Radiation Report

ISOS510-SEP 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 ISOS510-SEP, current-driven analog isolator with transistor output. Heavy-ions with LET_{EFF} of 47MeV×cm^2/mg was used to irradiate seven production devices. Flux of 10^5 ions×cm^2/s and fluence of 1 × 10^7 – 1.5 × 10^7ions/cm^2 per run were used for the characterization. The results demonstrated that the ISOS510-SEP is SEL-free up to 47MeV×cm^2/mg at T = 125°C. SET transient performance for output voltage excursions ≥|3%| and |5%| from the nominal voltage are presented and discussed.

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1 Introduction

The ISOS510 radiation-hardened device is a single-channel, current-driven, analog isolator with transistor output. The device offers significant reliability and performance advantages compared to other current-driven analog isolators, including high bandwidth, low turn-off delay, low power consumption, wider temperature ranges, flat current transfer ratio (CTR), and tight process controls resulting in small part-to-part skew. These performance advantages stay stable across radiation, temperature, and lifetime.

ISOS510 is offered in small a SOIC-4 package with 2.54mm pin pitch, supporting a 3.75kVRMS isolation rating. The high performance and reliability of ISOS510 enables these devices to be used in aerospace and defense applications such as feedback loops in isolated DC/DC modules, satellite propulsion power processing units, spacecraft battery management systems, and more.

The device is offered in a 4-pin SOIC (DFG) 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(1)	DEVICE INFORMATION
TI Part Number	ISOS510-SEP
Orderable Part Number	ISOS510DFGTSEP
VID/SMD Number	V62/26607-01XE
Device Function	Current-Driven Analog Isolator With Transistor Output
Technology	LBC9 / ISOSAX
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15MeV/nucleon)
Heavy Ion Fluence per Run	1×10^7 – 1.5×10^7 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 ISOS510-SEP is the robustness against single-event latch-up (SEL). In mixed technologies such as the BiCMOS process used on the ISOS510-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) 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 ISOS510-SEP was tested for SEL at the maximum recommended operating conditions of input forward current (I_F) of 10mA and collector-emitter voltage (V_{CE}) of 30V. During testing of the three devices, the ISOS510-SEP did not exhibit any SEL with heavy-ions with LET_{EFF} = 47MeV×cm^2/mg at flux of approximately 10^{5}ions×cm^2/s , fluence of approximately 1 × 10^7 – 1.5 × 10^{7}ions/cm^2, and a die temperature of 125°C.

The ISOS510-SEP was characterized for SET at flux of 10^{5}ions×cm^2/s , fluences of 1 × 10^7 – 1.5 × 10^{7}ions/cm^2, and room temperature conditions. The device was characterized at I_F of approximately 1.9mA and V_{CE} of 3.3V. Heavy-ions with LET_{EFF} from 1.34 to 47MeV×cm^2/mg were used to characterize the transient performance. To see the SET results of the ISOS510-SEP, please refer to Single-Event Transients (SET) Results.

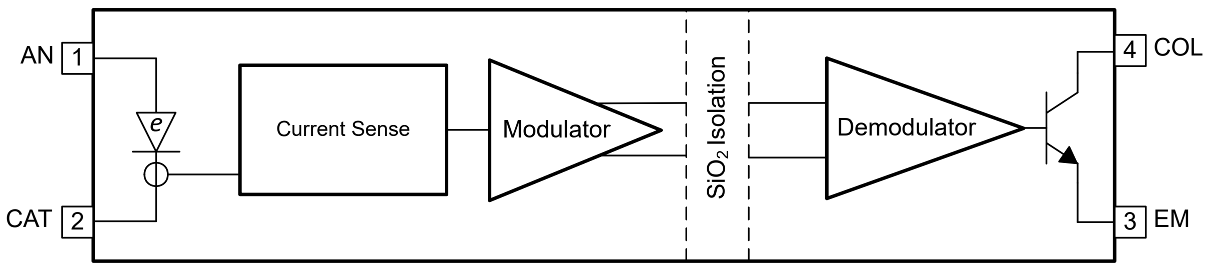

Figure 2-1. Functional Block Diagram of the ISOS510-SEP

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3 Device and Test Board Information

The ISOS510-SEP is packaged in a 4-pin SOIC (DFG) plastic package as shown in the pinout diagram in Figure 3-1. Figure 3-2 shows the device package decapped to reveal the die face for all heavy-ion testing. The ISOM8110DFGEVM evaluation module was used to evaluate the performance and characteristics of the ISOS510-SEP under heavy ion radiation. The ISOM8110DFGEVM is shown in Figure 3-3. Figure 3-4, Figure 3-5, and Figure 3-6 show the bias diagrams used for SEL testing. Figure 3-7 shows the bias diagram used for SET testing.

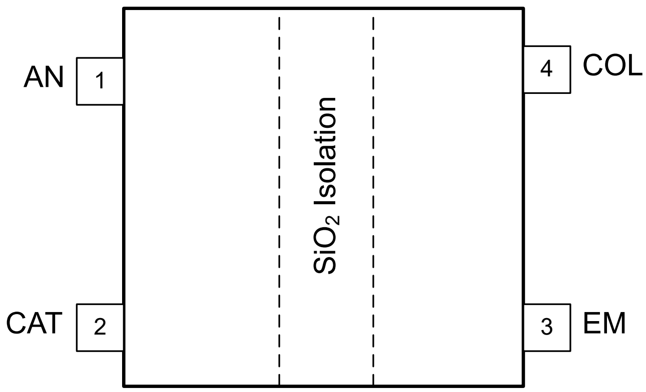

Figure 3-1. ISOS510-SEP Pinout Diagram

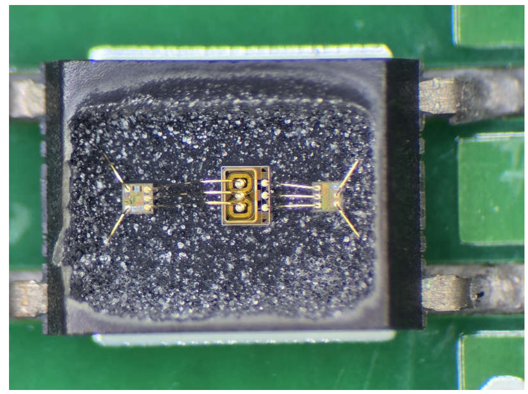

Figure 3-2. Photo of ISOS510-SEP Package Decapped

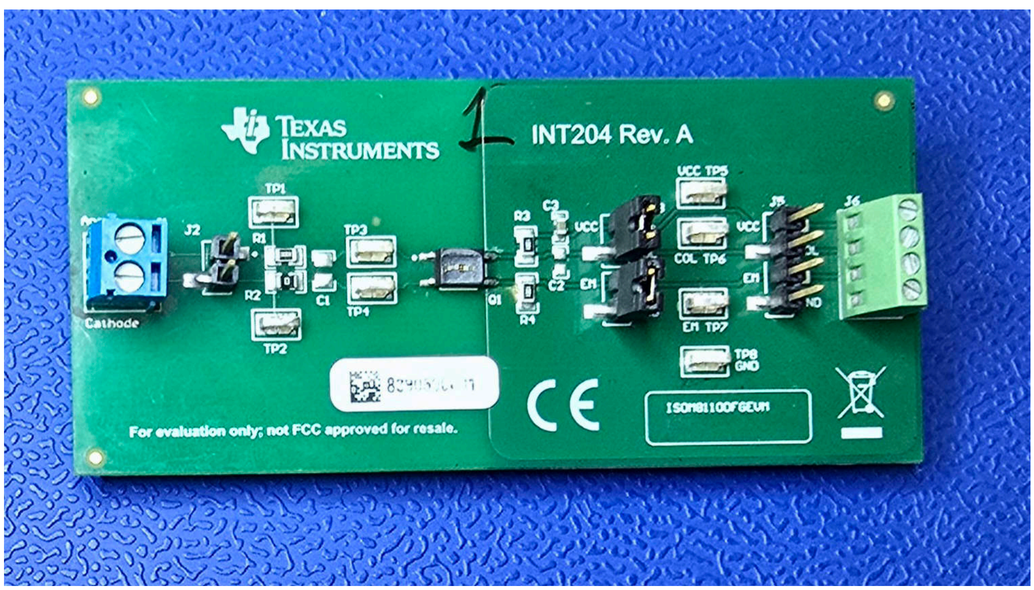

Figure 3-3. ISOS510-SEP EVM Top View

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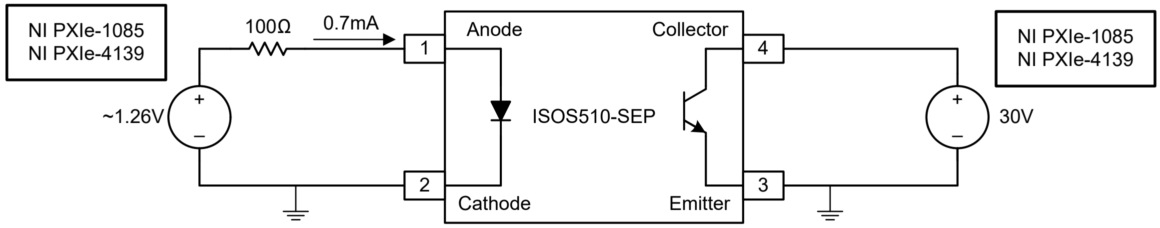

Figure 3-4. ISOS510-SEP SEL Bias Diagram 1

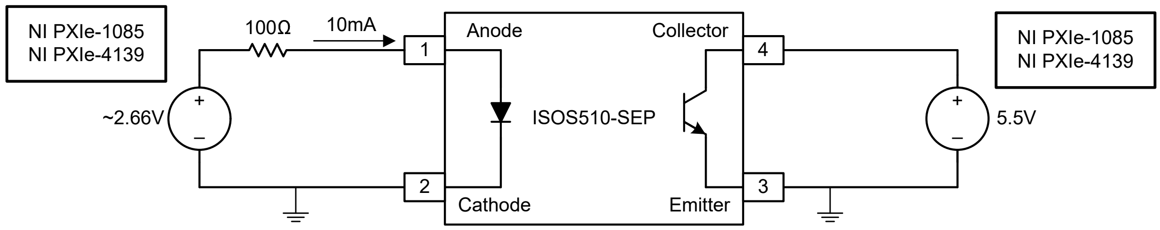

Figure 3-5. ISOS510-SEP SEL Bias Diagram 2

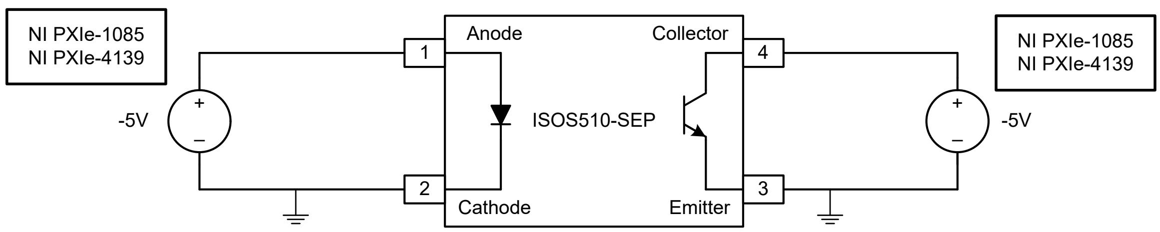

Figure 3-6. ISOS510-SEP SEL Bias Diagram 3

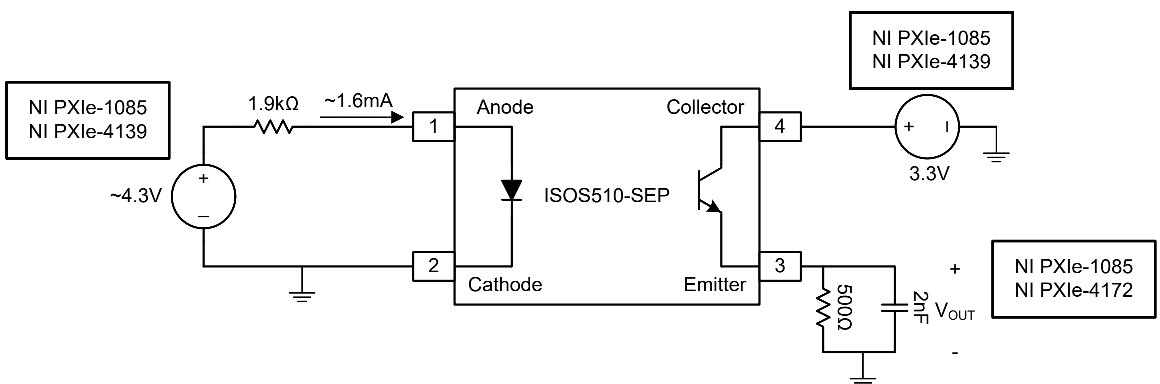

Figure 3-7. ISOS510-SEP SET Bias Diagram

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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 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 1in 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 10^5ions/cm^2×s was used to provide heavy-ion fluences of 1 × 10^7 – 1.5 × 10^7ions/cm^2. 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 40mm for all runs.

For the experiments conducted on this report, there were four ions used, ^{109}Ag, ^{84}Kr, ^{40}Ar, and ^{14}N. The list of ions and the respective LET are:

Table 4-1. Ion LET_{EFF} and Range in Silicon

Facility	Beam Energy (MeV/ nucleon)	Ion Type	Number of Degrader Steps	Degrader Angle (°)	Beam Port Window	Air Gap (mm)	Angle of Incidence	LET_{EFF} (MeV×cm^2/ mg)	Beam Uniformity across Runs (%)	Range in Silicon (µm)
TAMU	15	^{109}Ag	0	0	1-mil Aramica	40	0	47	94% – 96%	95.1
TAMU	15	^{84}Kr	0	0	1-mil Aramica	40	0	30.1	95%	114.3
TAMU	15	^{40}Ar	0	0	1-mil Aramica	40	0	8.54	96%	177
TAMU	15	^{14}N	0	0	1-mil Aramica	40	0	1.34	90% – 91%	367.8

Figure 4-2 shows EVM#1 in front of the beam line at the TAMU Cyclotron facility. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.Figure 4-1 shows EVM#1 through the beam line camera at TAMU Cyclotron facility. A FLIR (FLIR ONE Pro LT) thermal camera was used to validate die temperature to make sure the device was accurately heated, (see Figure 4-3).

Figure 4-1. ISOS510-SEP EVM through Beam Line Camera at the Texas A&M Cyclotron

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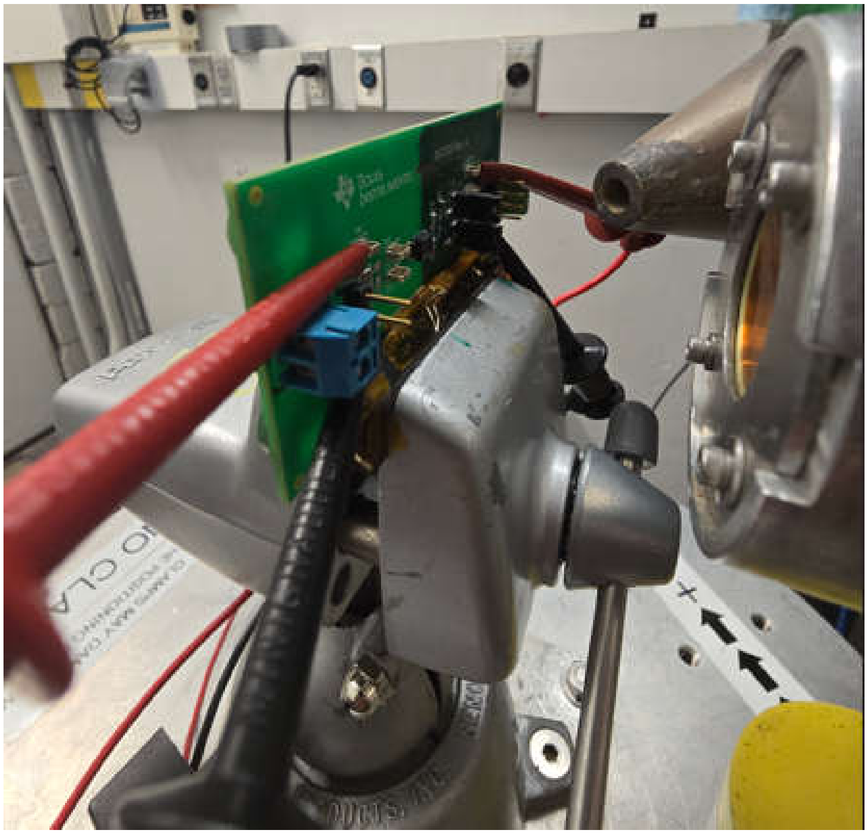

Figure 4-2. ISOS510-SEP EVM in Front of Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

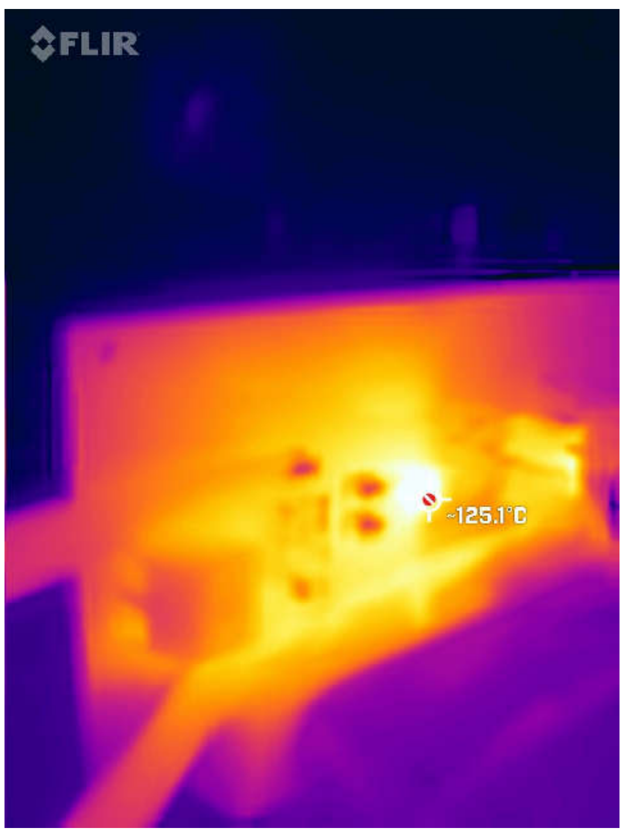

Figure 4-3. ISOS510-SEP EVM FLIR Thermal Image for SEL

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5 Test Setup and Procedures

There were two input supplies used to power the ISOS510-SEP which provided V_{IN} and V_{CE}. The V_{IN} for the device was provided by a National Instruments (NI) PXIe-4139 SMU and ranged from –5V for SET to 4.3V for SEL and SET. The V_{CE} for the device was provided by a National Instruments (NI) PXIe-4139 SMU and ranged from –5V to 30V depending on the type of test. The three different SEL biased schemes we designed to test the max V_{CE} of 30V, the max I_F or 10mA and the disable case where V_{IN} and V_{CE} are both –5V.

During SET testing, the primary signal monitored was a V_{OUT} signal that was measured on a load on the Emmiter pin of the device. This was done with a NI PXIe-5172 Scope card which was set to trigger on a 3% and 5% window based on the DC nominal value of VOUT.

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 via an MXI controller and NI PXIe-8381 remote control module. Equipment Settings and Parameters Used During the SEE Testing of the ISOS510-SEP shows the connections, limits, and compliance values used during the testing of the ISOS510-SEP.

Table 5-1. Equipment Settings and Parameters Used During the SEE Testing of the ISOS510-SEP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{IN}	NI-PXIe 4139-1 (CH # 1)	±60V, 3A	0.5A	–5 to 4.3V
V_{CE}	NI-PXIe 4139-2 (CH # 1)	±60V, 3A	0.5A	–5 to 30V
V_{OUT}	PXIe-5172	100MS/s	—	100MS/s

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 test facility. During the heavy-ion testing, the LabVIEW control program powered up the ISOS510-SEP 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 (SET only), the NI scope cards continuously monitored the signals. When the output exceeded the predefined 3% or 5% window trigger, a data capture was initiated. 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.

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6 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 also verified using a standalone FLIR((FLIR ONE Pro LT) thermal camera prior to exposure to heavy ions.

The species used for SEL testing was ^{109}Ag at 15MeV/nucleon (for more details refer to Table 4-1). Flux of approximately 10^5ions×cm^2/s and a fluence of approximately 1×10^7 – 1.5×10^7ions/cm^2 per run was used. Run duration to achieve this fluence was approximately 100 seconds. The three devices were powered up and exposed to the heavy-ions using the maximum recommended input forward voltage (see Figure 3-4) or maximum recommended collector-emitter voltage (see Figure 3-5).The device was also tested in the disabled case of –5V on the anode and the collector-emitter voltage (see Figure 3-6). No SEL events were observed during all twelve runs, indicating that the ISOS510-SEP is SEL-free up to 47MeV×cm^2/mg.Table 6-1 shows the SEL test conditions and results. Figure 6-1 and Figure 6-2 show the plots of the current vs time for runs number four and ten respectively. Please note all runs picked are a different bias scheme and will reflect different current readings.

Table 6-1. Summary of ISOS510-SEP SEL Test Condition and Results

Run #	Unit #	Facility	Ion	LET_{EFF} (MeV×cm^2/mg)	Flux (ions×cm^2/mg)	Fluence (number of ions)	V_{IN} (V)	I_F (mA)	V_{CE}	SEL (number of Events)
1	1	TAMU	^{109}Ag	47	1×10^5	1×10^7	1.28	0.7	30	0
2	1	TAMU	^{109}Ag	47	1×10^5	1×10^7	2.65	10	5.5	0
3	1	TAMU	^{109}Ag	47	1×10^5	1×10^7	–5	–	–5	0
4	2	TAMU	^{109}Ag	47	1×10^5	1×10^7	1.27	0.7	30	0
5	2	TAMU	^{109}Ag	47	1×10^5	1×10^7	2.67	10	5.5	0
6	2	TAMU	^{109}Ag	47	1×10^5	1×10^7	–5	–	–5	0
7	3	TAMU	^{109}Ag	47	1×10^5	1×10^7	1.26	0.7	30	0
8	3	TAMU	^{109}Ag	47	1×10^5	1.5×10^7	1.26	0.7	30	0
9	3	TAMU	^{109}Ag	47	1×10^5	1×10^7	2.68	10	5.5	0
10	3	TAMU	^{109}Ag	47	1×10^5	1.5×10^7	2.68	10	5.5	0
11	3	TAMU	^{109}Ag	47	1×10^5	1×10^7	–5	–	–5	0
12	3	TAMU	^{109}Ag	47	1×10^5	1.5×10^7	–5	–	–5	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the four runs at 125°C. Calculations are being done per bias scheme. Each bias scheme saw 0 SEL events and had a total fluence of 4.5×10^7ions/cm^2. The upper-bound cross-section (using a 95% confidence level) for all 3 different biases is calculated as:

$$\sigma_{SEL} \leq 8.20 \times 10^{-8} \text{cm}^2/\text{device for } LET_{EFF} = 47 \text{MeV} \cdot \text{cm}^2/\text{mg and } T = 125°\text{C} \quad (1)$$

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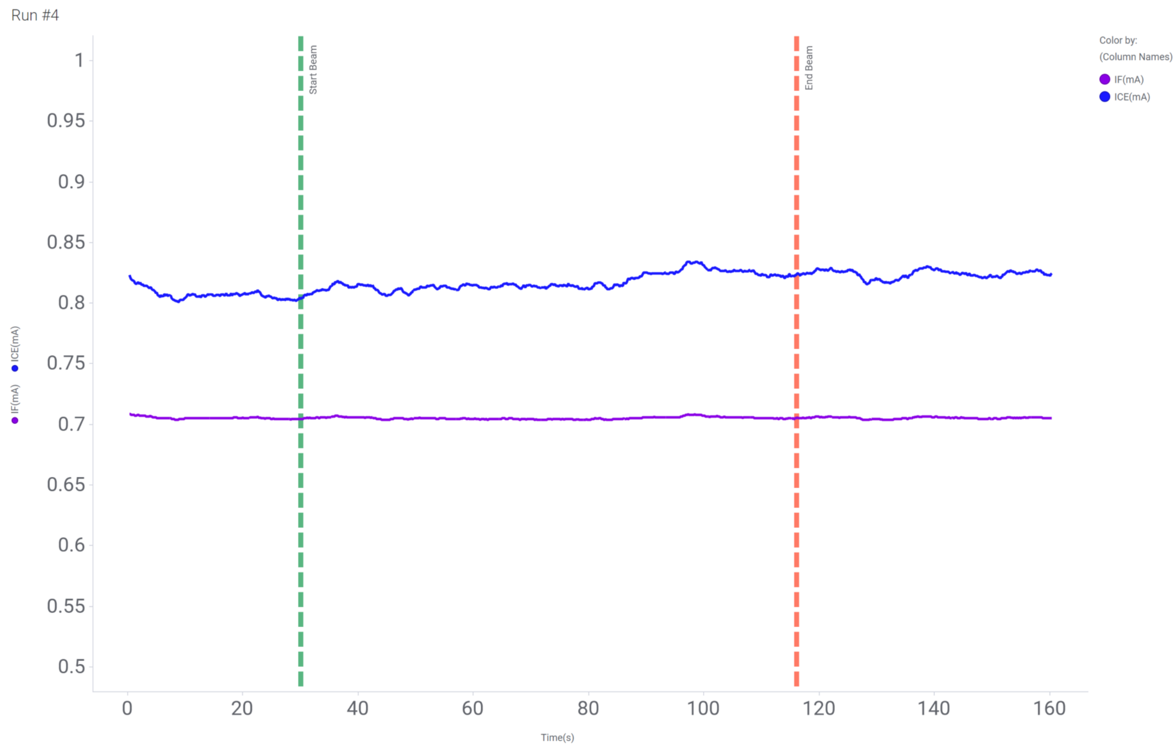

Figure 6-1. Current vs Time for Run #4 (I_F = 0.7mA; V_{CE} = 30V) of the ISOS510-SEP at T = 125°C

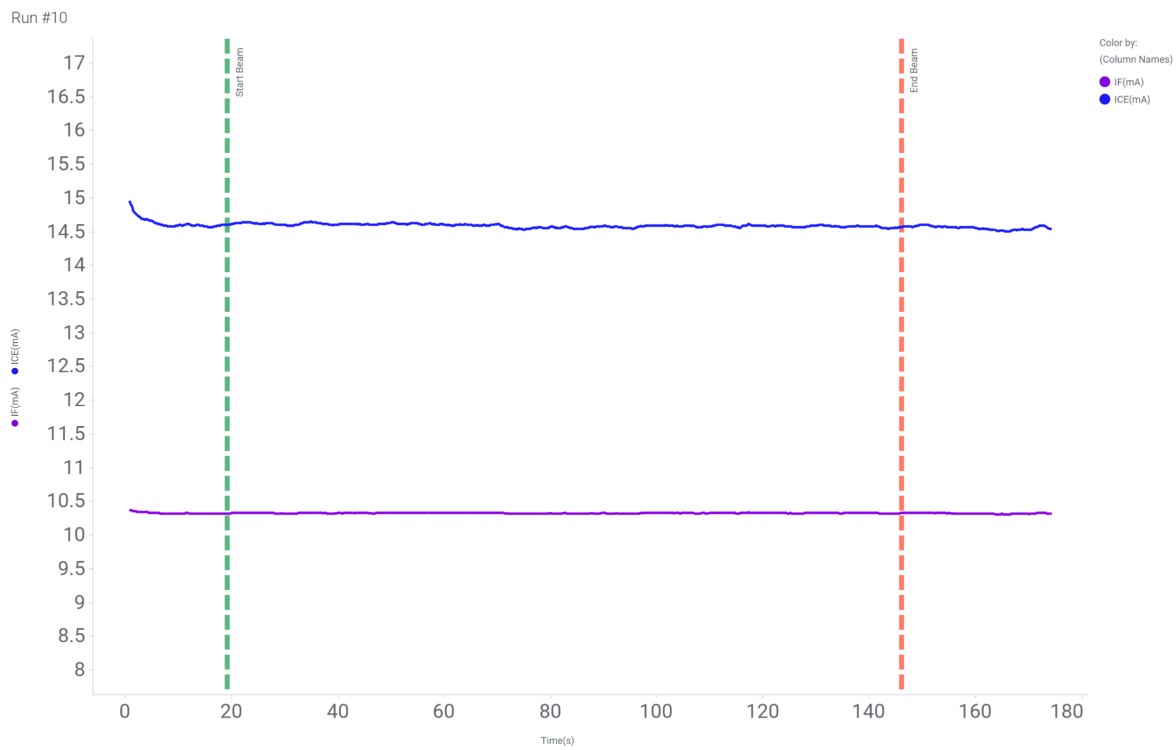

Figure 6-2. Current vs Time for Run #10 (I_F = 10mA; V_{CE} = 5.5V) of the ISOS510-SEP at T = 125°C

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7 Single-Event Transients (SET) Results

SET are defined as heavy-ion-induced transients upsets on the VOUT of the ISOS510-SEP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for SET testing was ^{109}Ag, ^{84}Kr, ^{40}Ar and ^{14}N at 15MeV/nucleon. ^{109}Ag, ^{84}Kr, ^{40}Ar, and ^{14}N for LET_{EFF} from 1.34 to 47MeV×cm^2/mg, for more details refer to Table 4-1. Flux of 10^5 ions×cm^2/s and a fluence of 1 × 10^7 ions/cm^2, per run were used for the characterization of the SET.

Table 7-1 shows the signal size, sample rate, trigger type, value, and signal for all scopes.

Table 7-1. Scope Settings

Only one Signal was used as a trigger source at a time, this table presents all possible sources for a given scope, the same is valid for the trigger type. All percentage specified on the trigger value are deviation from the nominal value.

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
PXIe-5172	V_{OUT}	Window	±3%	10k	100MS/s
			±5%		

For the V_{IN} of approximately 4.3V and V_{CE} of 3.3V with a V_{OUT} of approximately 1V, four units were characterized from 47MeV down to 1.34MeV. ^{109}Ag was used to achieve LET_{EFF} = 47MeV and ^{14}N was used to achieve LET_{EFF} = 1.34MeV. A PXIe-5172 scope was used to monitor the V_{OUT} signals of the ISOS510-SEP with V_{OUT} triggering off a 3% and 5% window. Table 7-2 summarizes the results for the four units tested.

Typical Low and High observed V_{OUT} transients are shown in Figure 7-1 and Figure 7-2 respectively. Figure 7-3 show that although the signal goes beyond the 3% window, the signal recovers back to nominal and the device continues to operate properly.

Table 7-4 shows the Weibull fit parameters and the Weibull fit plot. Figure 7-4 and Figure 7-5 shows the Weibull fit plots for the V_{OUT} 3% and 5% triggers.

Table 7-2. Summary of ISOS510-SEP SET Test Condition and Results

RUN #	UNIT #	Facility	Ion	LET_{EFF} (MeV×cm^2/mg)	FLUX (ions×cm^2/mg)	FLUENCE (number of ions)	Window Trigger	PXIe-5172 V_{OUT} SET Upsets
13	4	TAMU	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	5%	2655
14	4	TAMU	^{109}Ag	47	1.00 × 10^5	1.00 × 10^7	3%	2890
15	5	TAMU	^{84}Kr	30.1	1.00 × 10^5	1.00 × 10^7	5%	2386
16	5	TAMU	^{84}Kr	30.1	1.00 × 10^5	1.00 × 10^7	3%	2796
17	6	TAMU	^{40}Ar	8.54	1.00 × 10^5	1.00 × 10^7	5%	1885
18	6	TAMU	^{40}Ar	8.54	1.00 × 10^5	1.00 × 10^7	3%	2279
19	7	TAMU	^{14}N	1.34	1.00 × 10^5	1.00 × 10^7	5%	690
20	7	TAMU	^{14}N	1.34	1.00 × 10^5	1.00 × 10^7	3%	2021

Figure 7-1 shows the typical low observed V_{OUT} for Run #14. Transient reached a peak of approximately 0.14V and recovered within approximately 18.8µs

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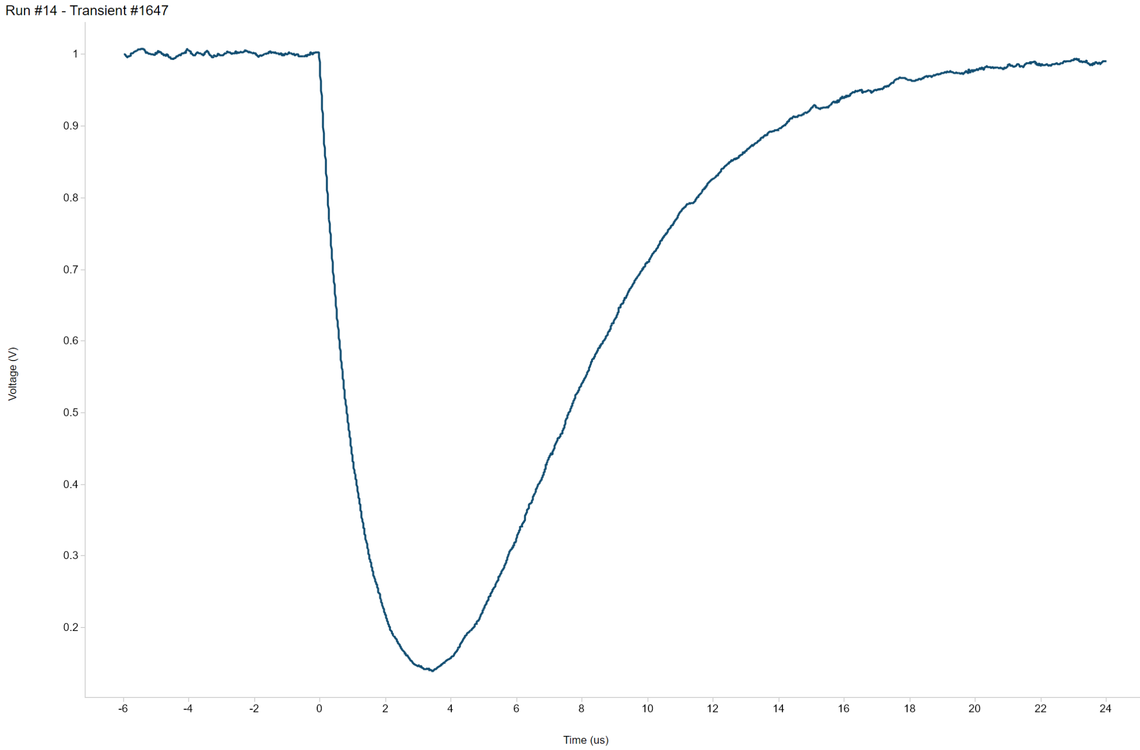

Figure 7-1. Typical Low Observed V_{OUT} Transient on Run #14

Figure 7-2 shows the typical high observed V_{OUT} for Run #14. Transient reached a peak of approximately 2.51V and recovered within approximately 17.3μs

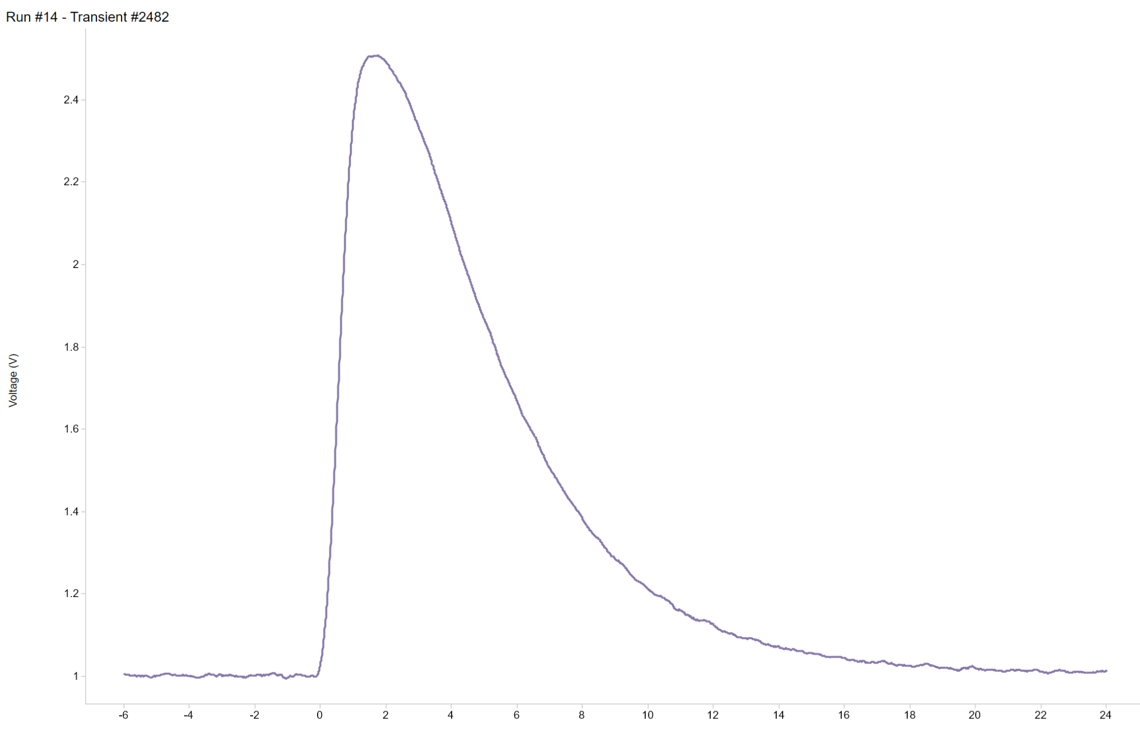

Figure 7-2. Typical High Observed V_{OUT} Transient on Run #14

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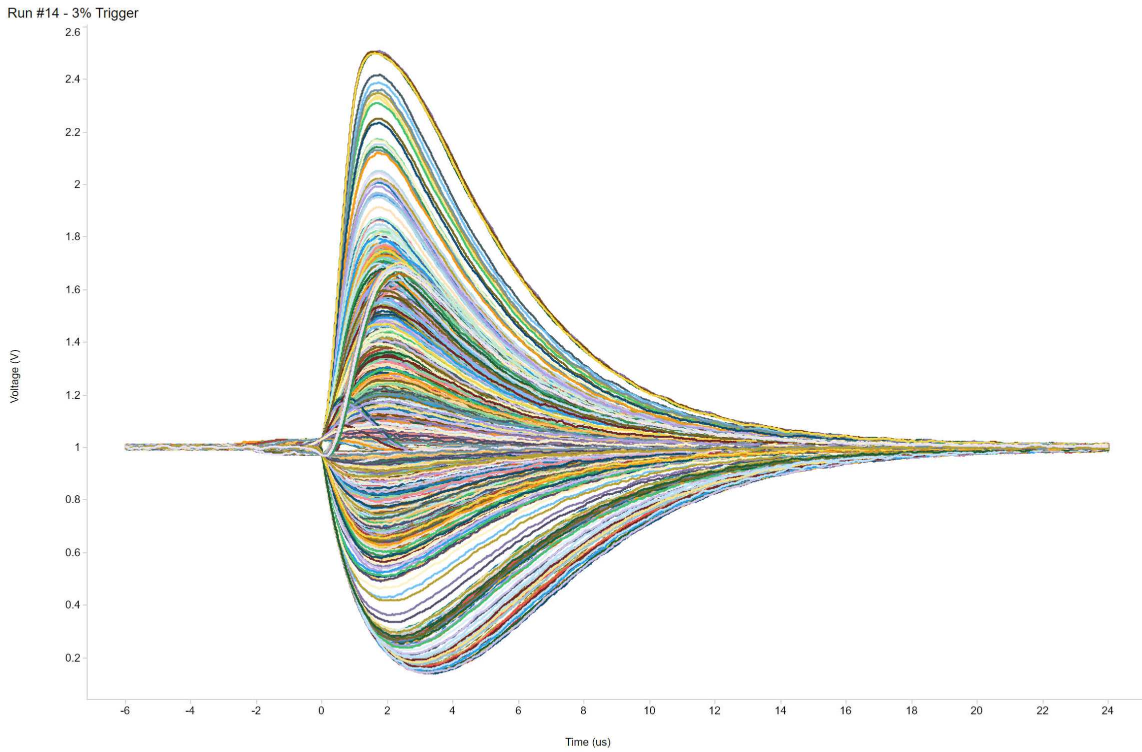

Figure 7-3. Overlay of all V_{OUT} Transients on Run # 14

Using the MFTF method, the upper-bound cross section (using a 95% confidence level) is calculated for the different SETs as shown below.

Table 7-3. Upper Bound Cross Section at 95% Confidence Interval

Ion	LET_{EFF} (MeV×cm²/mg)	FLUENCE (# ions)	Window Trigger	PXIe-5172 V_{OUT} SET Upsets	Upper Bound Cross Section (cm² /device)
^{109}Ag	47	1.00×10^{7}	5%	2655	2.76×10^{-4}
^{109}Ag	47	1.00×10^{7}	3%	2890	3.00×10^{-4}
^{84}Kr	30.1	1.00×10^{7}	5%	2386	2.48×10^{-4}
^{84}Kr	30.1	1.00×10^{7}	3%	2796	2.90×10^{-4}
^{40}Ar	8.54	1.00×10^{7}	5%	1885	1.97×10^{-4}
^{40}Ar	8.54	1.00×10^{7}	3%	2279	2.37×10^{-4}
^{14}N	1.34	1.00×10^{7}	5%	690	7.43×10^{-5}
^{14}N	1.34	1.00×10^{7}	3%	2021	2.11×10^{-4}

Table 7-4. Weibull Parameters for V_{OUT} Signal

Parameters	3%	5%
Cross-saturation (cm²)	4.18×10^{-4}	3.43×10^{-4}
w	14.99	14.98
s	0.15	0.32

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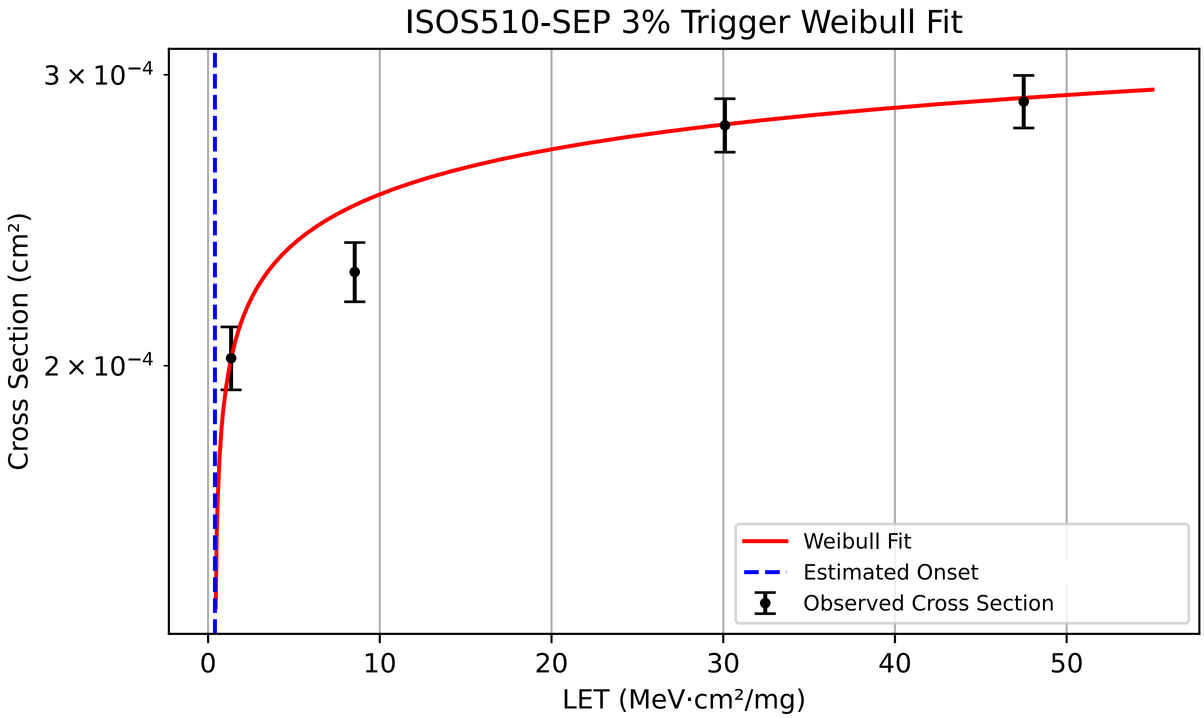

Figure 7-4. Weibull Fit for V_{OUT} 3% Trigger

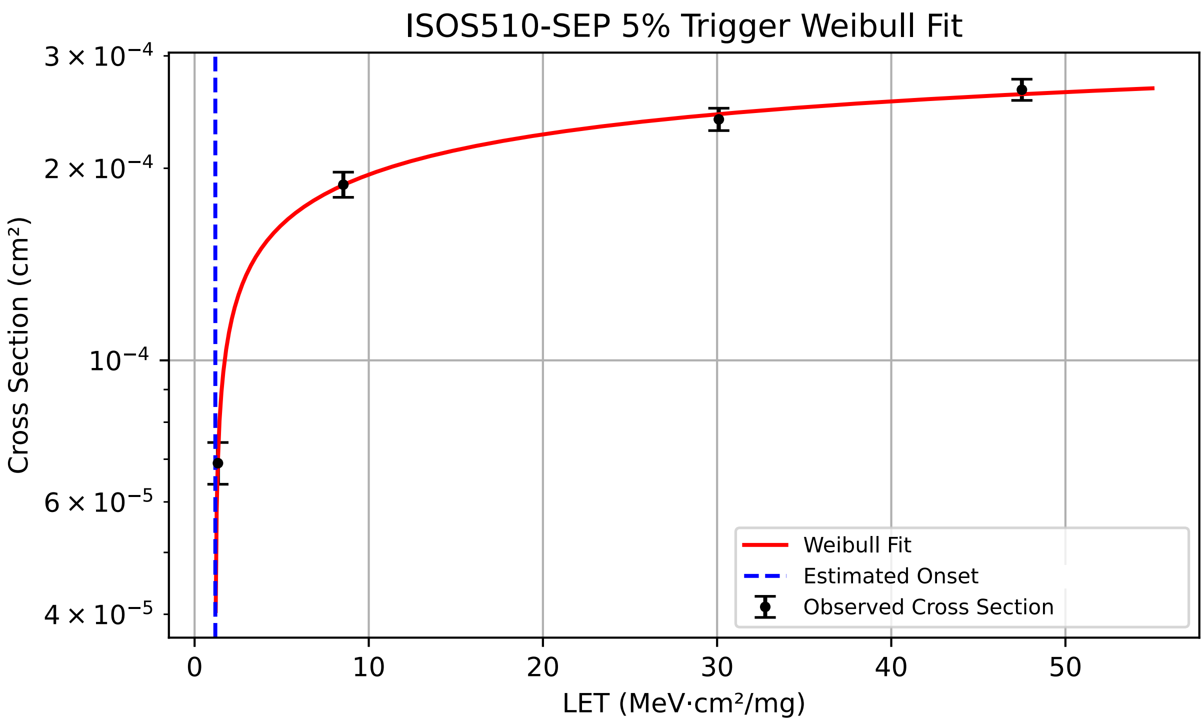

Figure 7-5. Weibull Fit for V_{OUT} 5% Trigger

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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 described in *Heavy Ion Orbital Environment Single-Event Effects Estimations* application report. We assume a minimum shielding configuration of 100 mils (2.54mm) of aluminum, and "worst-week" solar activity (this is similar to a 99% upper bound for the environment). Using the 95% upper-bounds for the SEL, the event rate calculation for the SEL is shown on Table 8-1. **Note that this number is for reference since no SEL events were observed.**

Table 8-1. SEL Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	47	4.81×10^{-4}	8.20×10^{-8}	3.94×10^{-11}	1.64×10^{-3}	6.95×10^{7}
GEO		1.58×10^{-3}		1.30×10^{-10}	5.40×10^{-3}	2.11×10^{7}

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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 ISOS510-SEP, current-driven analog isolator with transistor output. Heavy-ions with LET_{EFF} = 47MeV×cm^2/mg were used for the SEE characterization campaign. Flux of approximately 10^{5}ions/cm^2×s and fluences of approximately 1 × 10^7 – 1.5 × 10^{7}ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the ISOS510-SEP is free of destructive SEL LET_{EFF} = 47MeV×cm^2/mg and across the full electrical specifications. Transients at LET_{EFF} = 1.34 to 47MeV×cm^2/mg on V_{OUT} are presented and discussed. CREME96-based worst week event-rate calculations for LEO(ISS) and GEO orbits for the SEL are presented for reference.

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