to the highest effective LET tested of 47.0 MeV·cm^2/mg at V_{IN} = 3.6V. Testing with input voltage of greater than 4.25V experience varying degrees of single event destructs. Table 3 describes the behavior of the RHP50000-CSL at different voltages and effective LETs.

Table 3
SEL Test Runs

Run	SN	Ion	Voltage Input	Effective LET	Angle	Flux	Fluence	SEL	Mitigation
			(V)	*MeV·cm^2/mg*	*degrees*	*ions/cm^2/s*	*ions/cm^2*		*(Yes/No)*
8	1	Ne	3.3	3.17	0	2.05E+05	9.95E+06		Software
12	1	Ne	3.6	3.17	0	1.98E+05	9.90E+06		Hardware
24	2	Kr	4.25	38.6	0	1.07E+05	1.00E+07		Hardware
9	1	Ne	4.5	3.17	0	2.05E+05	1.00E+07		Software
13	1	Ne	4.5	3.17	0	2.03E+05	9.94E+06		Hardware
14	1	Ne	4.5	3.17	0	2.05E+05	9.98E+06		Software
26	2	Cu	4.5	27.1	0	8.21E+04	9.86E+06		Hardware
28	3	Cu	4.5	27.1	0	1.41E+05	9.98E+06		Hardware
25	2	Kr	4.5	38.6	0	1.10E+05	1.00E+07		Hardware
23	1	Kr	4.5	44.36	25	1.07E+05	9.26E+06	SED	Hardware
10	1	Ne	5.3	3.17	0	2.10E+05	1.01E+07		Software
11	1	Ne	5.3	3.17	0	2.04E+05	1.01E+07		Software
15	1	Ne	5.3	3.17	0	3.19E+05	9.97E+06		Hardware
27	2	Cu	5.3	27.1	0	7.57E+04	7.58E+06	SED	Hardware

SET – Four devices were tested at up to 27.1 MeV·cm^2/mg. The test runs are shown in MeVcm2/mg (Table 4). SET plots for the V_{PG}, V_{SSTT}, and V_{OUT} are shown in the Appendix. Run 35 started at a voltage input of 3.6V but was corrected mid run to 3.0V around 30 seconds into the run. Transients were counted through qualitative observation of the graph outputs.

Table 4
SET Test Runs

Run	SN	Ion	V_{IN}	Effective LET	Angle	Flux	Fluence	V_{OUT} Count	V_{PG} Count	V_{SSTT} Count	All Outputs	Total SET	Cross Section	Mitigation
			V	*MeV·cm²/mg*	*degrees*	*ions/cm²/s*	*ions/cm²*	#	#	#	#	#	*#/ions/cm²*	*(Yes/No)*
16	1	Ne	3.0	3.17	0	1.99E+05	9.90E+06					0		None
35	5	Ar	3.0	14.41	36	9.84E+04	1.00E+07	6*	3	6*		9	9.0E-7	Software
21	1	Ar	3.0	16.74	42	4.99E+04	1.00E+07	1*	3	1*		4	4.0E-7	None
33	5	Cu	3.0	27.1	0	1.12E+05	9.99E+06		36		5	41	4.1E-6	Software
17	1	Ne	3.6	3.17	0	2.00E+05	9.93E+06					0		None
34	5	Ar	3.6	14.41	36	1.04E+05	1.00E+07	9*	3	9*		12	1.2E-6	Software
22	1	Ar	3.6	16.74	42	4.50E+04	1.00E+07	2*	2, 2*			4	4.0E-7	None
29	3	Cu	3.6	27.1	0	1.22E+05	1.01E+07	1*	4	1*	1	6	6.0E-7	None
32	5	Cu	3.6	27.1	0	1.12E+05	1.00E+07	9*	24	9*		33	3.3E-6	Software
18	1	Ne	4.5	3.17	0	1.99E+05	1.01E+07	3*		3*		3	3.0E-7	None
36	5	Ar	4.5	14.41	36	9.81E+04	9.97E+06		1		1	2	2.0E-7	None
30	3	Cu	4.5	27.1	0	7.31E+04	6.86E+06					SED		None
31	4	Cu	4.5	27.1	0	1.13E+05	1.01E+07					SED		Software
19	1	Ne	5.3	3.17	0	1.96E+05	1.01E+07					0		None
20	1	Ne	5.3	3.17	0	1.91E+05	9.92E+06					0		None
37	5	Ar	5.3	14.41	36	9.66E+04	2.76E+06					SED		Software

*Indicates that an event affected multiple outputs simultaneously and/or counted as a single transient

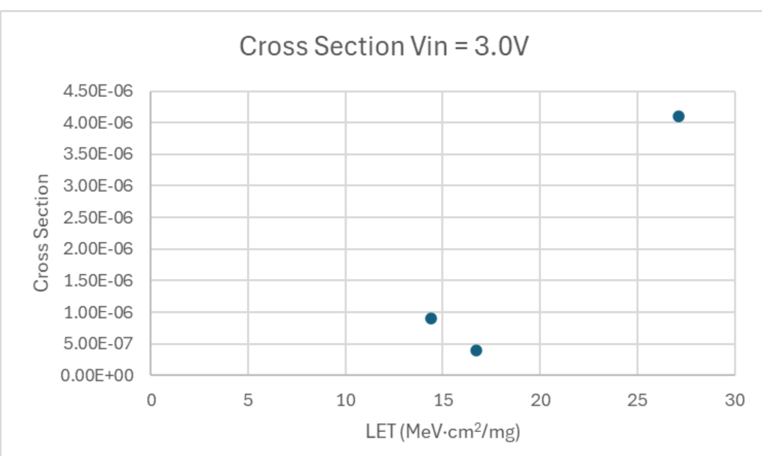


Figure 3: Vin = 3.0V

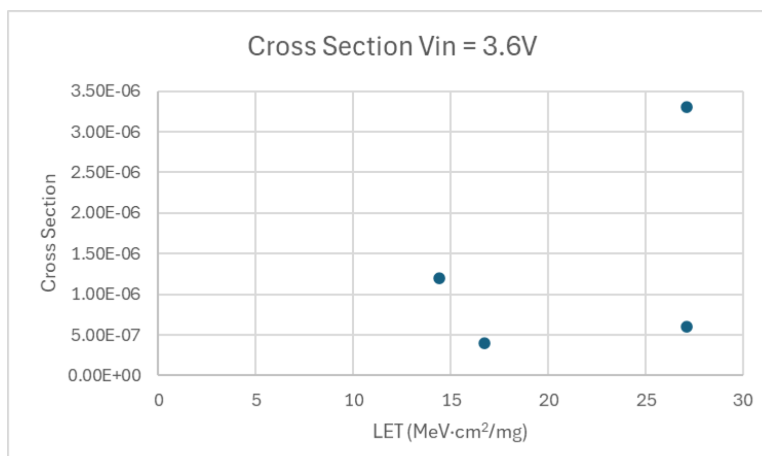


Figure 4: Vin = 3.6V

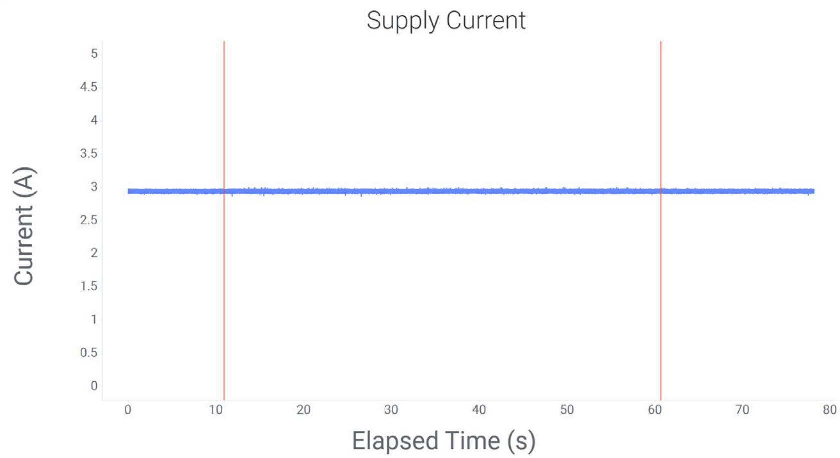
VI. Conclusion

The device experiences an SED at 27.1 MeV·cm^2/mg with V_{IN} = 4.5V and at **25°C** (Runs 30 and 31). Runs 30 and 31 were SET runs and did not have the hardware mitigation turned on. The proprietary mitigation circuit assists the device's survival up to 38.6 MeV·cm^2/mg when V_{IN} = 4.5V at 125°C (Run 25).

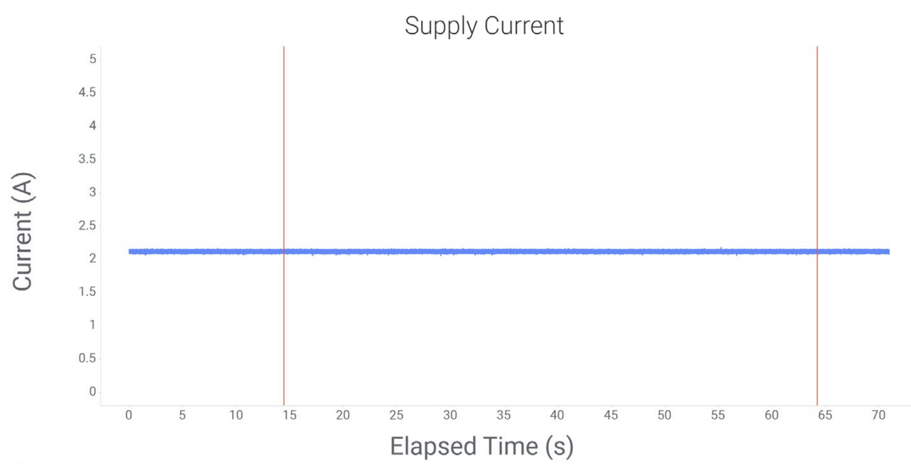
Without mitigation, the device can survive up to ~47.0 MeV·cm^2/mg when $V_{IN} \leq 3.6$V based on data collected in October 2023 which did not use any form of hardware SEL mitigation. The capability of the mitigation circuit is shown in Runs 25, 26, and 28. The device experiences SED at an LET of 27.1 MeV·cm^2/mg with a V_{IN} = 5.3V at 125°C with hardware SEL mitigation turned on and at 14.41 MeV·cm^2/mg at 25°C with SEL mitigation turned off.

Appendix

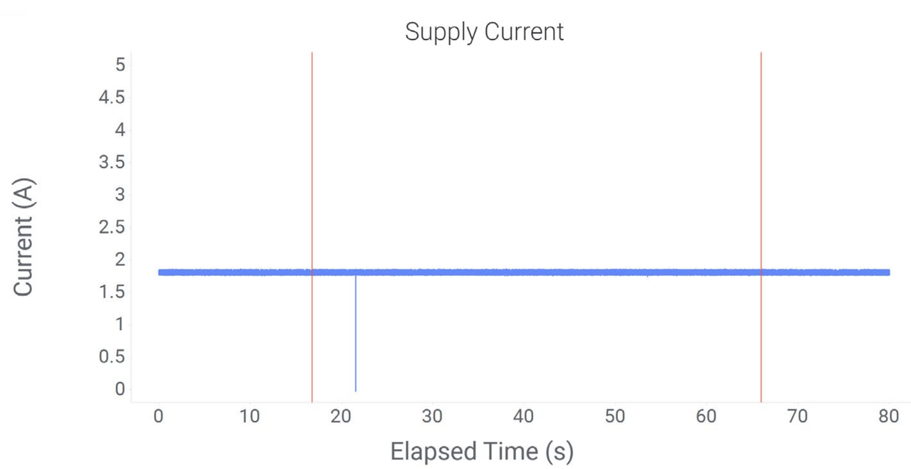
A1.0 Single Event Latchup (SEL)



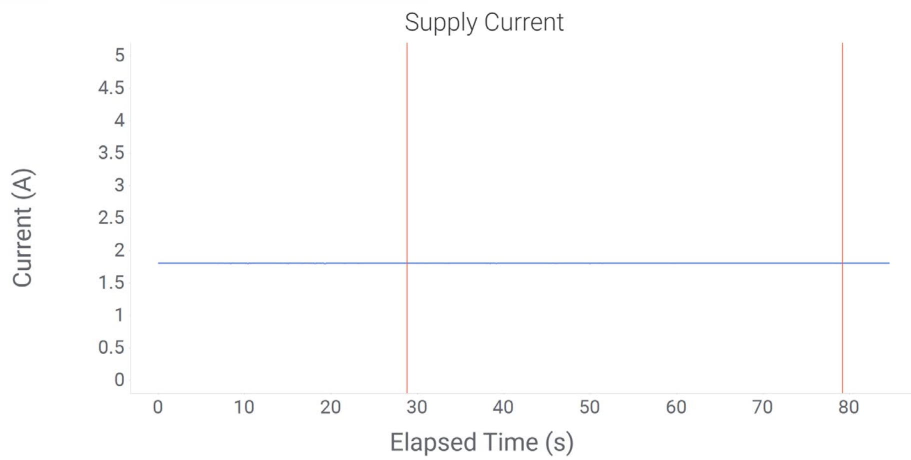
Run 8, SEL, V_{IN} = 3.3V, LET = 3.17 MeV·cm^2/mg, Software Mitigation



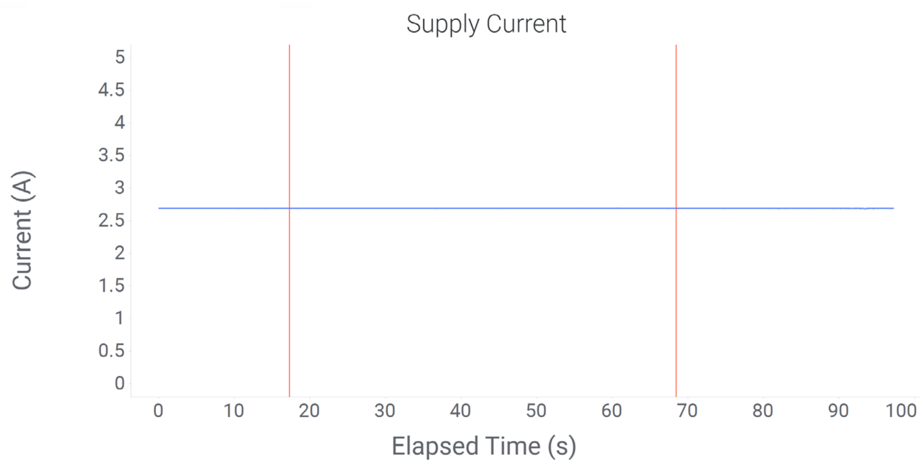
Run 9, SEL, V_{IN} = 4.5V, LET = 3.17 MeV·cm^2/mg, Software Mitigation



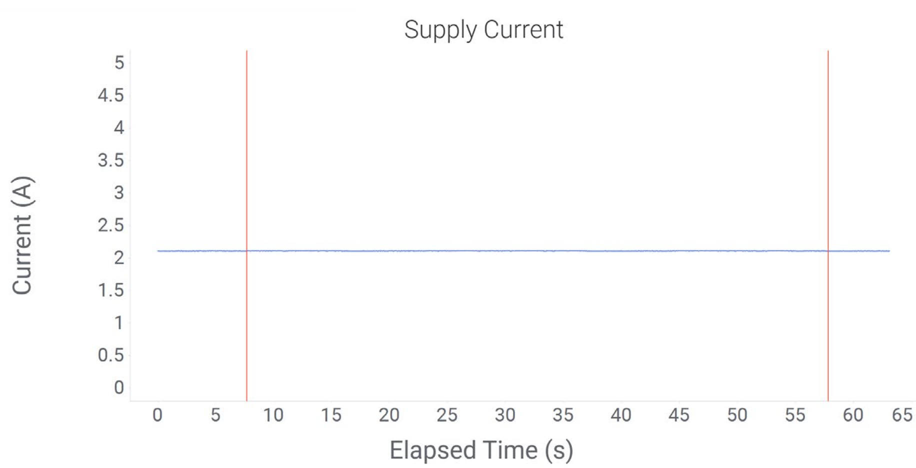
Run 10, SEL, V_{IN} = 5.3V, LET = 3.17 MeV·cm^2/mg, Software Mitigation



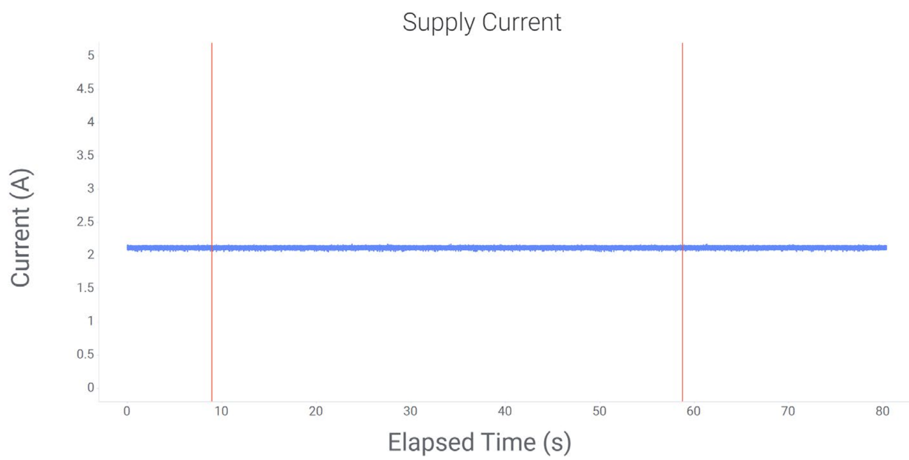
Run 11, SEL, V_{IN} = 5.3V, LET = 3.17 MeV·cm^2/mg, Software Mitigation



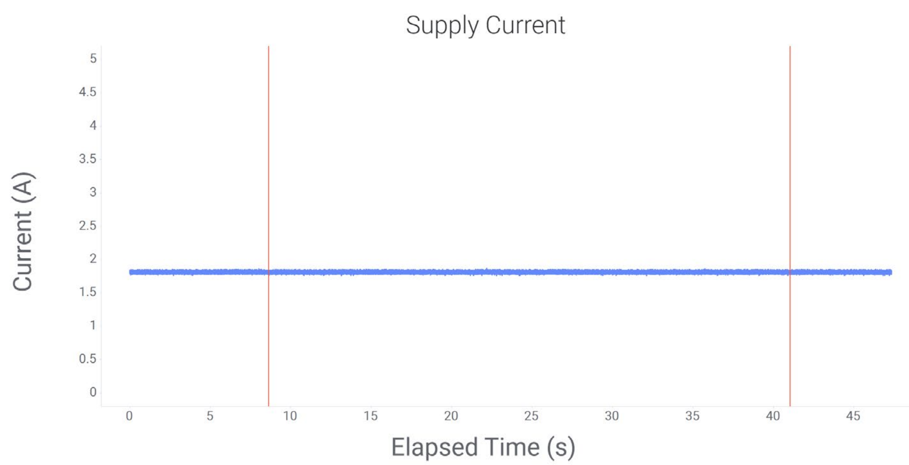
Run 12, SEL, V_{IN} = 3.6V, LET = 3.17 MeV·cm^2/mg, Hardware Mitigation



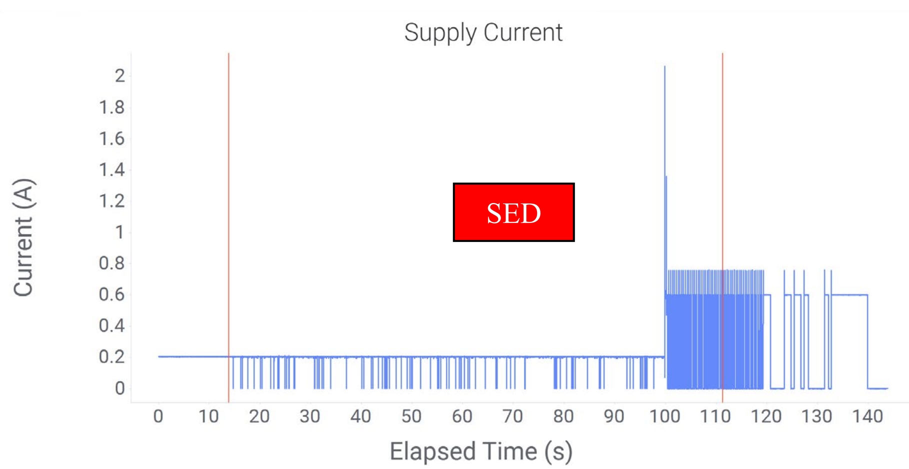
Run 13, SEL, V_{IN} = 4.5V, LET = 3.17 MeV·cm^2/mg, Hardware Mitigation



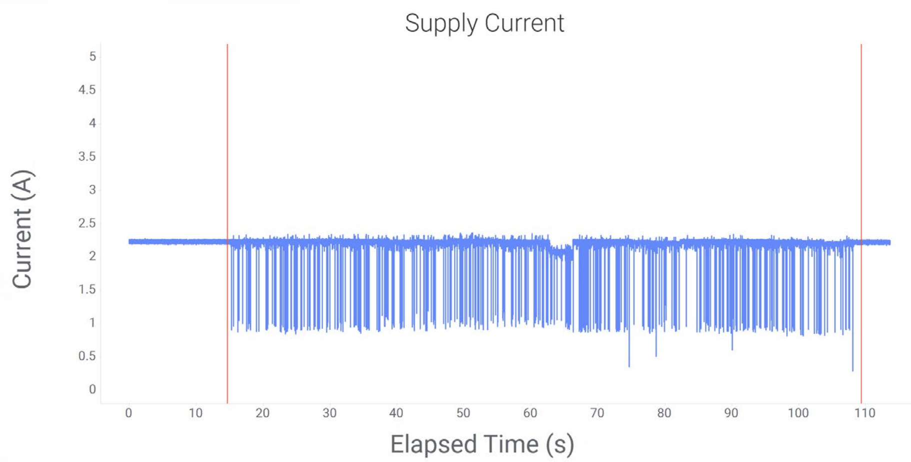
Run 14, SEL, V_{IN} = 4.5V, LET = 3.17 MeV·cm^2/mg, Software Mitigation



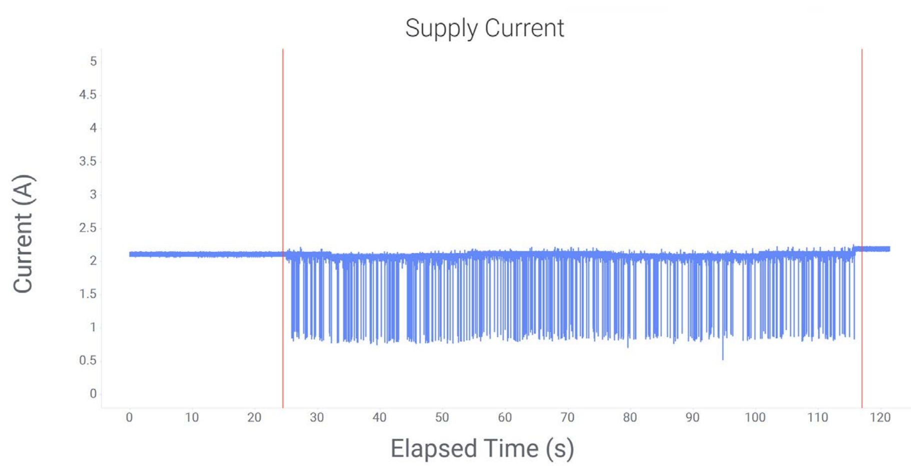
Run 15, SEL, V_{IN} = 5.3V, LET = 3.17 MeV·cm^2/mg, Hardware Mitigation



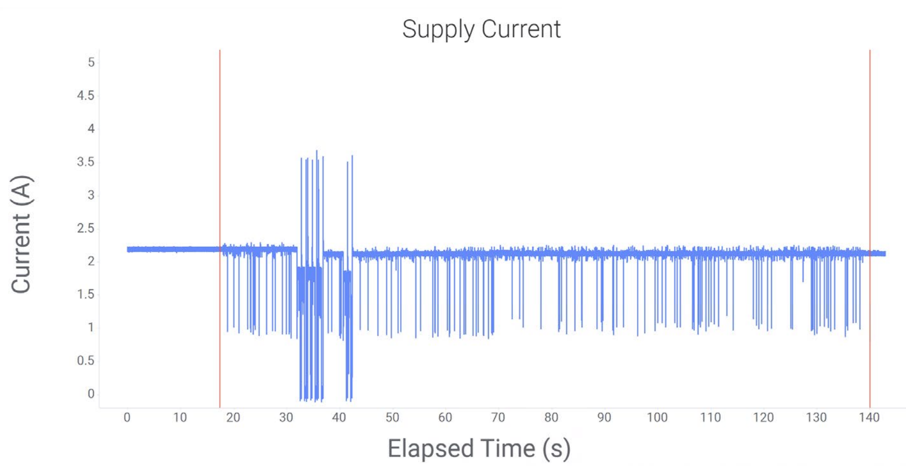
Run 23, SEL, V_{IN} = 4.5V, LET = 44.36 MeV·cm^2/mg, Hardware Mitigation



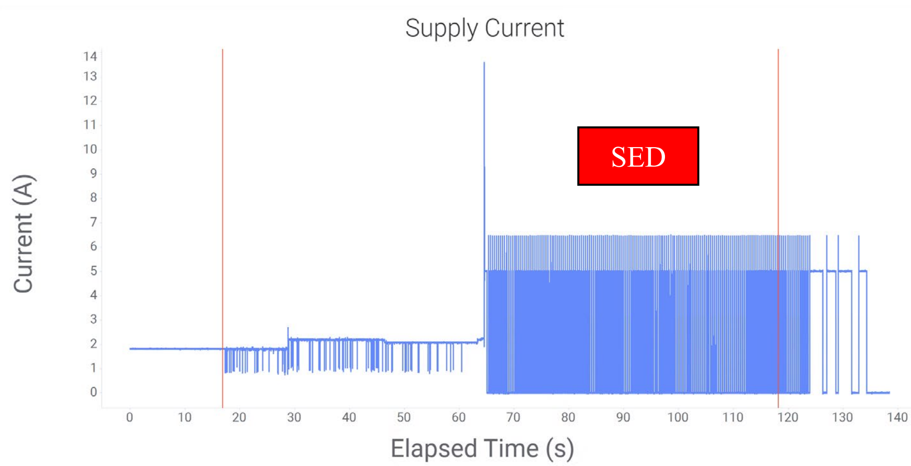
Run 24, SEL, 4.25V input, LET = 38.60 MeV·cm^2/mg, Hardware Mitigation



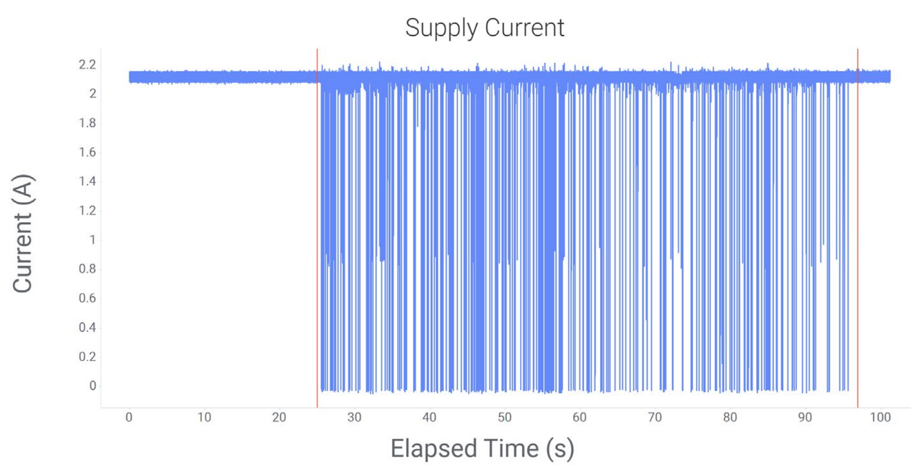
Run 25, SEL, V_{IN} = 4.5V, LET = 38.60 MeV·cm^2/mg, Hardware Mitigation



Run 26, SEL, V_{IN} = 4.5V, LET = 27.1 MeV·cm^2/mg, Hardware Mitigation

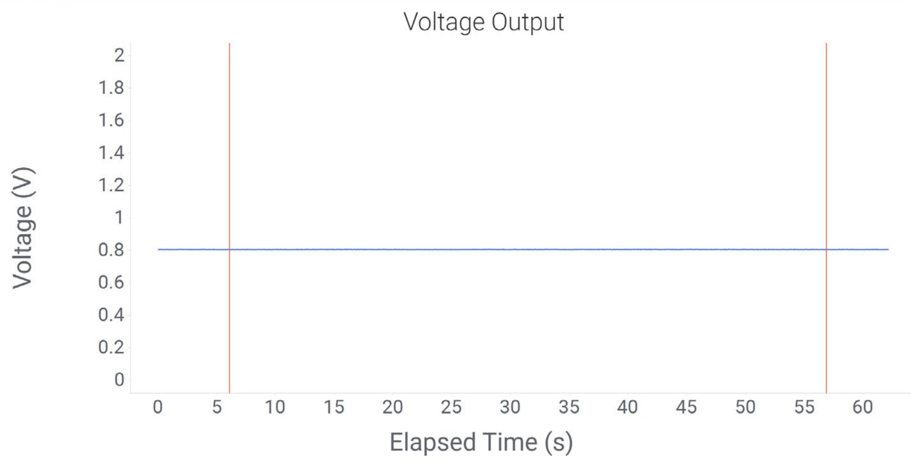


Run 27, SEL, V_{IN} = 5.3V, LET = 27.1 MeV·cm^2/mg, Hardware Mitigation

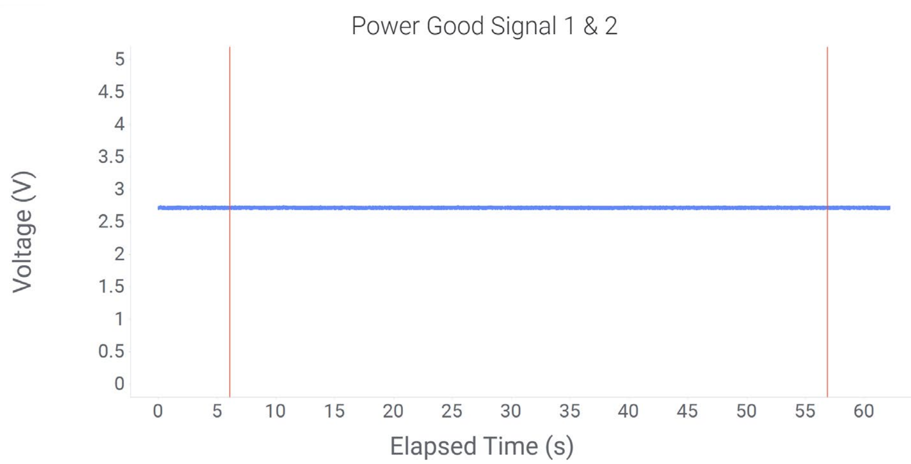


Run 28, SEL, V_{IN} = 4.5V, LET = 27.10 MeV·cm^2/mg, Hardware Mitigation

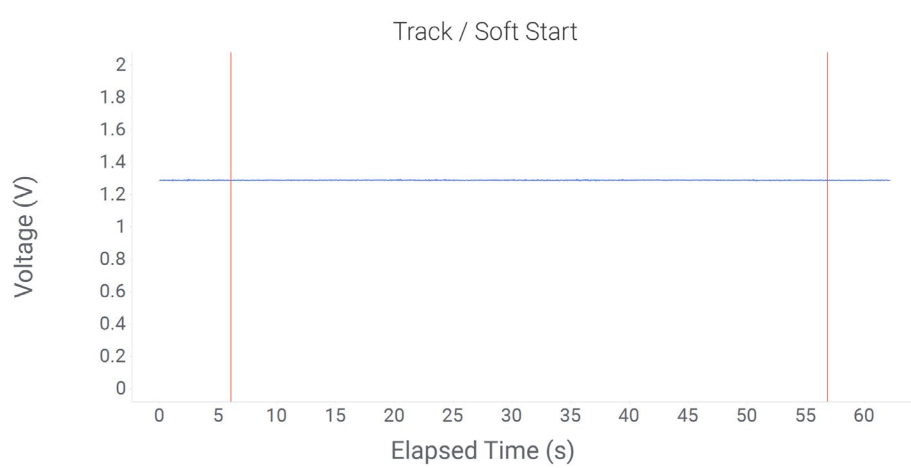
A2.0 Single Event Transients (SET)



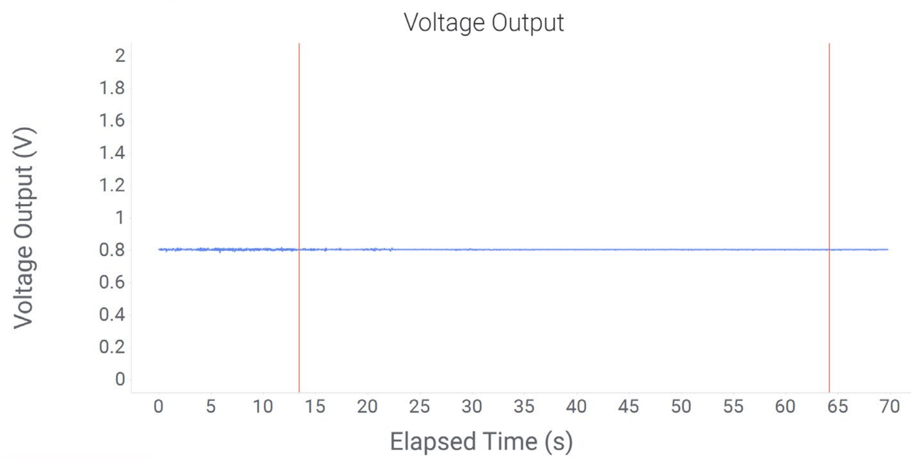
Run 16, SET, V_{IN} = 3.0V, LET = 3.17 MeV·cm^2/mg, No Mitigation



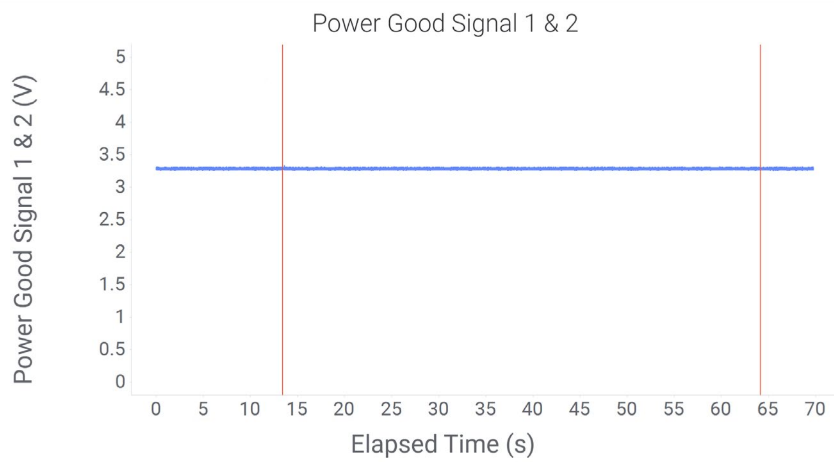
Run 16, SET, V_{IN} = 3.0V, LET = 3.17 MeV·cm^2/mg, No Mitigation



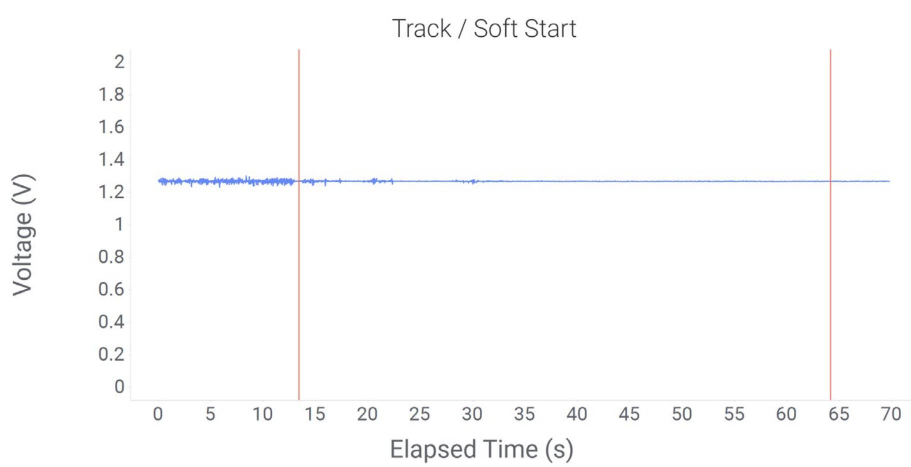
Run 16, SET, V_{IN} = 3.0V, LET = 3.17 MeV·cm^2/mg, No Mitigation



Run 17, SET, V_{IN} = 3.6V, LET = 3.17 MeV·cm^2/mg, No Mitigation



Run 17, SET, V_{IN} = 3.6V, LET = 3.17 MeV·cm^2/mg, No Mitigation



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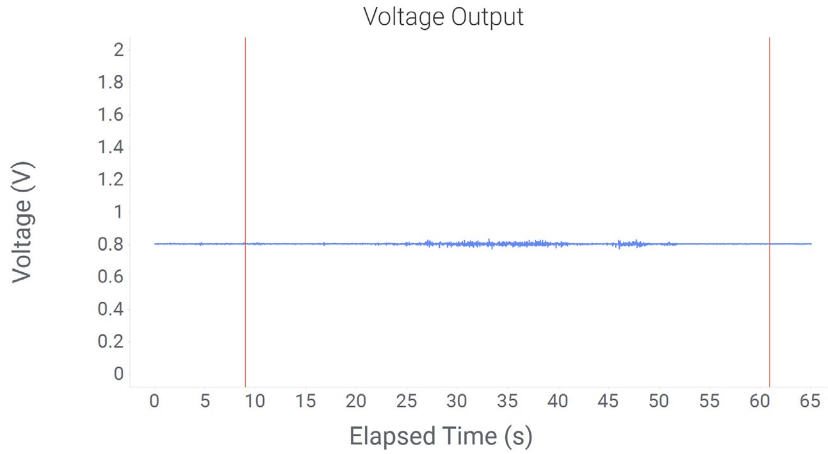
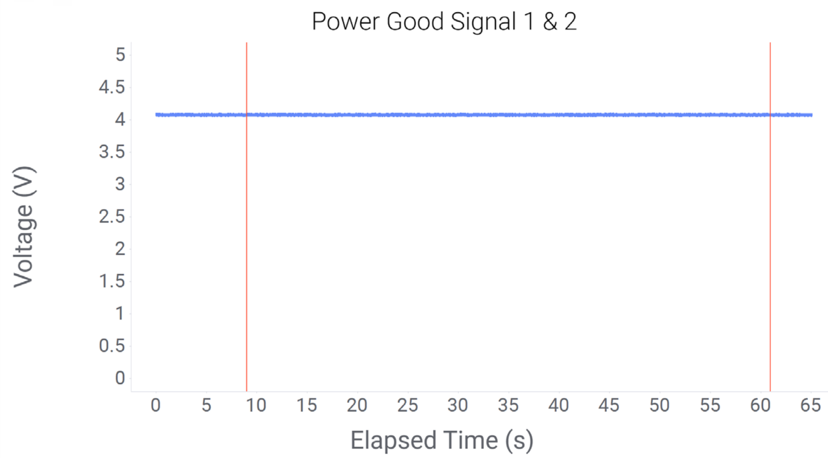
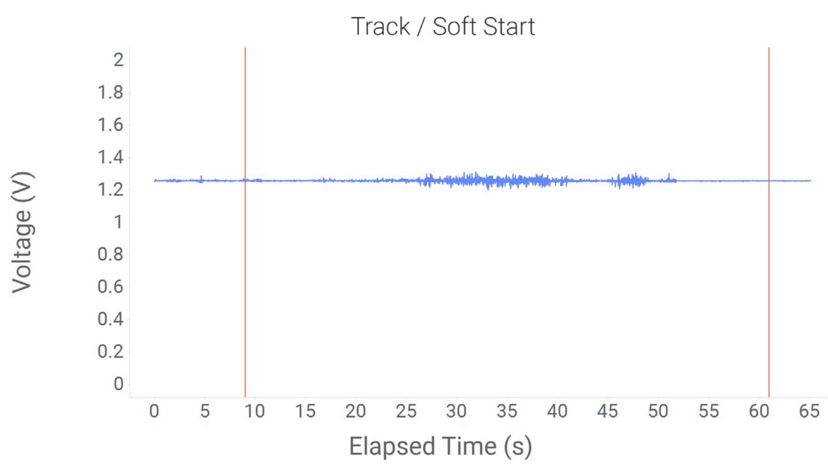


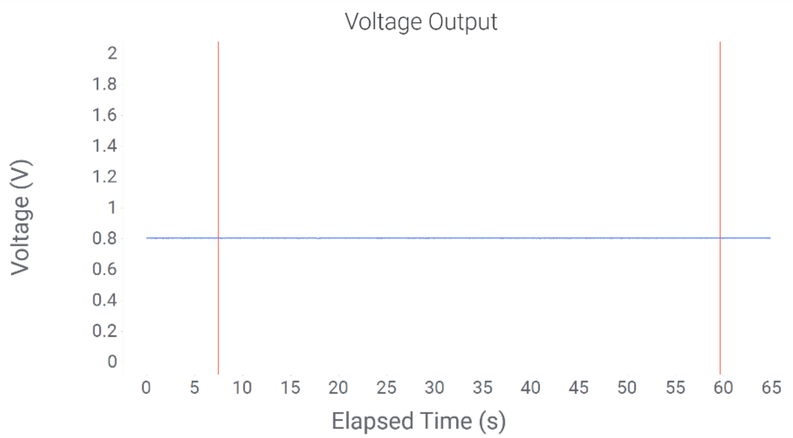
Run 18, SET, V_{IN} = 4.5V, LET = 3.17 MeV·cm^2/mg, No Mitigation



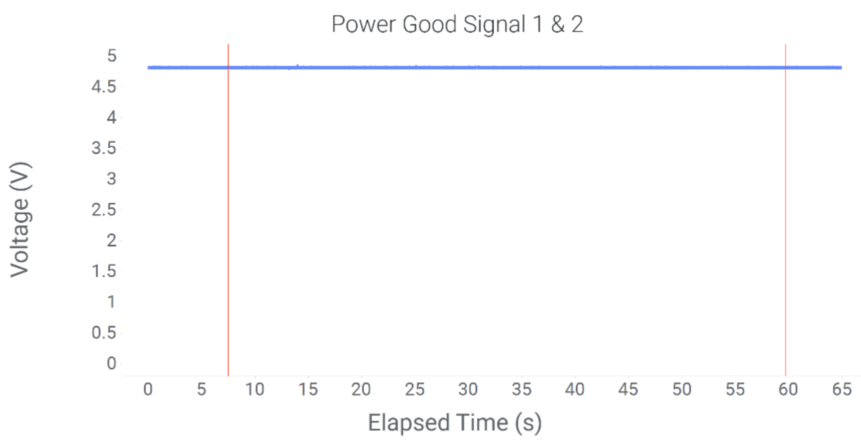
Run 18, SET, V_{IN} = 4.5V, LET = 3.17 MeV·cm^2/mg, No Mitigation



Run 18, SET, V_{IN} = 4.5V, LET = 3.17 MeV·cm^2/mg, No Mitigation



Run 19, SET, V_{IN} = 5.3V, LET = 3.17 MeV·cm^2/mg, No Mitigation



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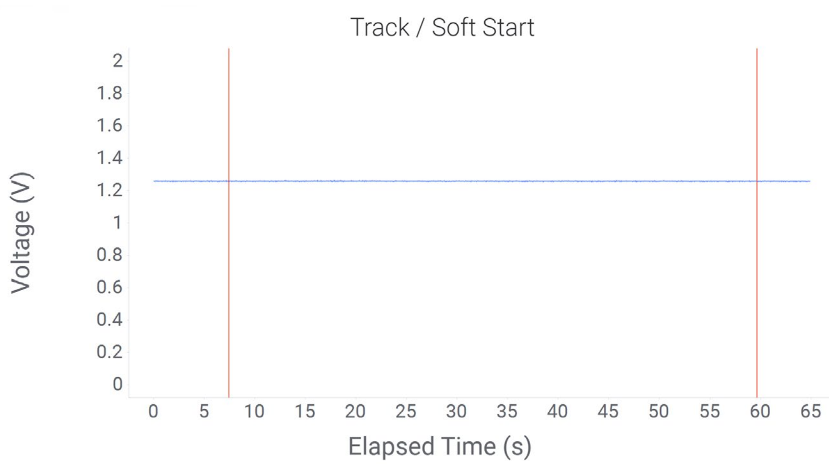
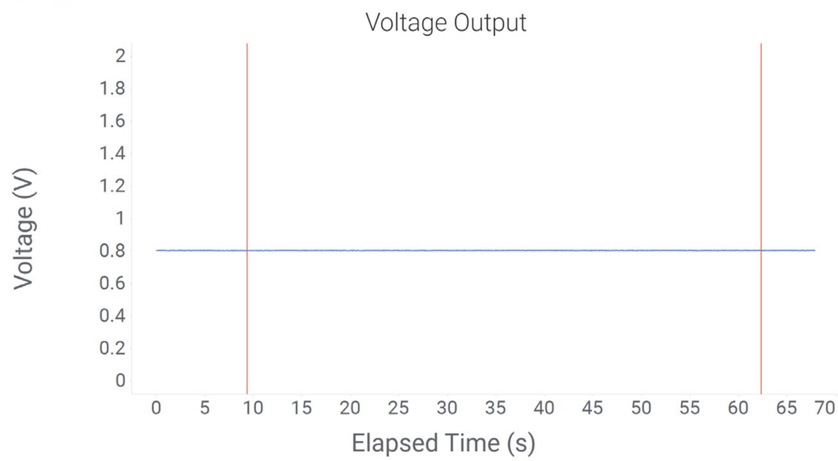
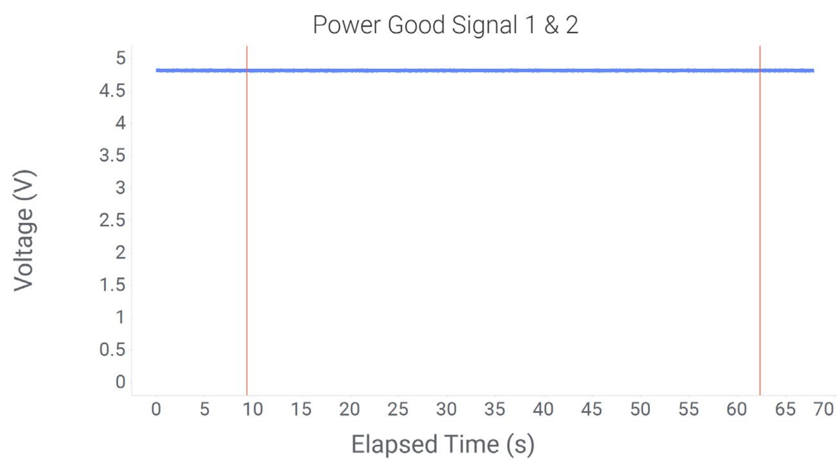


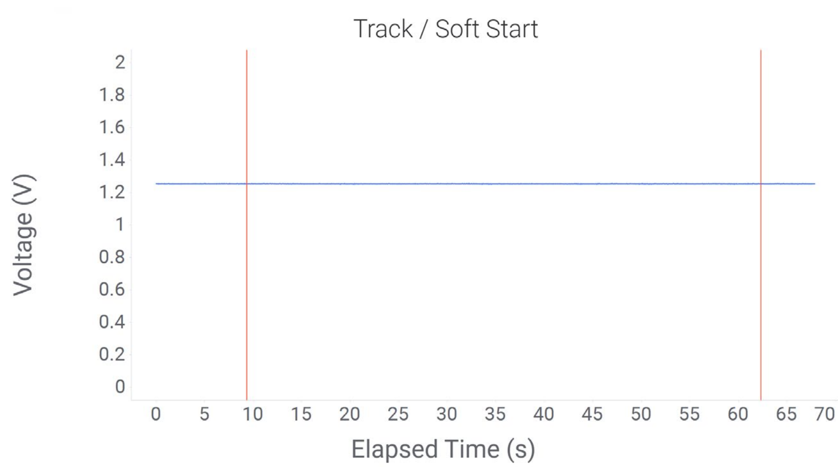
Run 19, SET, V_{IN} = 5.3V, LET = 3.17 MeV·cm^2/mg, No Mitigation



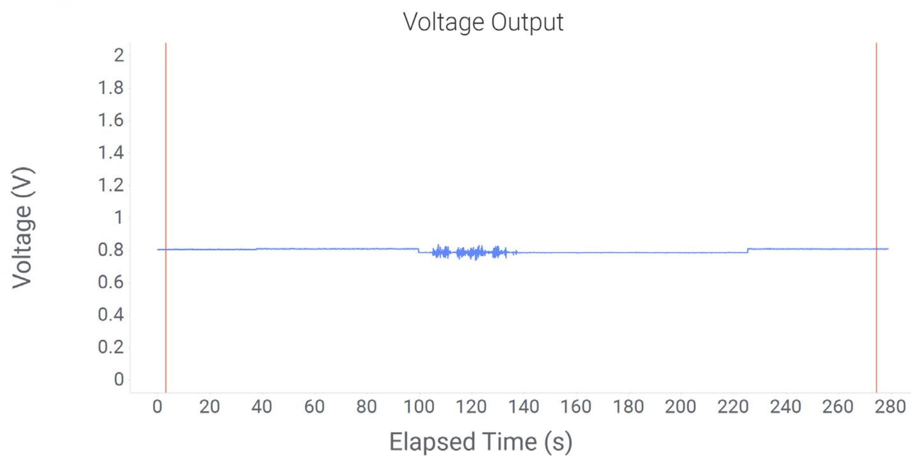
Run 20, SET, V_{IN} = 5.3V, LET = 3.17 MeV·cm^2/mg, No Mitigation



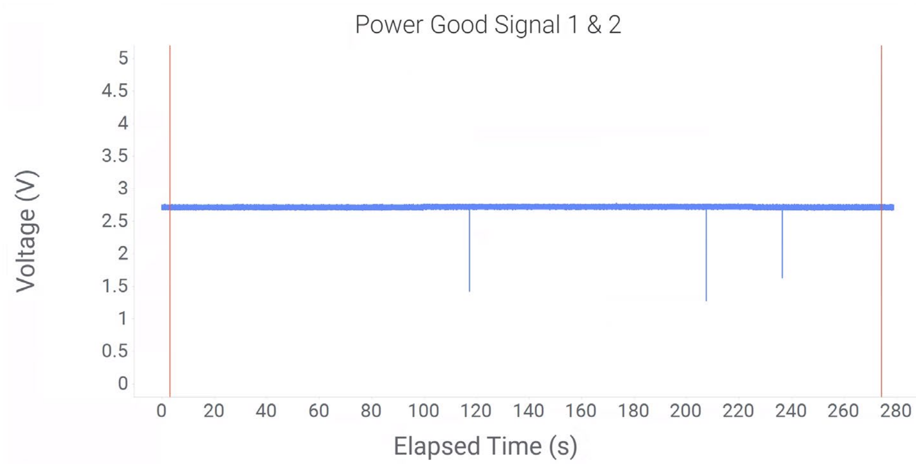
Run 20, SET, V_{IN} = 5.3 V, LET = 3.17 MeV·cm^2/mg, No Mitigation



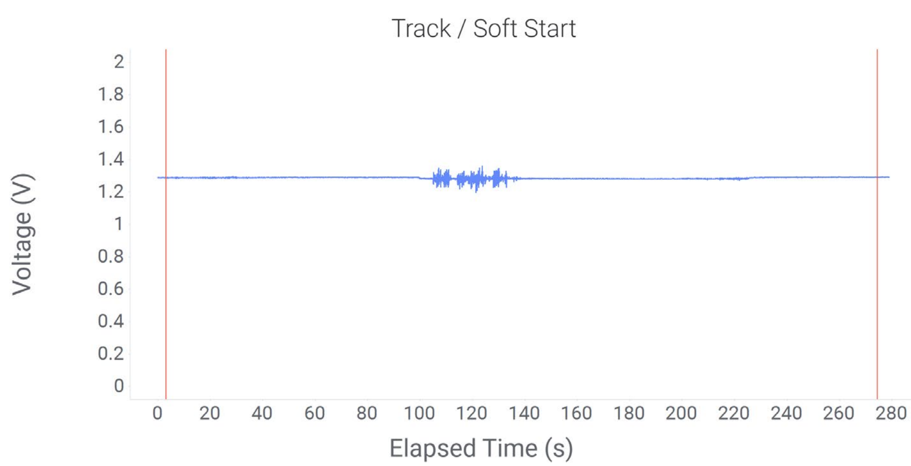
Run 20, SET, V_{IN} = 5.3V input, LET = 3.17 MeV·cm^2/mg, No Mitigation



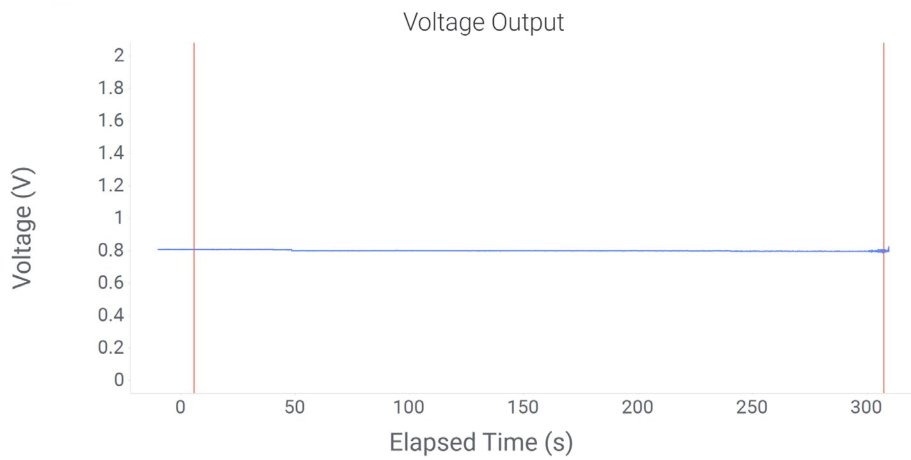
Run 21, SET, V_{IN} = 3.0V, LET = 16.74 MeV·cm^2/mg, No Mitigation



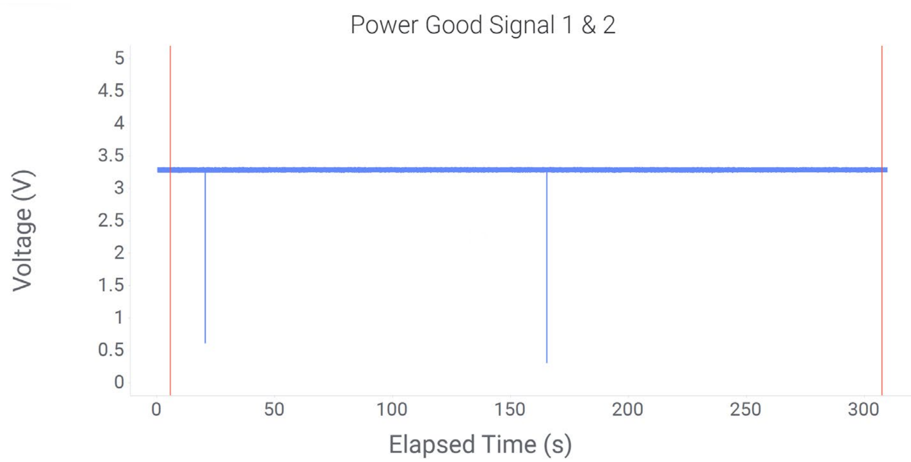
Run 21, SET, V_{IN} = 3.0V, LET = 16.74 MeV·cm^2/mg, No Mitigation



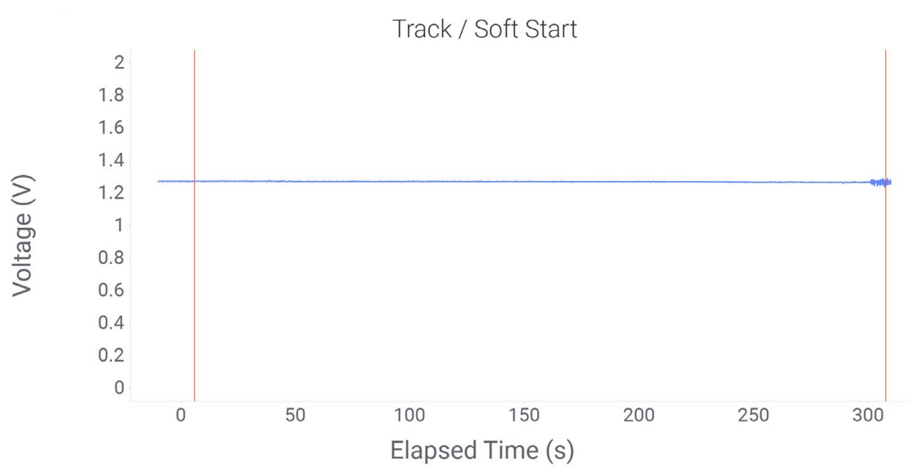
Run 21, SET, V_{IN} = 3.0V, LET = 16.74 MeV·cm^2/mg, No Mitigation



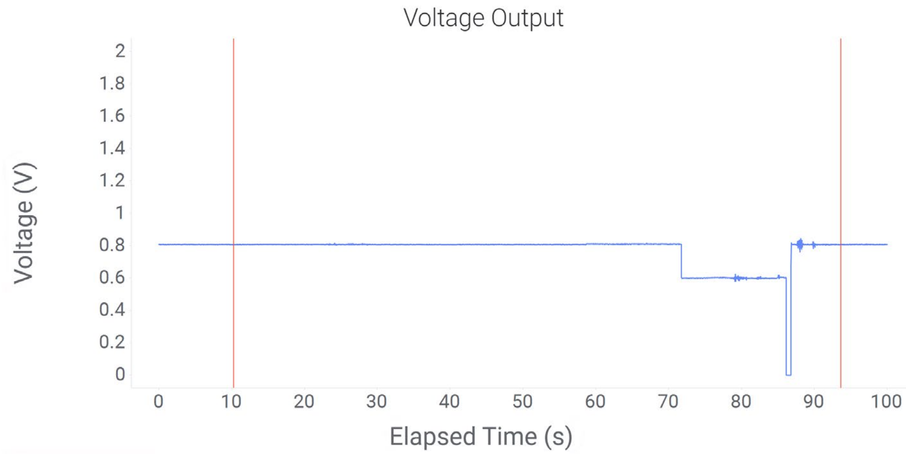
Run 22, SET, V_{IN} = 3.6V, LET = 16.74 MeV·cm^2/mg, No Mitigation



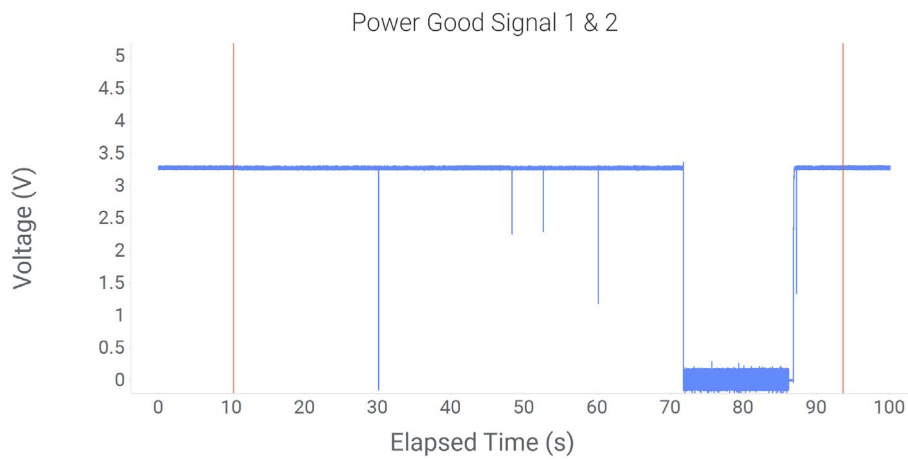
Run 22, SET, V_{IN} = 3.6V, LET = 16.74 MeV·cm^2/mg, No Mitigation



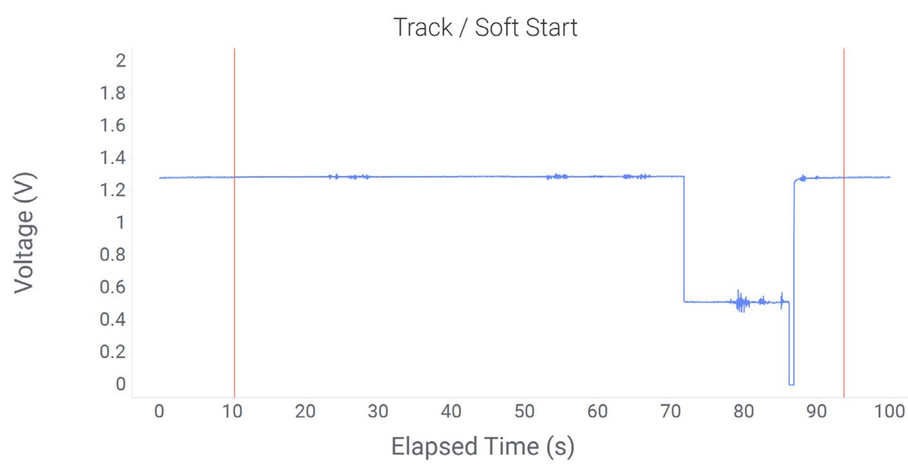
Run 22, SET, V_{IN} = 3.6V, LET = 16.74 MeV·cm^2/mg, No Mitigation



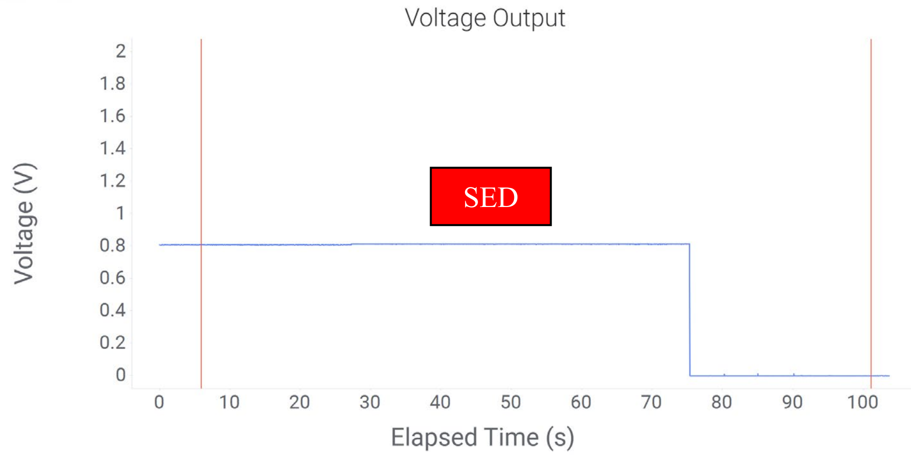
Run 29, SET, V_{IN} = 3.6V, LET = 27.10 MeV·cm^2/mg, No Mitigation



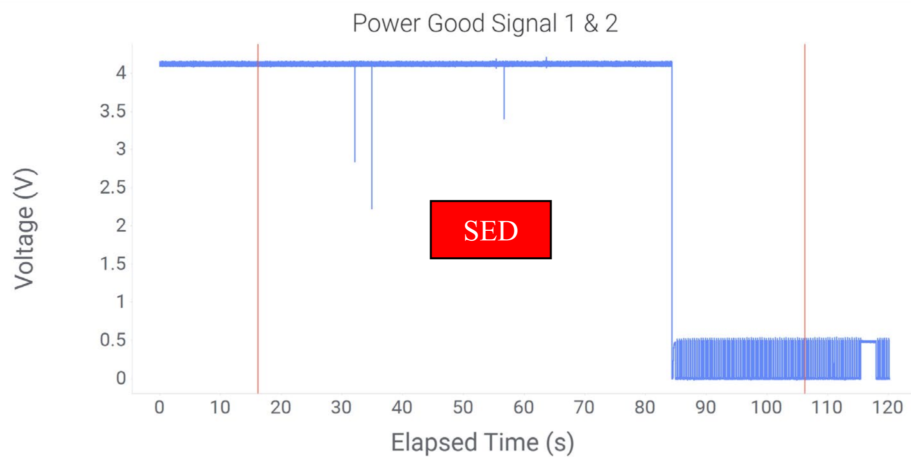
Run 29, SET, V_{IN} = 3.6V, LET = 27.10 MeV·cm^2/mg, No Mitigation



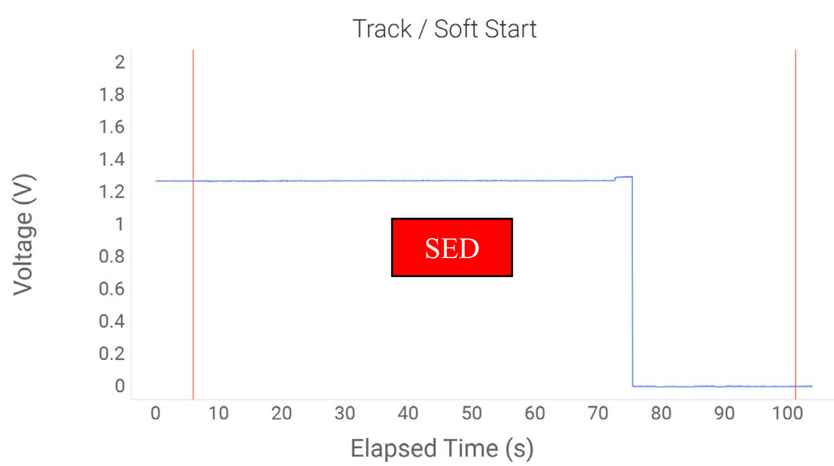
Run 29, SET, V_{IN} = 3.6V, LET = 27.10 MeV·cm^2/mg, No Mitigation



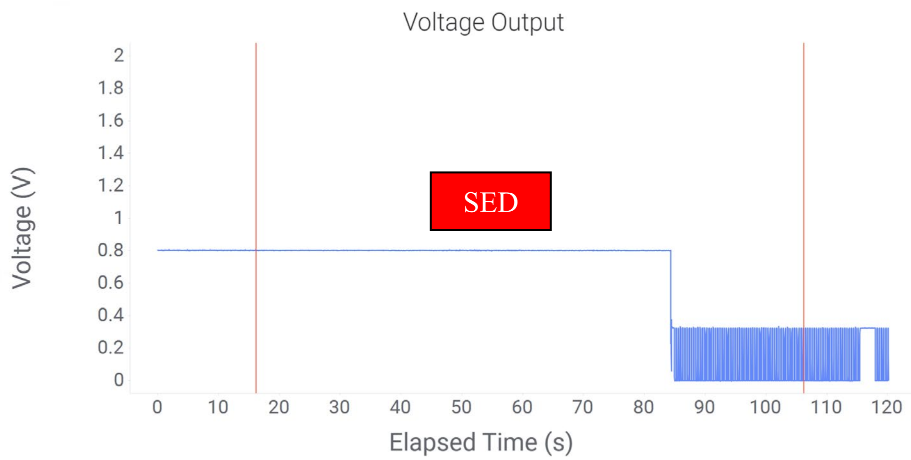
Run 30, SET, V_{IN} = 4.5V, LET = 27.10 MeV·cm^2/mg, No Mitigation



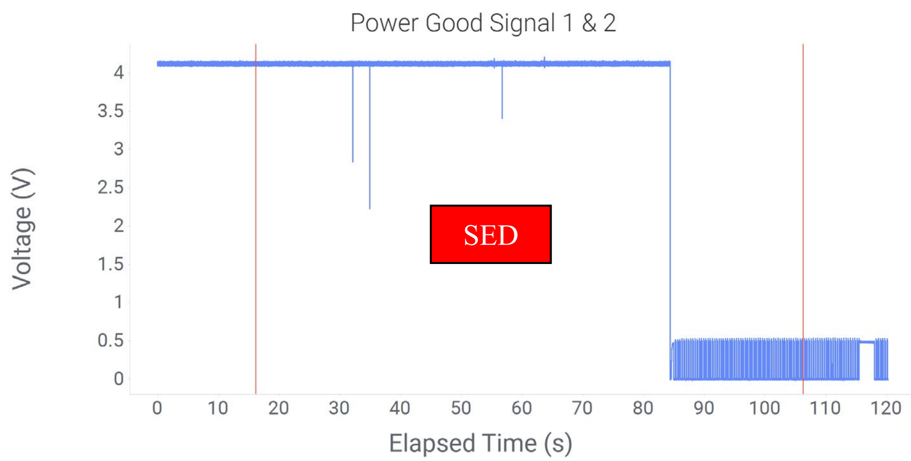
Run 30, SET, V_{IN} = 4.5V, LET = 27.10 MeV·cm^2/mg, No Mitigation



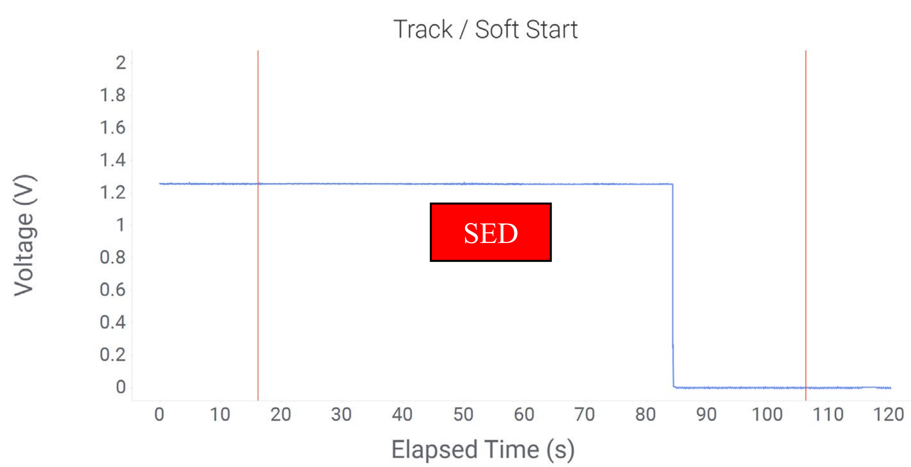
Run 30, SET, V_{IN} = 4.5V, LET = 27.10 MeV·cm^2/mg, No Mitigation



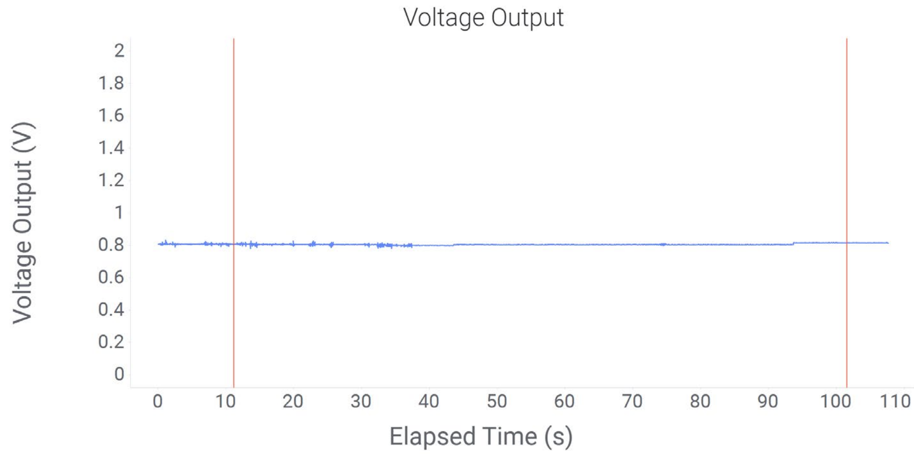
Run 31, SET, V_{IN} = 4.5V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



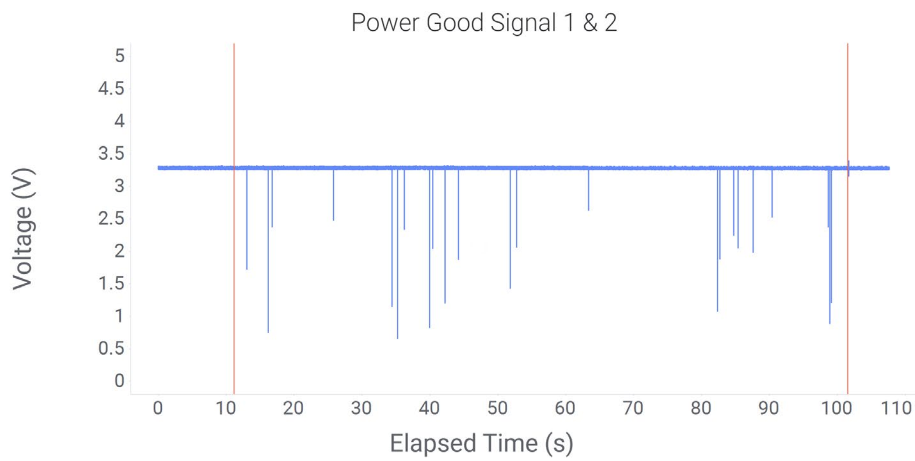
Run 31, SET, V_{IN} = 4.5V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



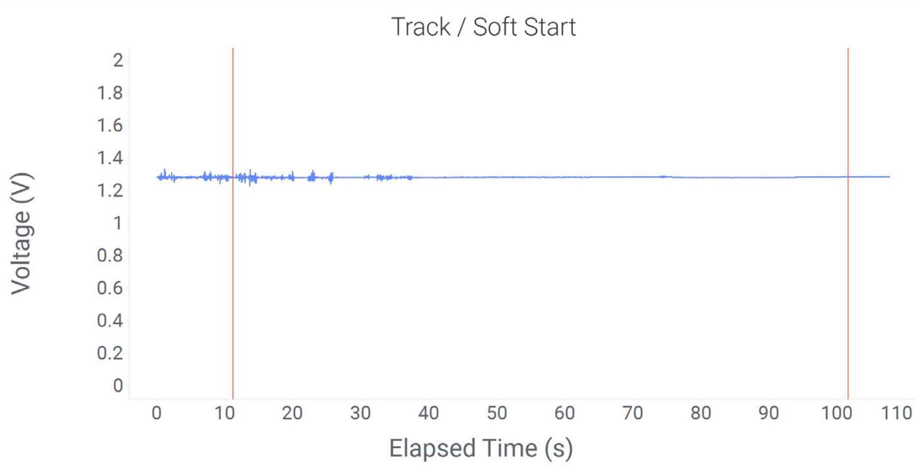
Run 31, SET, V_{IN} = 4.5V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



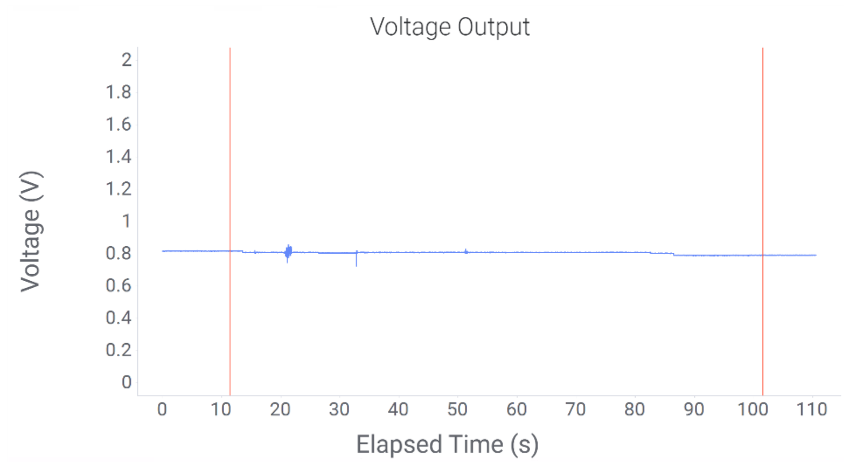
Run 32, SET, V_{IN} = 3.6V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



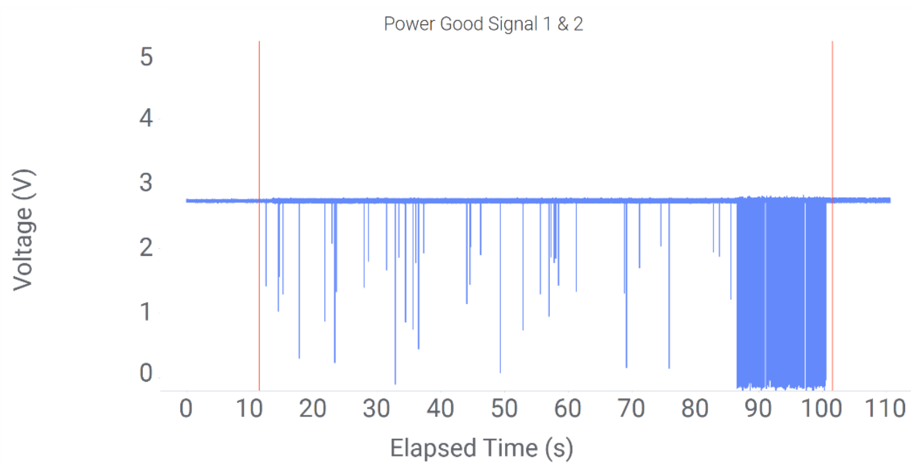
Run 32, SET, V_{IN} = 3.6V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



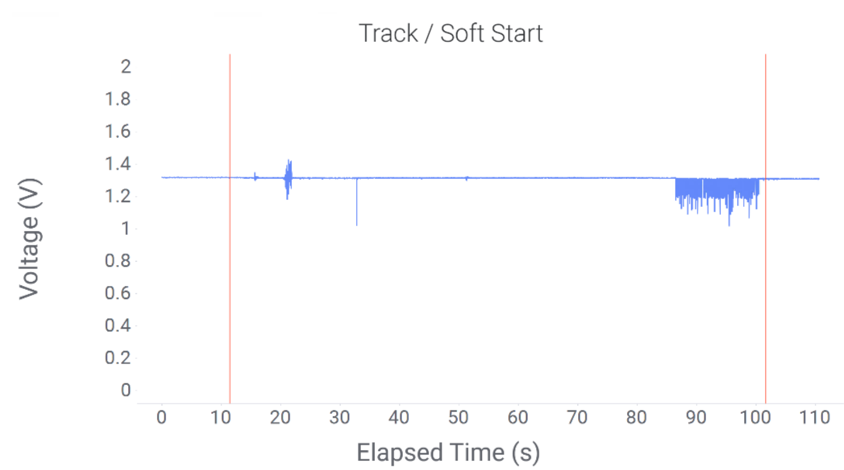
Run 32, SET, V_{IN} = 3.6V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



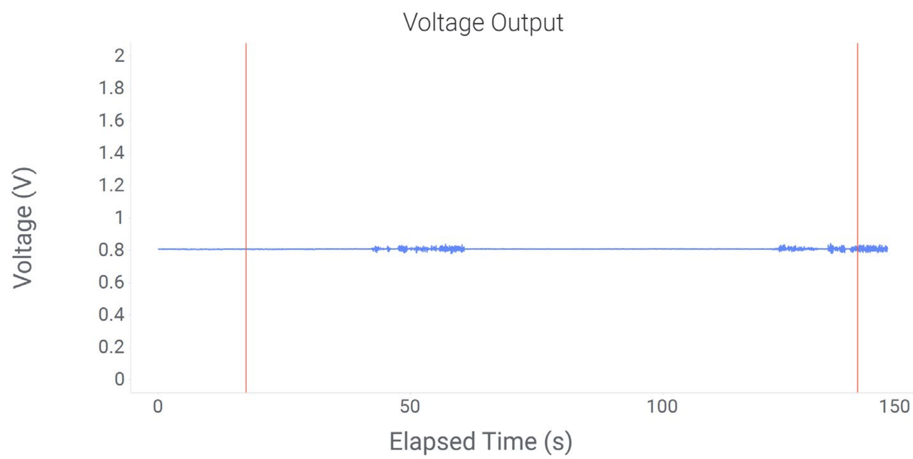
Run 33, SET, V_{IN} = 3.0V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



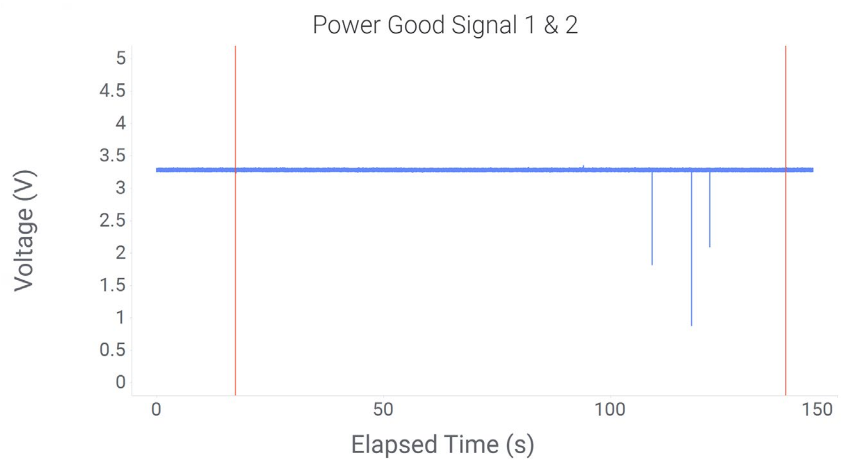
Run 33, SET, V_{IN} = 3.0V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



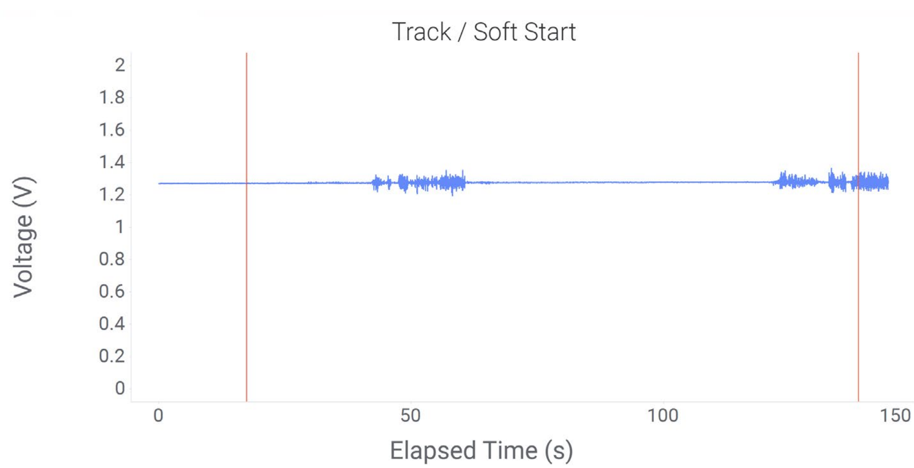
Run 33, SET, V_{IN} = 3.0V, LET = 27.10 MeV·cm^2/mg, Software Mitigation



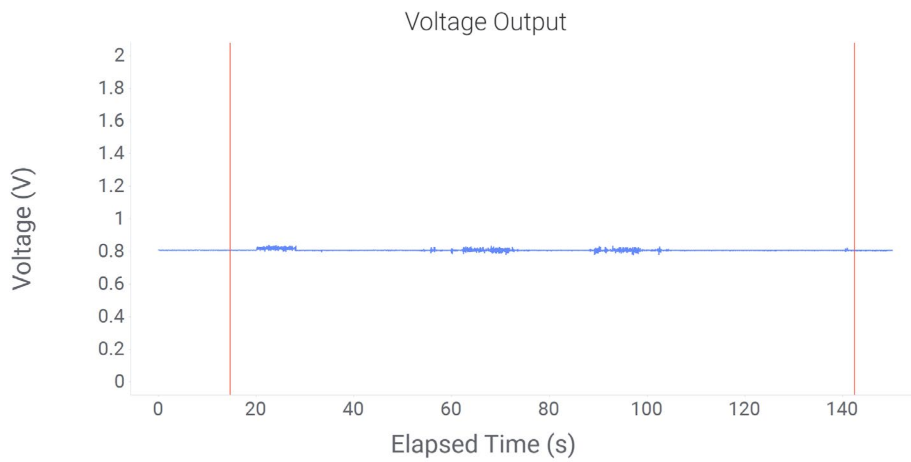
Run 34, SET, V_{IN} = 3.6V, LET = 14.41 MeV·cm^2/mg, Software Mitigation



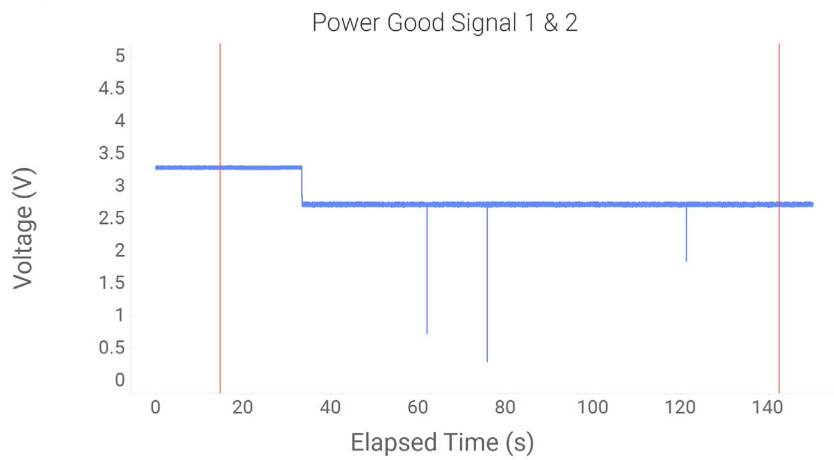
Run 34, SET, V_{IN} = 3.6V, LET = 14.41 MeV·cm^2/mg, Software Mitigation



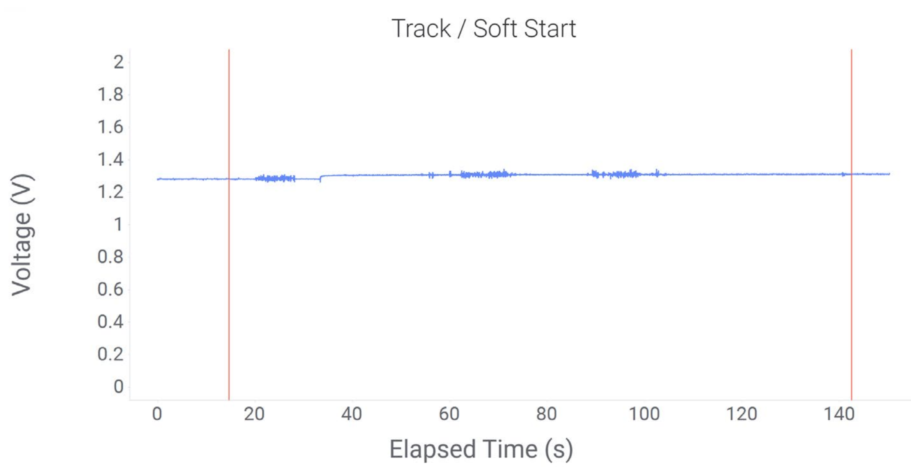
Run 34, SET, V_{IN} = 3.6V, LET = 14.41 MeV·cm^2/mg, Software Mitigation



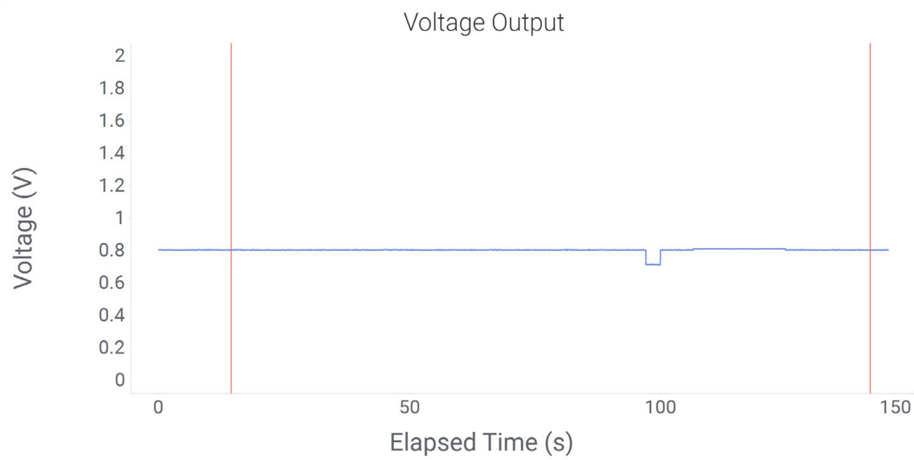
Run 35, SET, V_{IN} = 3.0V, LET = 14.41 MeV·cm^2/mg, Software Mitigation



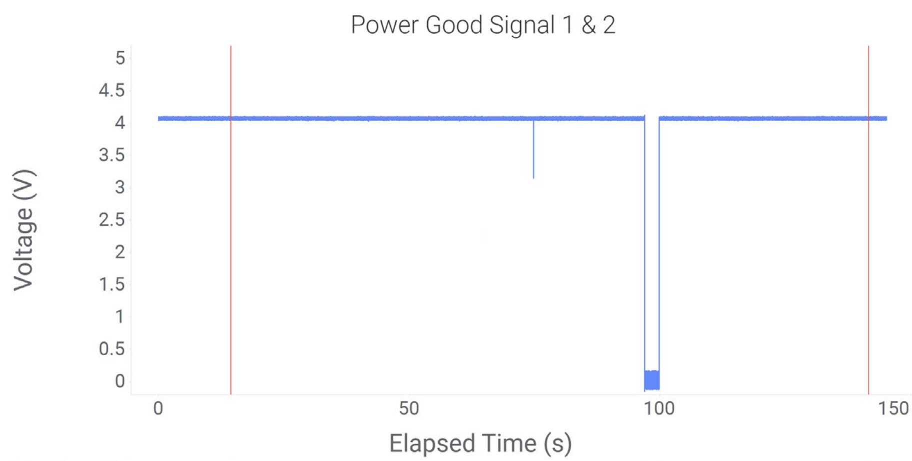
Run 35, SET, V_{IN} = 3.0V, LET = 14.41 MeV·cm^2/mg, Software Mitigation



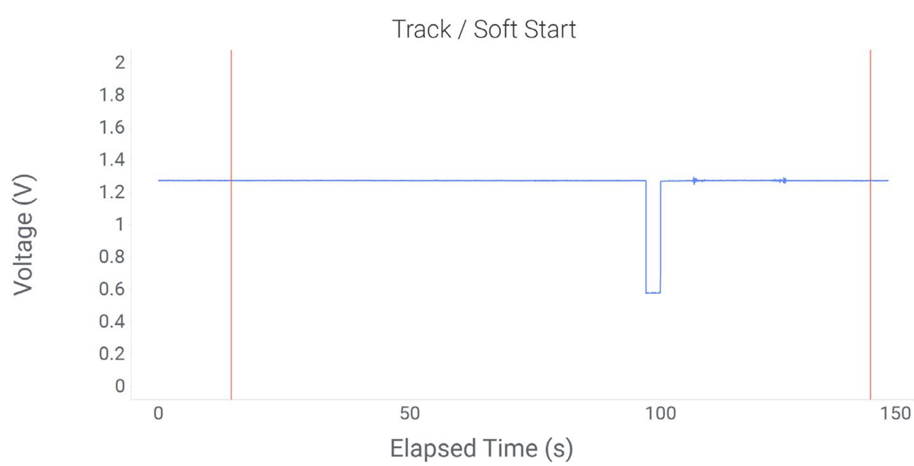
Run 35, SET, V_{IN} = 3.0V, LET = 14.41 MeV·cm^2/mg, Software Mitigation



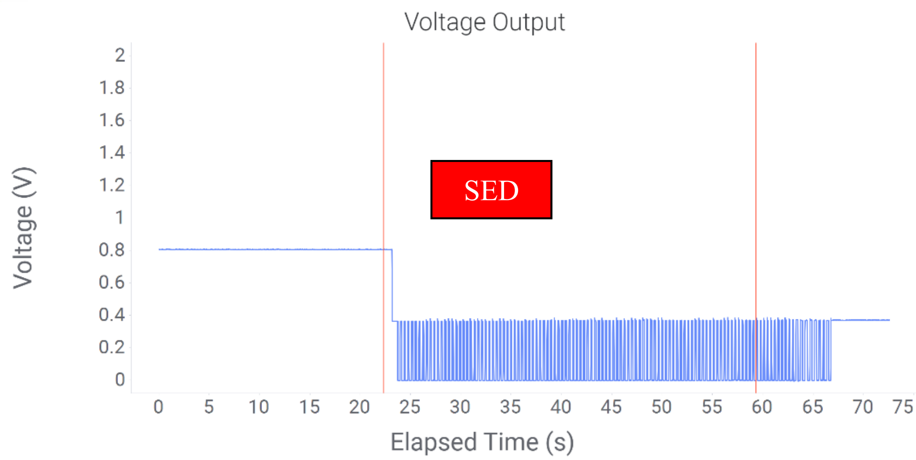
Run 36, SET, V_{IN} = 4.5V, LET = 14.41 MeV·cm^2/mg, No Mitigation



Run 36, SET, V_{IN} = 4.5V, LET = 14.41 MeV·cm^2/mg, No Mitigation

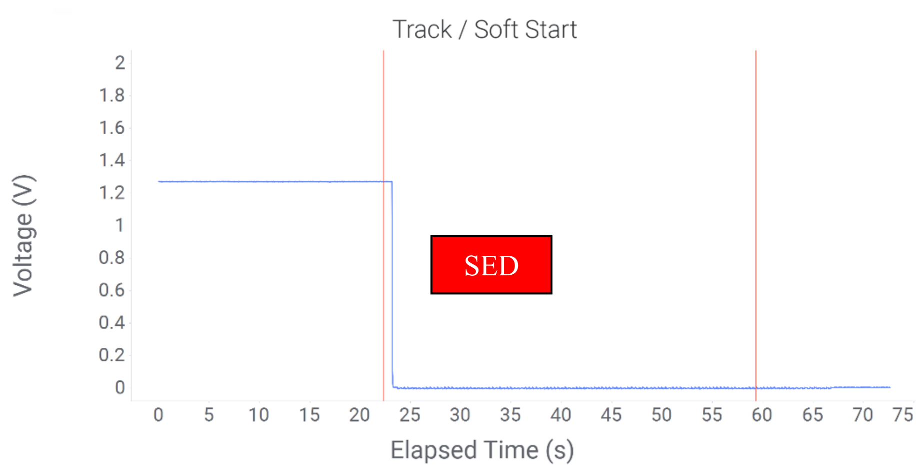


Run 36, SET, V_{IN} = 4.5V, LET = 14.41 MeV·cm^2/mg, No Mitigation



Run 37, SET, V_{IN} = 5.3V, LET = 14.41 MeV·cm^2/mg, Software Mitigation

Run 37, SET, V_{IN} = 5.3V, LET = 14.41 MeV·cm^2/mg, Software Mitigation



Run 37, SET, V_{IN} = 5.3V, LET = 14.41 MeV·cm^2/mg, Software Mitigation