Radiation Report

TMUX582F-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 TMUX582F-SEP, latch-up immune 8:1 multiplexer with adjustable fault thresholds. Heavy-ions with an LET_{EFF} of 43MeV-cm^2/mg were used to irradiate six production devices. Flux of ~10^5 ions / cm^2 *s and fluence of ~10^7 ions / cm^2 per run were used for the single-event latch-up (SEL) characterization and flux of ~10^4 ions / cm^2 *s and fluence of ~10^6 ions / cm^2 per run were used for the single-event transients (SET) characterization. The results demonstrate that the TMUX582F-SEP is SEL-free up to LET_{EFF} = 43MeV-cm^2/ mg at 125°C. Additionally, the single-event transient (SET) performance for output voltage excursions ≥ |10%| from the nominal voltage are discussed.

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1 Overview

The TMUX582F-SEP device is a modern 8:1 multiplexer designed for both single-ended and differential operation. This latch-up immune device offers robust overvoltage protection up to +60V making the device designed for harsh space environments. Additionally, this protection operates in powered-on, powered-off, and floating supply conditions.

See the product page for more information.

Table 1-1. Overview Information [1]

Description	Device Information
TI Part Number	TMUX582F-SEP
MLS Number	TMUX582FPWTSEP
Device Function	Latch-up immune 8:1 multiplexer with adjustable fault thresholds
Technology	LBCSOI2
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15MeV/nucleon)
Heavy Ion Fluence per Run	1×10^7 ions/cm^2 And 1×10^6 ions/cm^2
Irradiation Temperature	125°C (for SEL testing) And 25°C (for SET testing)

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2 Single-Event Effects (SEE)

The primary single-event effect (SEE) event of interest in the TMUX582F-SEP is the destructive single-event latch-up. From a risk or impact perspective, the occurrence of an SEL is potentially the most destructive SEE event and the biggest concern for space applications. In mixed technologies such as the linear BiCMOS (LBCSOI2) process used for TMUX582F-SEP, the CMOS circuitry introduces a potential 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-substrate and n-well and n+ and p+ contacts).

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 or until the device is destroyed by the high-current state. The process modifications applied for SEL-mitigation were sufficient, as the TMUX582F-SEP exhibited no SEL with heavy-ions up to an $\mathrm{LET_{EFF}}$ of 43MeV-cm^2/ mg at a fluence of 1 × 10^{7} ions / cm^2 at a chip temperature of 125°C.

The TMUX582F-SEP was characterized for SET at a flux of ~10^4 ions / cm^2 * s and a fluence of ~10^6 ions / cm^2 with a die temperature of about 25°C. The device was characterized with 3 different bias schemes shown below. Under these bias conditions, all recorded V_{OUT} voltage excursions self-recover with no external intervention.

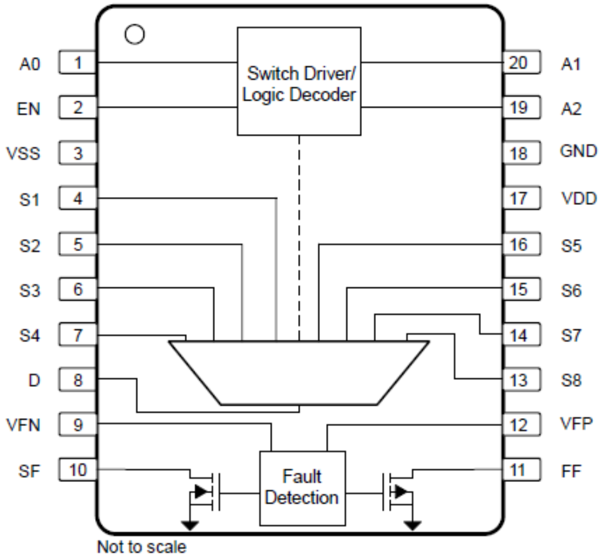

Figure 2-1. Functional Block Diagram of the TMUX582F-SEP

3 Test Device and Test Board Information

The TMUX582F-SEP is a packaged 20-pin, TSSOP plastic package shown in the pinout diagram in Figure 3-1. Figure 3-2 shows the device with the package decapped to reveal the die for heavy ion testing. Figure 3-3 shows the evaluation board used for radiation testing. Figure 3-4 shows the bias diagrams used for Single-Event Latch-up (SEL) testing.

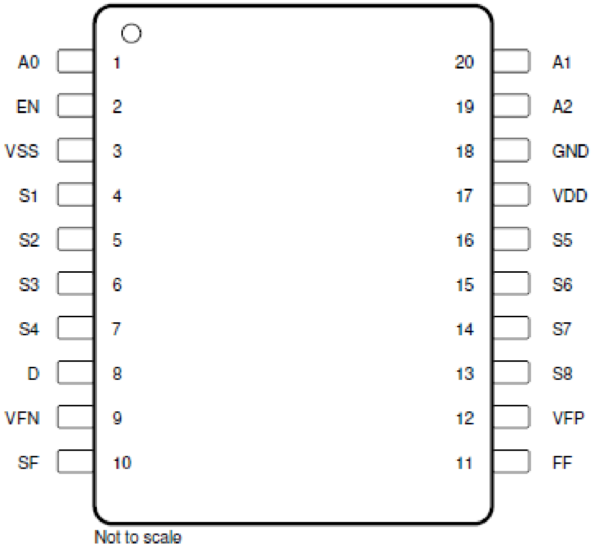

Figure 3-1. TMUX582F-SEP Pinout Diagram

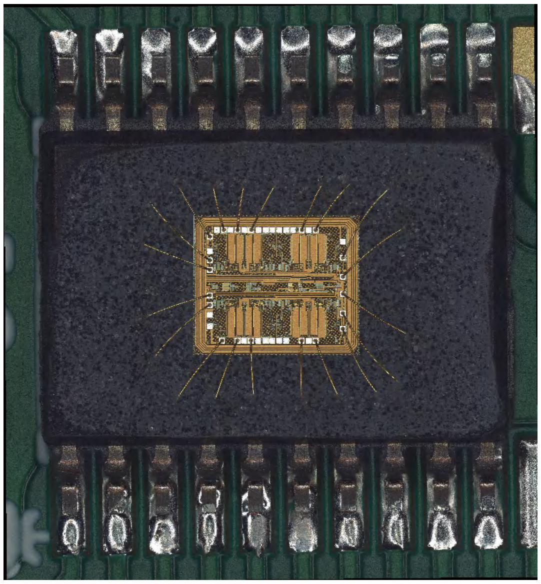

Figure 3-2. Photo of TMUX582F-SEP Package Decapped

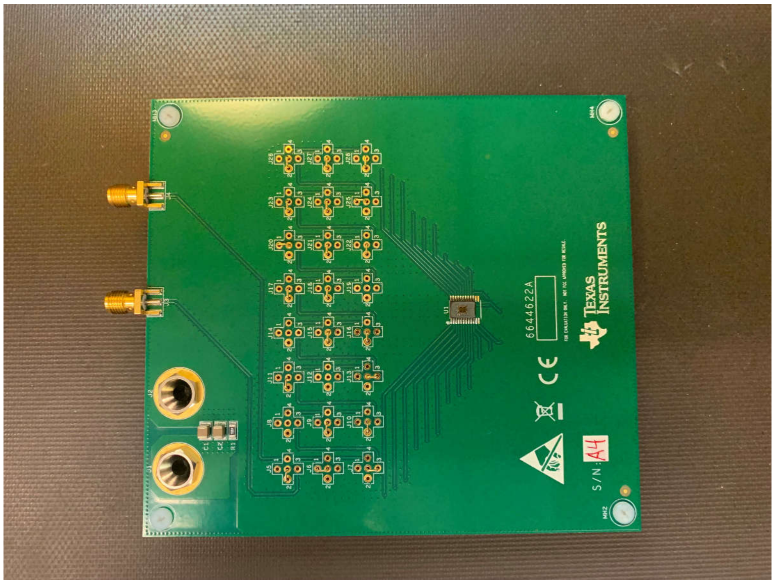

Figure 3-3. TMUX582F-SEP Evaluation Board Top View

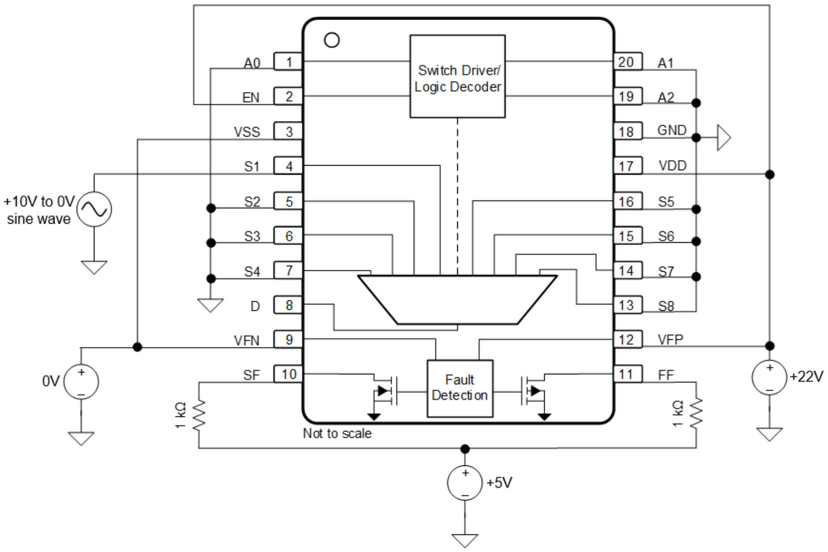

Figure 3-4. TMUX582F-SEP SEL Bias #1 Diagram

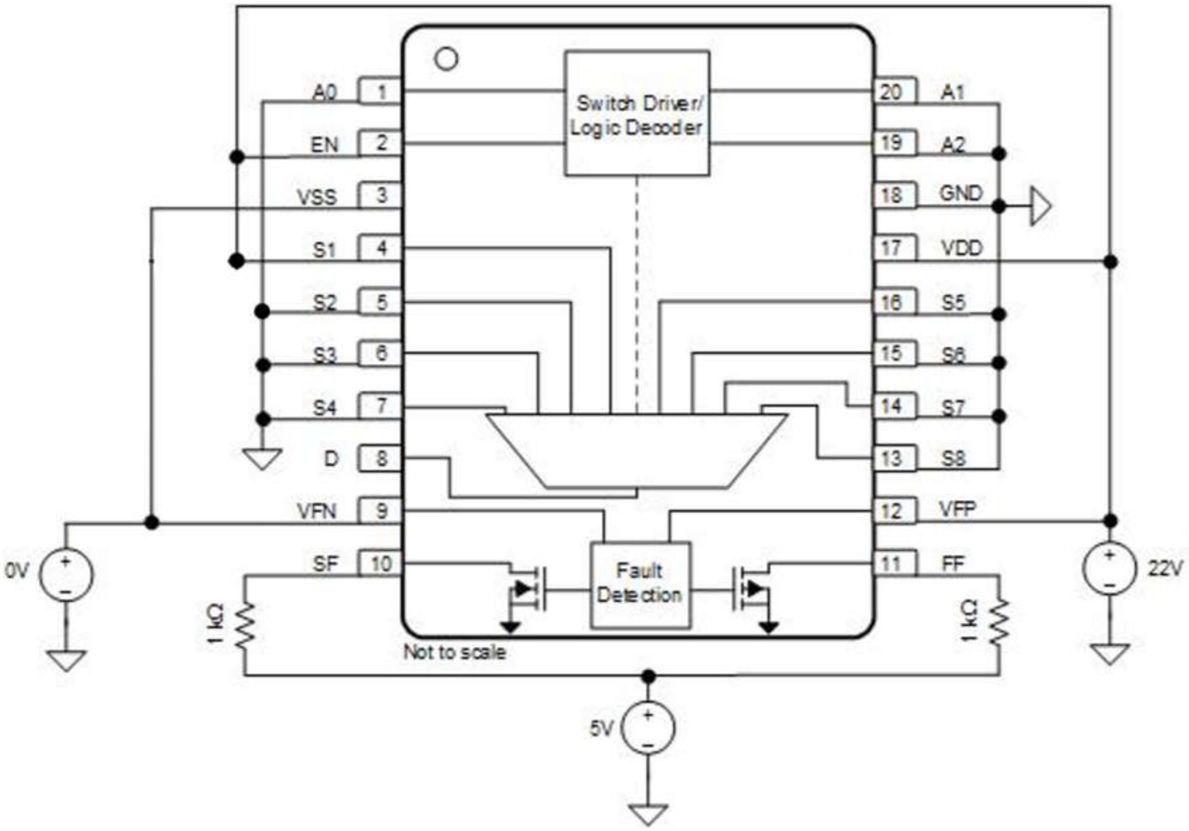

Figure 3-5. TMUX582F-SEP SEL Bias #2 Diagram

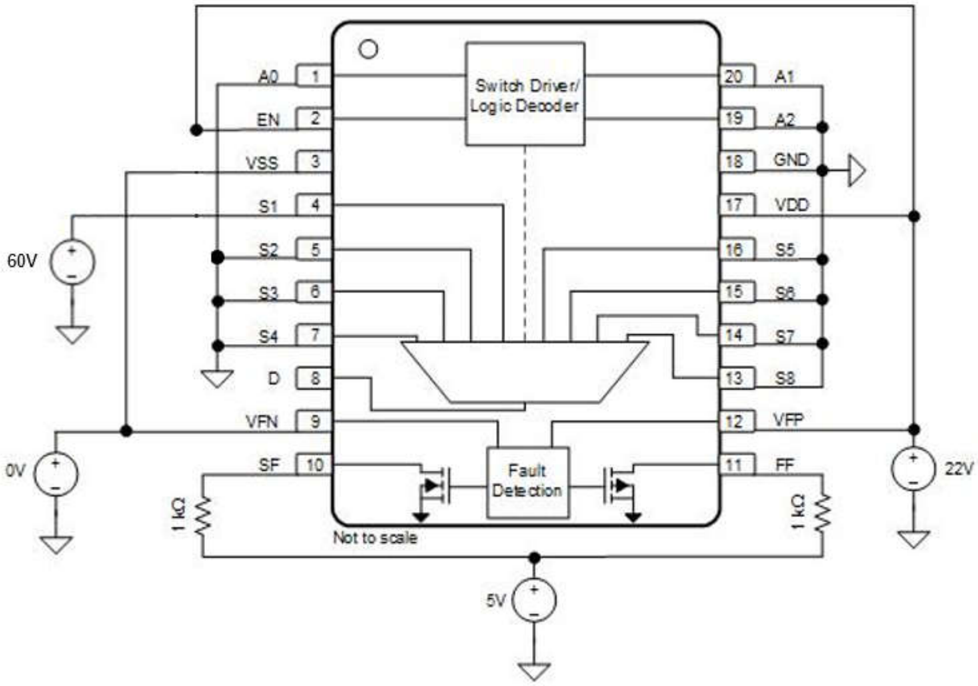

Figure 3-6. TMUX582F-SEP SEL Bias #3 Diagram

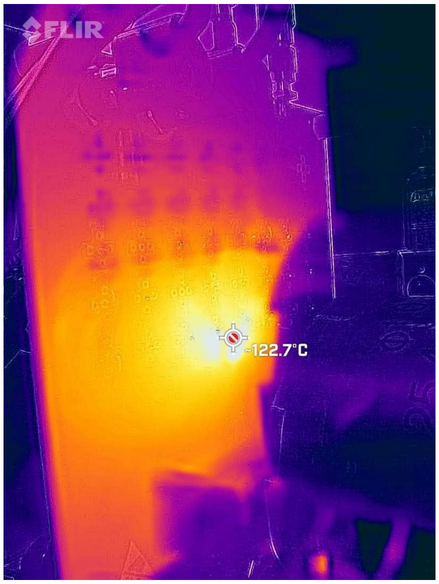

Figure 3-7. TMUX582F-SEP Thermal Image for SEL

Table 3-1. TMUX582F-SEP SET Bias #1 Chart

Pin Name	Condition	Pin Name	Condition
A0	Sq Wv (0V to 3.3V pk-pk, 100kHz freq)	A1	GND (0V)
EN	3V	A2	GND (0V)
VSS	GND (0V)	GND	GND (0V)
S1	3V	VDD	12V
S2	GND (0V)	S5	GND (0V)
S3	GND (0V)	S6	GND (0V)
S4	GND (0V)	S7	GND (0V)
D	Output (Monitored for SET)	S8	GND (0V)
VFN	GND (0V)	VFP	12V
SF	1 kOhm pull-up to 5V	FF	1 kOhm pull-up to 5V

Table 3-2. TMUX582F-SEP SET Bias #2 Chart

Pin Name	Condition	Pin Name	Condition
A0	12V	A1	12V
EN	12V	A2	12V
VSS	GND (0V)	GND	GND (0V)
S1	12V	VDD	12V
S2	12V	S5	12V
S3	12V	S6	12V
S4	12V	S7	12V
D	Output (Monitored for SET)	S8	11 kOhm load to GND (0V)
VFN	GND (0V)	VFP	12V
SF	1 kOhm pull-up to 5V	FF	1 kOhm pull-up to 5V

Table 3-3. TMUX582F-SEP SET Bias #3 Chart

Pin Name	Condition	Pin Name	Condition
A0	GND (0V)	A1	GND (0V)

Table 3-3. TMUX582F-SEP SET Bias #3 Chart (continued)

Pin Name	Condition	Pin Name	Condition
EN	12V	A2	GND (0V)
VSS	GND (0V)	GND	GND (0V)
S1	60V [Fault]	VDD	12V
S2	GND (0V)	S5	0GND (0V)
S3	GND (0V)	S6	GND (0V)
S4	GND (0V)	S7	GND (0V)
D	Output	S8	GND (0V)
VFN	GND (0V)	VFP	12V
SF	1 kOhm pull-up to 5V (Monitored for SET)	FF	1 kOhm pull-up to 5V (Monitored for SET)

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by the TAMU Cyclotron Radiation Effects Facility using a 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 this study, ion flux of 10^5 ions / cm^2 * s were used to provide heavy-ion fluences of approximately 10^7 ions / cm^2 for SEL testing and ion flux of 10^4 ions / cm^2 * s were used to provide heavy-ion fluences of approximately 10^6 ions / cm^2 for SET testing.

For the experiments conducted on this report, ^{109}Ag ions at angle of incidence of 0° for an LET_{EFF} of 43MeV × cm^2 / mg were used. The total kinetic energy of ^{109}Ag in the vacuum is 1.634GeV (15 MeV/nucleon). Ion uniformity for these experiments was between 93% and 97%.

Figure 4-1 shows one of the TMUX582F-SEP test boards used for experiments at the TAMU Cyclotron Radiation Effects Facility. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.

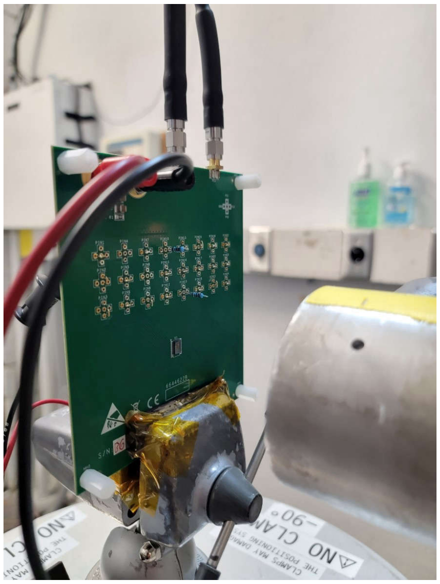

Figure 4-1. TMUX582F-SEP Evaluation Board at the TAMU Cyclotron Radiation Effects Facility

5 Results

5.1 Single-Event Latch-Up (SEL) Results

During SEL characterization, the device was heated using forced hot air, maintaining device temperature at 125°C ± 5°C. A FLIR (FLIR ONE Pro LT) thermal camera was used to validate die temperature to make sure the device was being accurately heated (see Figure 3-7). The species used for SEL testing was a silver (^{109}Ag) ion at an energy of 15MeV/μ with an angle-of-incidence of 0° for an LET_{EFF} of 43MeV-cm^2/ mg. A fluence of approximately 1 × 10^7 ions / cm^2 were used for the runs.

The three devices were powered up and exposed to the heavy-ions using the maximum recommended operating conditions under multiple bias schemes using two National Instruments PXI Chassis PXIe-4139 channels and a Keysight 33600A Waveform Generator for Bias #1, and three National Instruments PXI Chassis PXIe-4139 channels for Bias #2 and #3. The run duration to achieve this fluence was approximately one to two minutes. As listed in Table 5-1, no SEL events were observed during the 15 runs, indicating that the TMUX582F-SEP is SEL-free. Figure 5-1 and Figure 5-2 show the plot of current versus time for runs number 4, 9, 14 and 15, respectively.

Table 5-1. Summary of TMUX582F-SEP Test Conditions and Results

Run Number	Unit Number	Bias	Ion	Distance (mm)	Angle	Temperature (°C)	LET_{EFF} (MeV.cm^2/mg)	FLUX (ions × cm^2/mg)	Fluence (# ions)	SEL Event Occurred?
1	1	1	Ag	40	0°	128	43	1.0E+05	1.0E+07	No
2	1	1	Ag	40	0°	128	43	1.0E+05	1.0E+07	No
3	1	1	Ag	40	0°	128	43	1.0E+05	1.0E+07	No
4	2	1	Ag	40	0°	122	43	1.0E+05	1.0E+07	No
5	2	1	Ag	40	0°	122	43	1.0E+05	1.0E+07	No
6	2	1	Ag	40	0°	122	43	1.0E+05	1.0E+07	No
7	3	1	Ag	40	0°	124	43	1.0E+05	1.0E+07	No
8	3	1	Ag	40	0°	124	43	1.0E+05	1.0E+07	No
9	3	1	Ag	40	0°	124	43	1.0E+05	1.0E+07	No
10	1	2	Ag	40	0°	125	43	1.0E+05	1.0E+07	No
11	1	3	Ag	40	0°	125	43	1.0E+05	1.0E+07	No
12	2	2	Ag	40	0°	123	43	1.0E+05	1.0E+07	No
13	2	3	Ag	40	0°	123	43	1.0E+05	1.0E+07	No
14	3	3	Ag	40	0°	126	43	1.0E+05	1.0E+07	No
15	3	2	Ag	40	0°	126	43	1.0E+05	1.0E+07	No

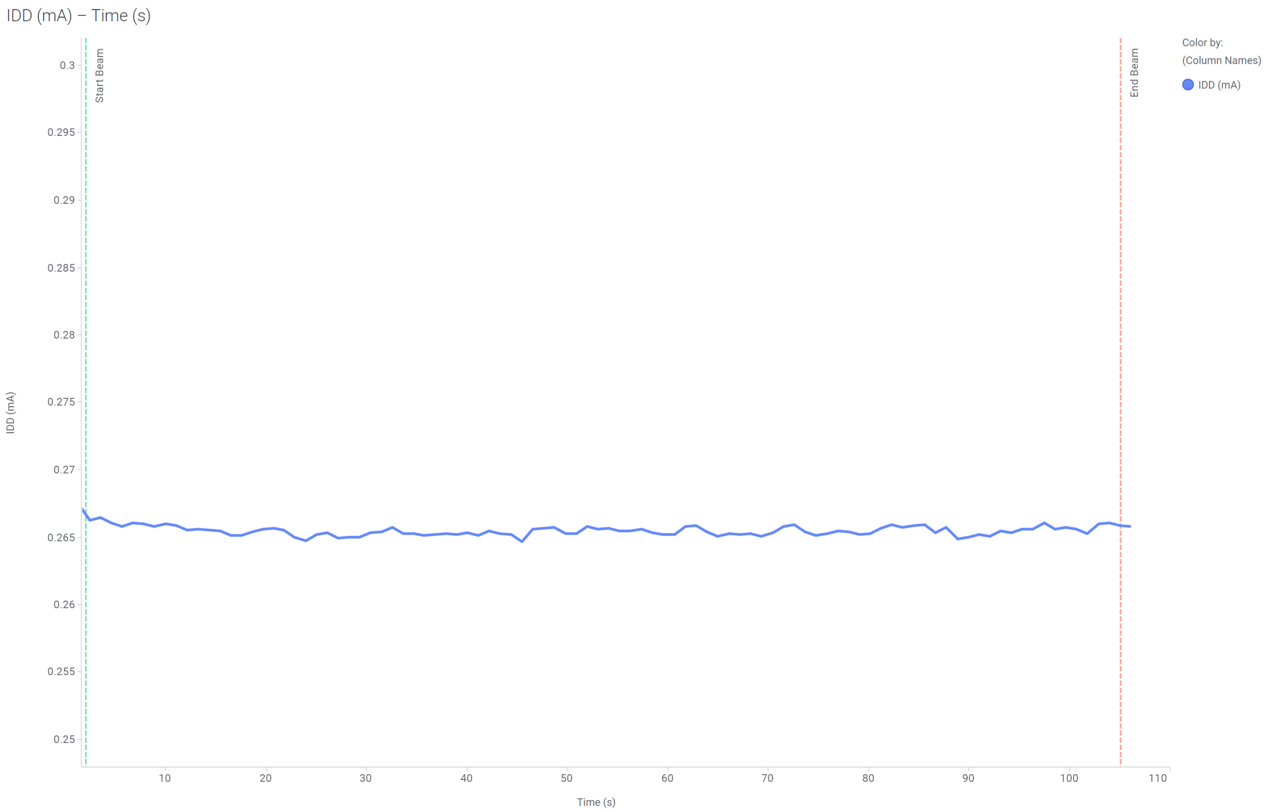

Figure 5-1. Current Versus Time for Run #4 of the TMUX582F-SEP at T=125°C

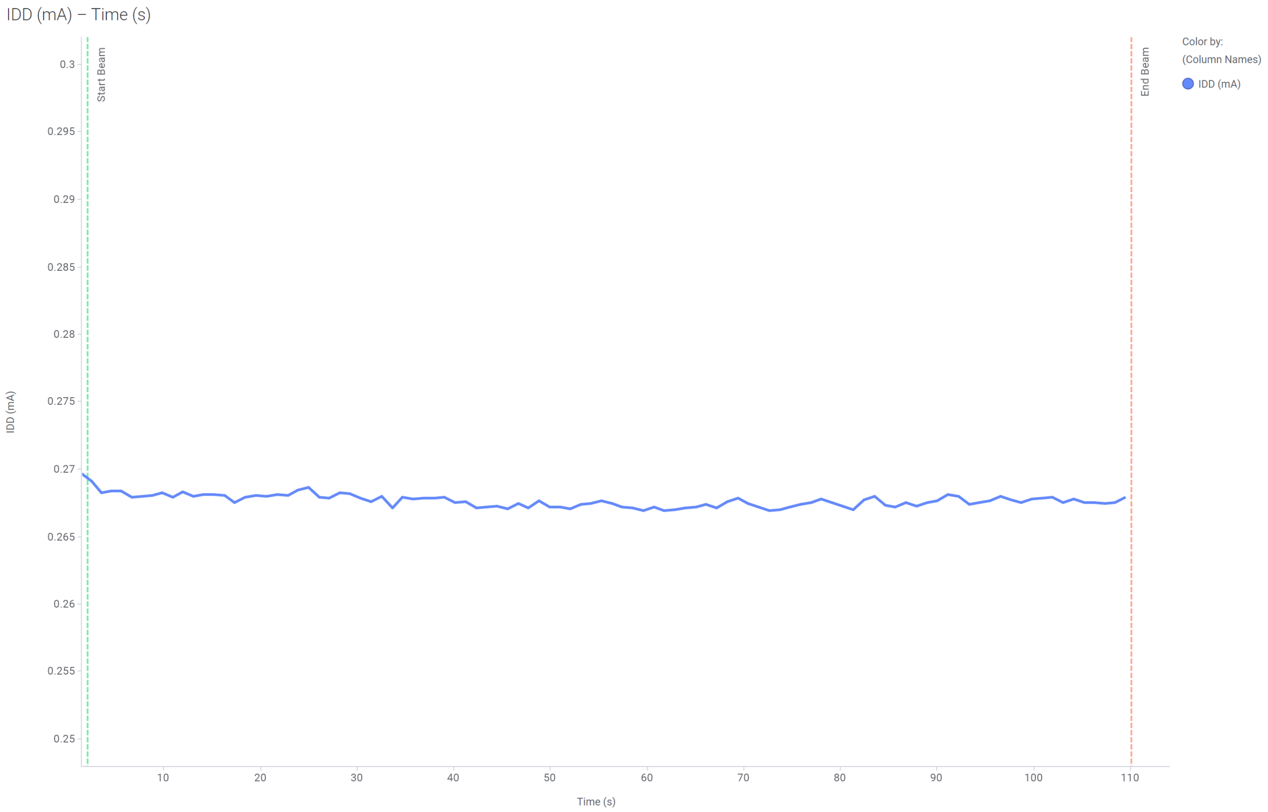

Figure 5-2. Current Versus Time for Run #9 of the TMUX582F-SEP at T=125°C

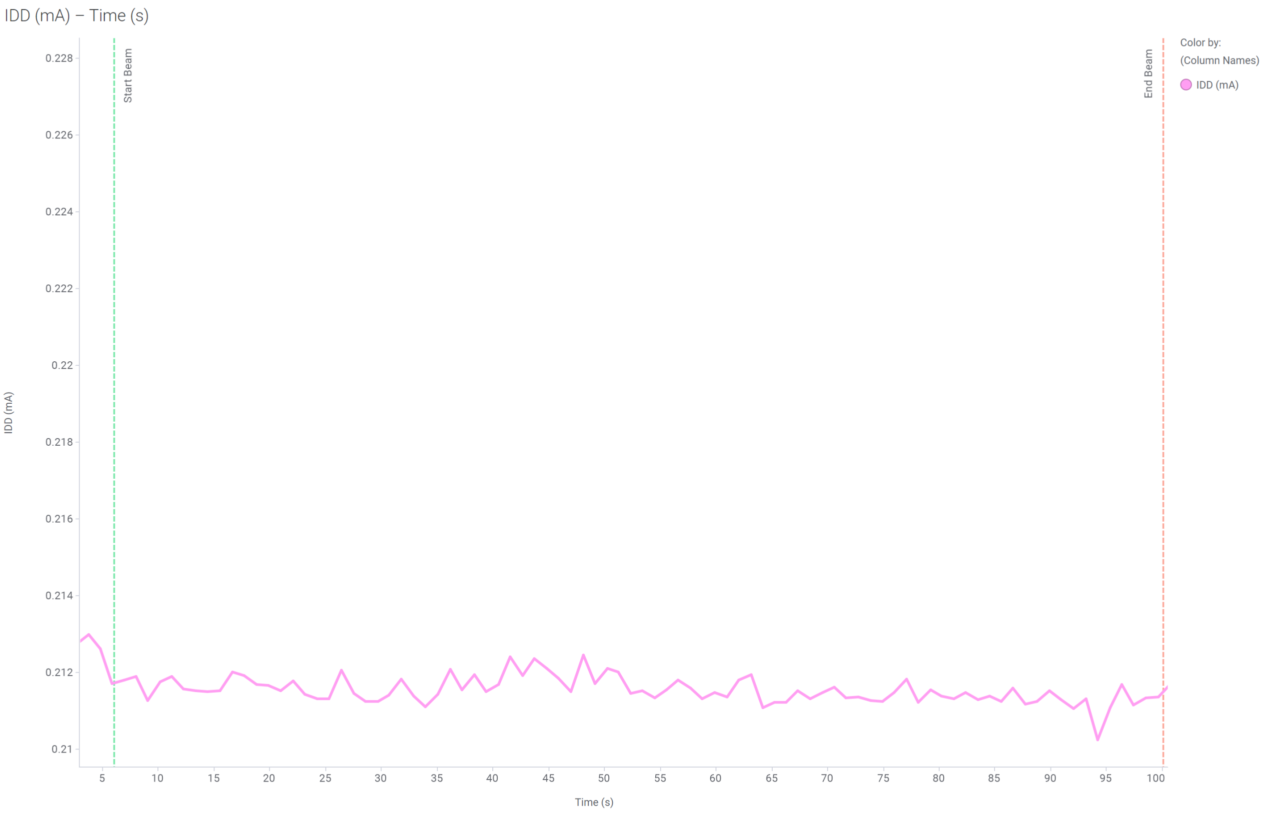

Figure 5-3. Current Versus Time for Run #14 of the TMUX582F-SEP at T=125°C

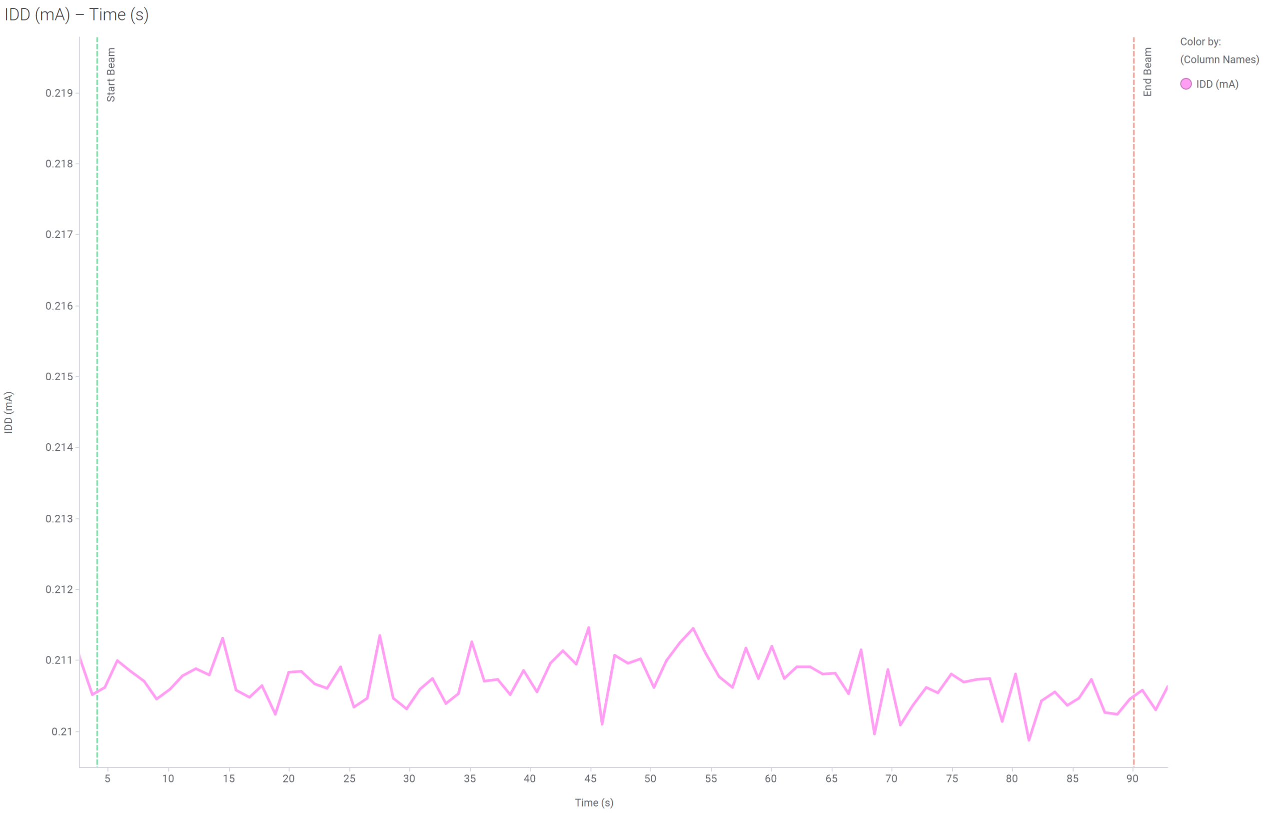

Figure 5-4. Current Versus Time for Run #15 of the TMUX582F-SEP at T=125°C

No SEL events were observed, indicating that the TMUX582F-SEP is SEL-immune at LET_{EFF} = 43MeV-cm^2/ mg and T = 125°C. The upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma SEL \leq 1.23 \times 10^{-7}\ cm^2 \text{ for } LET_{EFF} = 43\ MeV\text{-}cm^2/mg \text{ and } T = 125°C. \quad (1)$$

5.2 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*. A minimum shielding configuration of 100mils (2.54mm) of aluminum and worst-week solar activity is assumed. (This is similar to a 99% upper bound for the environment). Table 5-2 lists the event rate calculations using the 95% upper-bounds for the SEL. It is important to note that this number is for reference since no SEL events were observed.

Table 5-2. SEL Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET (MeV–cm^2 / mg)	CREME96 Integral Flux (/ day–cm^2)	σ_{SAT} (cm^2)	Event Rate (/ day)	Event Rate (FIT)	MTBE (years)
LEO(ISS)	43	6.40×10^{-4}	1.23×10^{-7}	7.87×10^{-11}	3.28×10^{-3}	3.48×10^{7}
GEO		2.17×10^{-3}		2.67×10^{-10}	1.11×10^{-2}	1.03×10^{7}

MTBE is the mean-time-between-events in years at the given event rates. These rates clearly demonstrate the SEE robustness of the TMUX582F-SEP in two harshly conservative space environments. Customers using the TMUX582F-SEP must only use the above estimations as a rough guide and TI recommends performing event rate calculations based on specific mission orbital and shielding parameters to determine if the product satisfies the reliability requirements for the specific mission.

5.3 Single-Event Transients (SET) Results

SETs are defined as heavy-ion-induced transients upsets on V_{OUT} of the TMUX582F-SEP. The species used for the SET testing was a Silver (Ag), a Krypton (Kr) and an Argon (Ar) with an angle-of-incidence of 0° for an LET_{EFF} of 47.5, 30.1 and 8.54 MeV-cm^2/ mg respectively. Flux of approximately 10^4 ions / cm^2 * s and a fluence of approximately 10^6 ions / cm^2 were used for all runs of SET testing.

V_{OUT} SETs were characterized using a window trigger of ±10% around the nominal output voltage. The devices were characterized in three different voltage cases. The first used a 12V input voltage with a square wave on the A0 pin to toggle the device output on the D pin between S1 of 3V and S2 of 0V. The second used a 12V input voltage with the S8 pin selected for outputting a static voltage of 0V to the D pin. The third used a 12V input voltage and was setup in a fault protection case with the S1 pin at 60V to monitor proper performance of the two fault protection pins, SF and FF. To capture the SETs a NI PXIe-5110 scope card was used to continuously monitor the switching output on the D pin for the first bias scheme. The second and third bias schemes used a NI PXIe-5172 to monitor the D pin and SF/FF pins, respectively.

The scope triggering from V_{OUT} was programmed to record 5k samples for bias #1 and 2k samples for bias #2 and #3 with a constant sample rate of 100 mega-samples per second (MS/s) in case of an event. The scope was programmed to record 20% of the data before the trigger.

Under heavy-ions, the TMUX582F-SEP exhibits transient upsets that were fully recoverable without the need for external intervention.

Test conditions and results are summarized in Table 5-3.

Table 5-3. Summary of TMUX582F-SEP Test Conditions and Results

Run Number	Unit Number	Ion	LET_{EFF} (MeV-cm^2/ mg)	FLUX (ions × cm^2 * s)	Fluence (ions / cm^2)	Bias #	Trigger Value (%)	$VOUT_{SET}$ (#) ≥10%
1	1	Ag	47.5	1.0E+04	1.0E+06	1	10	113* (D pin)
2	1	Ag	47.5	1.0E+04	1.0E+06	1	20	905* (D pin)
3	2	Ag	47.5	1.0E+04	1.0E+06	2	10	14 (D pin)
4	2	Ag	47.5	1.0E+04	1.0E+06	2	5	12 (D pin)
5	3	Ag	47.5	1.0E+04	1.0E+06	3	10	16 (SF pin), 16 (FF pin)

Table 5-3. Summary of TMUX582F-SEP Test Conditions and Results (continued)

Run Number	Unit Number	Ion	LET_{EFF} (MeV-cm^2/ mg)	FLUX (ions × cm^2 * s)	Fluence (ions / cm^2)	Bias #	Trigger Value (%)	$VOUT_{SET}$ (#) ≥10%
6	3	Ag	47.5	1.0E+04	1.0E+06	3	5	16 (SF pin), 14 (FF pin)
7	3	Kr	30.1	1.0E+04	1.0E+06	3	10	14 (SF pin), 14 (FF pin)
8	3	Kr	30.1	1.0E+04	1.0E+06	3	5	24 (SF pin), 23 (SF pin)
9	2	Kr	30.1	1.0E+04	1.0E+06	2	10	12 (D pin)
10	2	Kr	30.1	1.0E+04	1.0E+06	2	5	14 (D pin)
11	1	Kr	30.1	1.0E+04	1.0E+06	1	10	19 (D pin)
12	1	Kr	30.1	1.0E+04	1.0E+06	1	5	17 (D pin)
13	1	Ar	8.54	1.0E+04	1.0E+06	1	10	9 (D pin)
14	1	Ar	8.54	1.0E+04	1.0E+06	1	5	5 (D pin)
15	2	Ar	8.54	1.0E+04	1.0E+06	2	10	12 (D pin)
16	2	Ar	8.54	1.0E+04	1.0E+06	2	5	15 (D pin)
17	3	Ar	8.54	1.0E+04	1.0E+06	3	10	5 (SF pin), 5 (FF pin)
18	3	Ar	8.54	1.0E+04	1.0E+06	3	5	2 (SF pin), 2 (SF pin)

First 2 runs on the dynamic bias showed extra false transients during the run due to a noisy probe, issue was fixed with a better probe for the other 4 runs on the first bias scheme

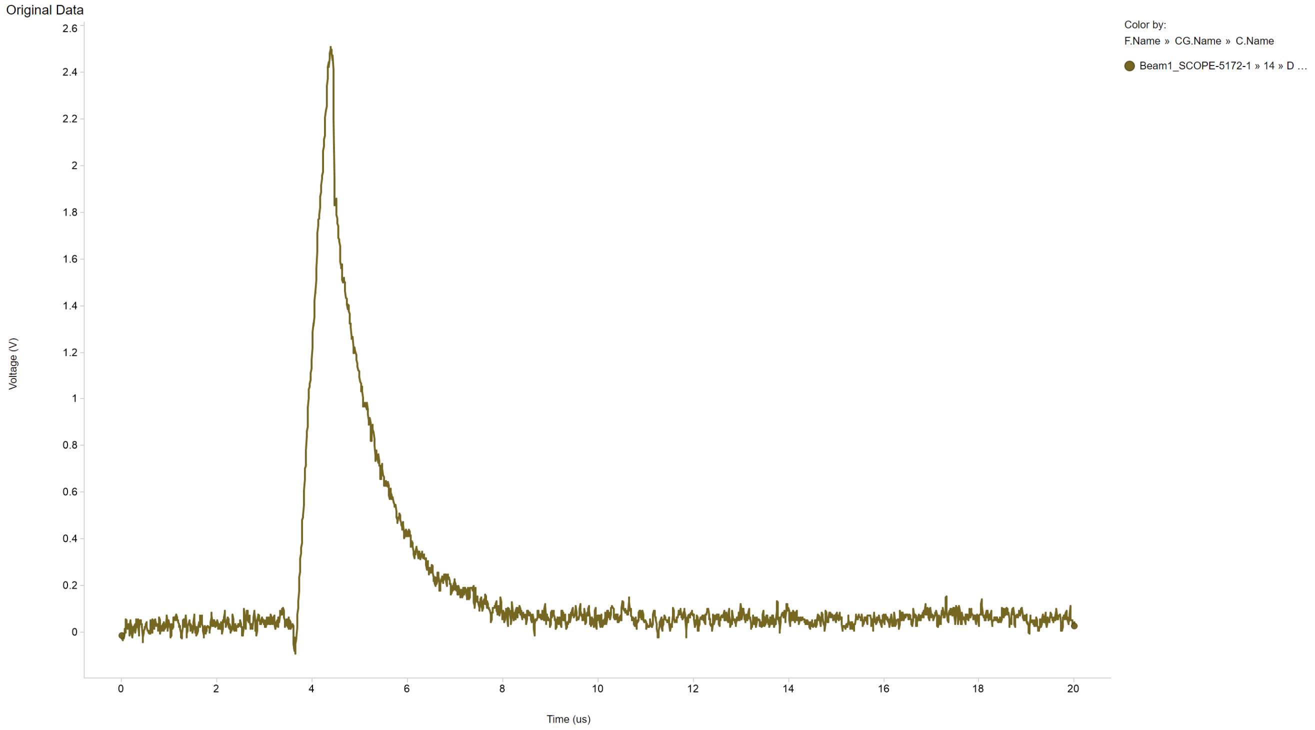

Figure 5-5. Worst Case Transient Plot [Run#3 - D Pin]

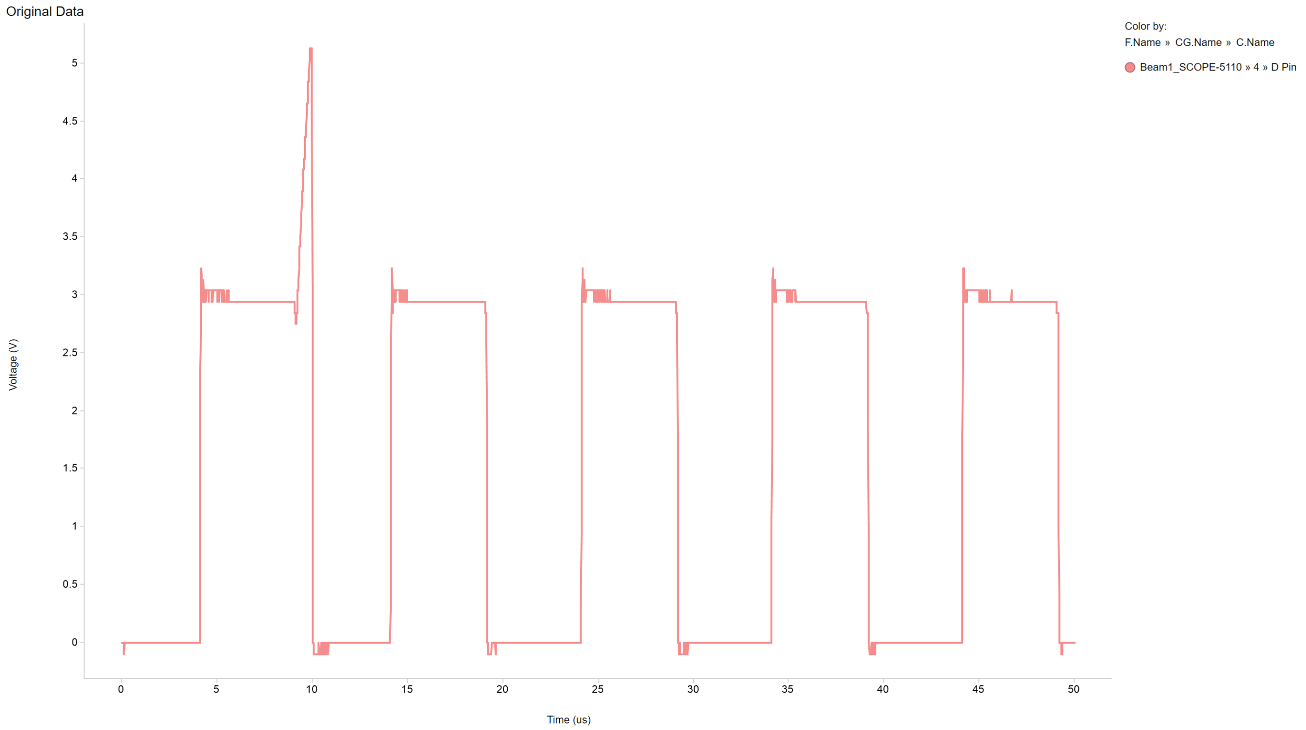

Figure 5-6. Worst Case Transient Plot #1 [Run #13 - D Pin]

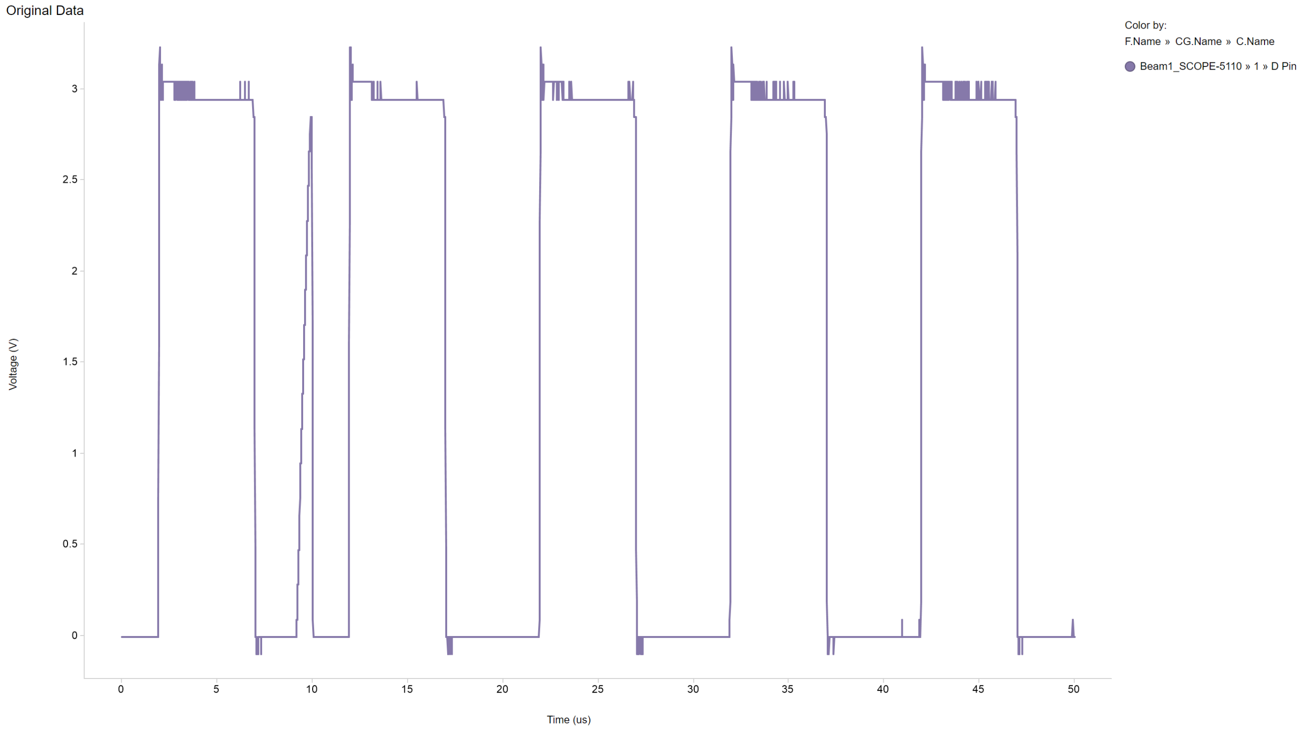

Figure 5-7. Worst Case Transient Plot #2 [Run #13 - D Pin]

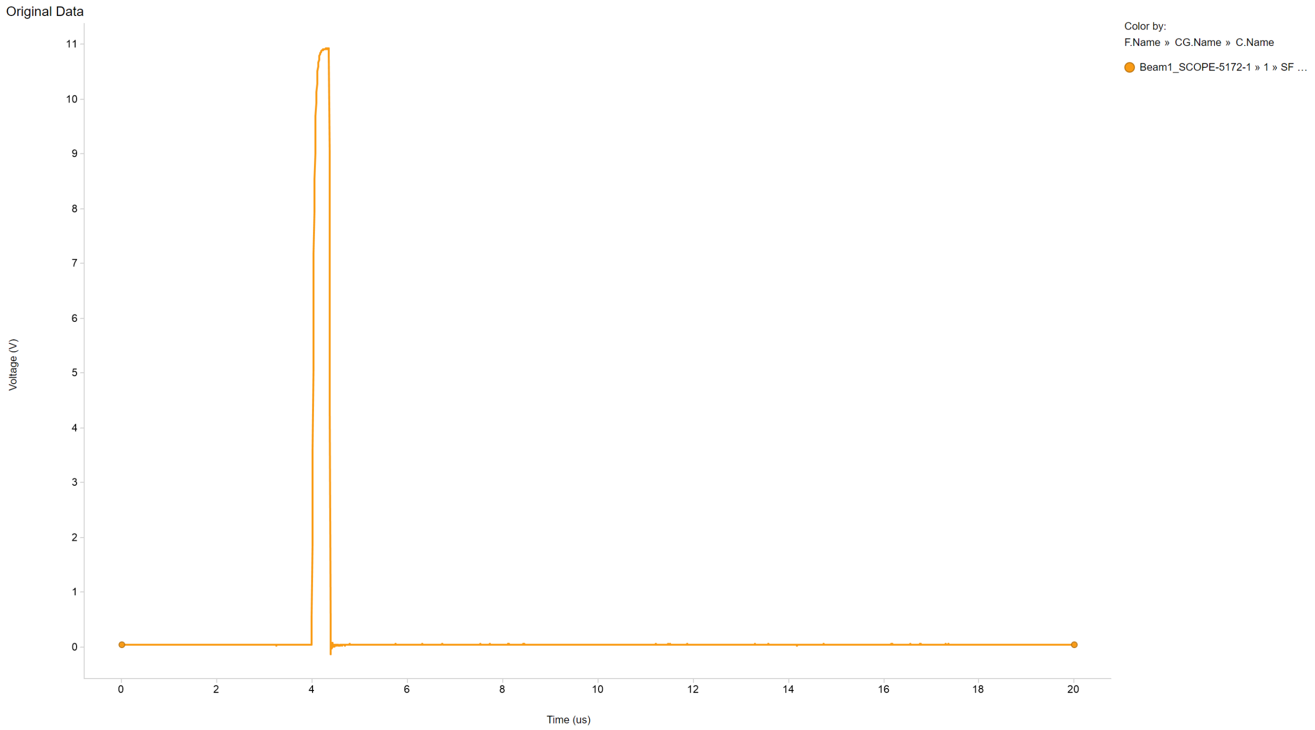

Figure 5-8. Worst Case Transient Plot [Run #19 - SF Pin]

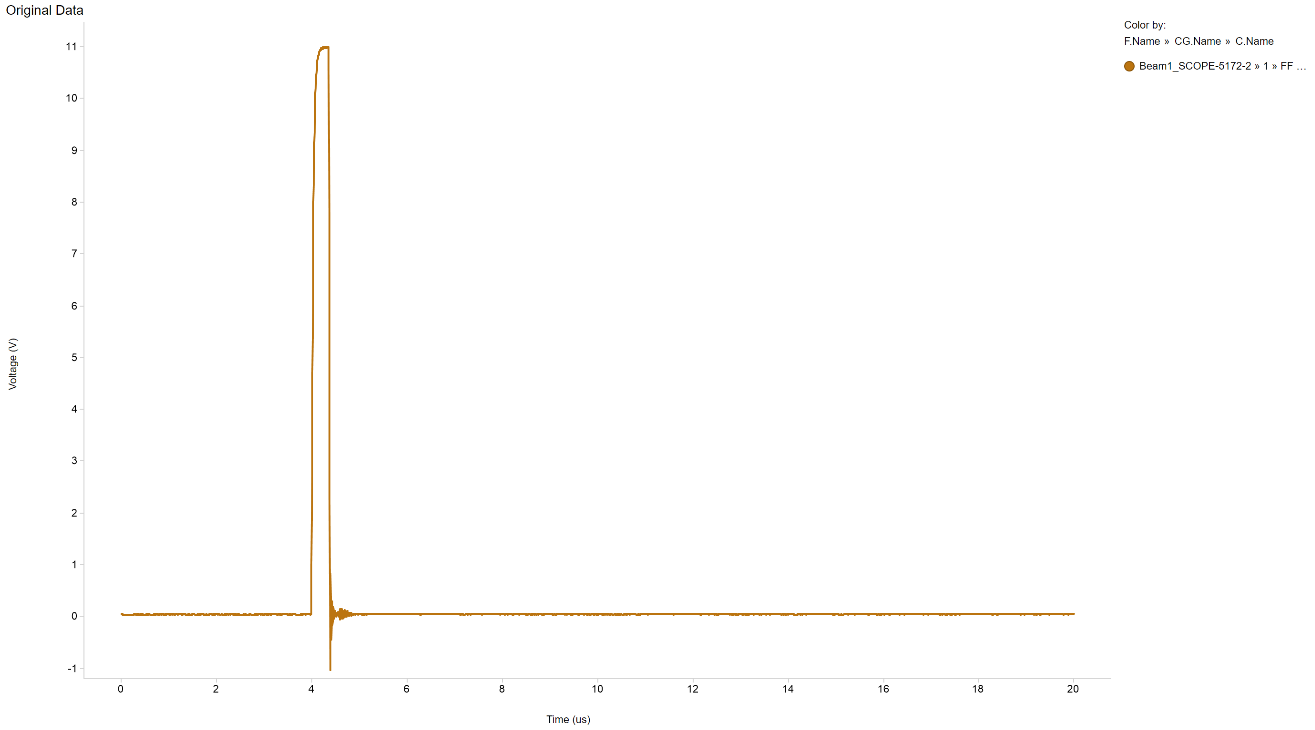

Figure 5-9. Worst Case Transient Plot [Run #19 - FF Pin]

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

Table 5-4. Upper Bound Cross Section at 95% Confidence Interval

SET Type	ION	Bias Scheme	# UPSETS	UPPER BOUND CROSS SECTION (cm^2/device)
$VOUT_{SET}$ ≥ 10%	Ag	2	14	2.349E-05
$VOUT_{SET}$ ≥ 10%	Ag	3	32	4.517E-05
$VOUT_{SET}$ ≥ 10%	Kr	1	19	2.967E-05
$VOUT_{SET}$ ≥ 10%	Kr	2	12	2.096E-05
$VOUT_{SET}$ ≥ 10%	Kr	3	28	4.047E-05
$VOUT_{SET}$ ≥ 10%	Ar	1	9	1.708E-05
$VOUT_{SET}$ ≥ 10%	Ar	2	12	2.096E-05
$VOUT_{SET}$ ≥ 10%	Ar	3	10	1.839E-05

* Due to the inaccurate probe on Bias #1 at the Silver (Ag) level, the cross section is not considered

6 Summary

The purpose of this study was to characterize the effects of heavy-ion irradiation on the single-event latch-up (SEL) performance and single-event transients (SET) performance of the TMUX582F-SEP, latch-up immune 8:1 multiplexer with adjustable fault thresholds. Heavy-ions with an LET_{EFF} of $43MeV\text{-}cm^2/$ mg were used for the SEE characterization. The SEE results demonstrated that the TMUX582F-SEP is SEL-free up to LET_{EFF} = $43MeV \times cm^2$ / mg and across the full electrical specifications. Transients at LET_{EFF} = $43MeV \times cm^2$ / mg on VOUT are presented and discussed. CREME96-based worst-week event-rate calculations for LEO (ISS) and GEO orbits for the DSEE are presented for reference.

7 References

1. M. Shoga and D. Binder, "Theory of Single-Event Latchup in Complementary Metal-Oxide Semiconductor Integrated Circuits", *IEEE Trans. Nucl. Sci., Vol. 33(6)*, Dec. 1986, pp. 1714-1717.
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8 Revision History

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

Changes from Revision * (August 2024) to Revision A (October 2024)	Page
• Updated SEL section to reflect the current device specifications	10
• Added SET data taken from the TMUX582F-SEP device	14

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