Radiation Report

DRV8351-SEP Single-Event Effects (SEE) Report

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the DRV8351-SEP. Heavy-ions with LET_{EFF} of 20.3, 30.1, 43.1 and 47.2MeV × cm^2 / mg, was used to irradiate four production devices. Flux of approximately 10^5 ions / cm^2 × s and fluence of approximately 10^7 ions / cm^2 per run were used for the characterization. The results demonstrate the performance of the DRV8351-SEP under SEL and SEB conditions at T = 125°C and T = 25°C, respectively. SET transients performance for output pulse width excursions ≥ |10%| from the nominal width and positive and negative edge transients on GHx,GLx, and SHx are presented and discussed.

Table of Contents

List of Figures

List of Tables

Trademarks

LabVIEW™ is a trademark of National Instruments, Inc.
HP-Z4® is a registered trademark of HP Inc.
All trademarks are the property of their respective owners.

1 Introduction

The DRV8351-SEP is a radiation-hardness-assured (RHA) 40V three half-bridge gate drivers, capable of driving high-side and low-side N-channel power MOSFETs. The DRV8351-SEP generates the correct gate drive voltages using an integrated bootstrap diode and external capacitor for the highside MOSFETs. GVDD is used to generate gate drive voltage for the low-side MOSFETs. The Gate Drive architecture supports peak up to 750mA source and 1.5A sink currents. The driver features:

- Absolute Maximum Voltage ratings
  - PVDD = 40V
  - GVDD = 15V
- Approximately 125ns propagation delay
- Approximately 4.0ns high-side and low-side matching
- 3x and 6x PWM Mode
  - 3x PWM allows for outputs to be controlled by dedicated input
  - PWM allows for two complementary outputs signals to be generated from single input
  - 6x PWM requires all INH and INL inputs to be supplied

3x PWM mode the user also has the ability to enable or disable the turn-on of both outputs when both inputs are on simultaneously (interlock protection). This gives the driver the ability to be used in multiple converter configurations.

The device is offered in a 20-pin plastic package. General device information and test conditions are listed in Table 1-1. For more detailed technical specifications, user guides, and application notes, see theDRV8351-SEP product pages.

Table 1-1. Overview Information

Description(1)	Device Information
TI part number	DRV8351-SEP
Orderable number	DRV8351DMPWTSEP, DRV8351DIMPWTSEP
Device function	40V Three Phase Half-Bridge Gate driver
Technology	LBC9 (Linear BiCMOS 9)
Exposure facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV / nucleon)
Heavy ion fluence per run	$1.0 \times 10^6 – 1.5 \times 10^7$ ions / cm^2
Irradiation temperature	25°C (for SEB), 25°C (for SET testing), and 125°C (for SEL testing)

(1) TI may provide technical, applications or design advice, quality characterization, and reliability data or service, providing these items shall not expand or otherwise affect TI's warranties as set forth in the Texas Instruments Incorporated Standard Terms and Conditions of Sale for Semiconductor Products and no obligation or liability shall arise from Semiconductor Products and no obligation or liability shall arise from TI's provision of such items.

2 Single-Event Effects (SEE)

SEE testing was performed on an evaluation board designed for testing the DRV8351-SEP under heavy-ion radiation. The board was powered up in different input and output conditions at Texas A&M University to cover the spectrum of destructive SEE (DSEE) and Single-Event Transients (SET). The devices were tested at the TAMU Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. DSEE testing included Single-Event Latch-up (SEL) and Single-Event Burnout (SEB).

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). 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 DRV8351-SEP was tested for SEL at the maximum recommended input voltage PVDD of 40V and the maximum recommended GVDD of 15V. 3X PWM mode was used here so only one input was needed to switch all three phases.

- PWM:
  - 0V - 5V square wave switching at 20kHz, 40kHz, 60kHz, 80kHz, 100kHz(SEL)
- PWM Modes:
  - Case 1- INH = 0V, INL = 5V (Static SEB_{ON})
  - Case 2-INH/INL square wave switching 0V - 5V at 20-100kHz offset by 180° (Switching SEB_{ON})

TheDRV8351-SEP was characterized for SET with LET_{EFF} = 20 to 47.2MeV × cm^2 / mg at flux of approximately 10^5 ions / cm^2 × s, fluence of approximately 10^7 ions / cm^2, and a die temperature of 25°C. For SET the device operated at nominal operating conditions with a PVDD of 42.5V and GVDD of 15V.

The specific test conditions for the devices for SET are as follows:

GVDD = 10 - 15V, PVDD = 20 - 40V , INH/INL square wave switching 0V - 5V at 20-100kHz offset by 180°. All INLx and INHx were tied together, thus switching all outputs at the same time . During testing, the DRV8351-SEP did exhibit a shoot through event across all LET levels. For further explanation see SET section. To see the SET results of the DRV8351-SEP, see Single-Event Transients (SET).

3 Device and Test Board Information

The DRV8351-SEP is packaged in a 20-pin plastic package as shown in Figure 3-1. A DRV8351-SEP evaluation board made specifically for radiation testing was used to evaluate the performance and characteristics of the DRV8351-SEP under heavy ion radiation. The DRV8351-SEP evaluation board is shown in Figure 3-1. The board schematic is shown in Figure 3-3. Red X represents not populated

The package was delidded to reveal the die face for all heavy-ion testing.

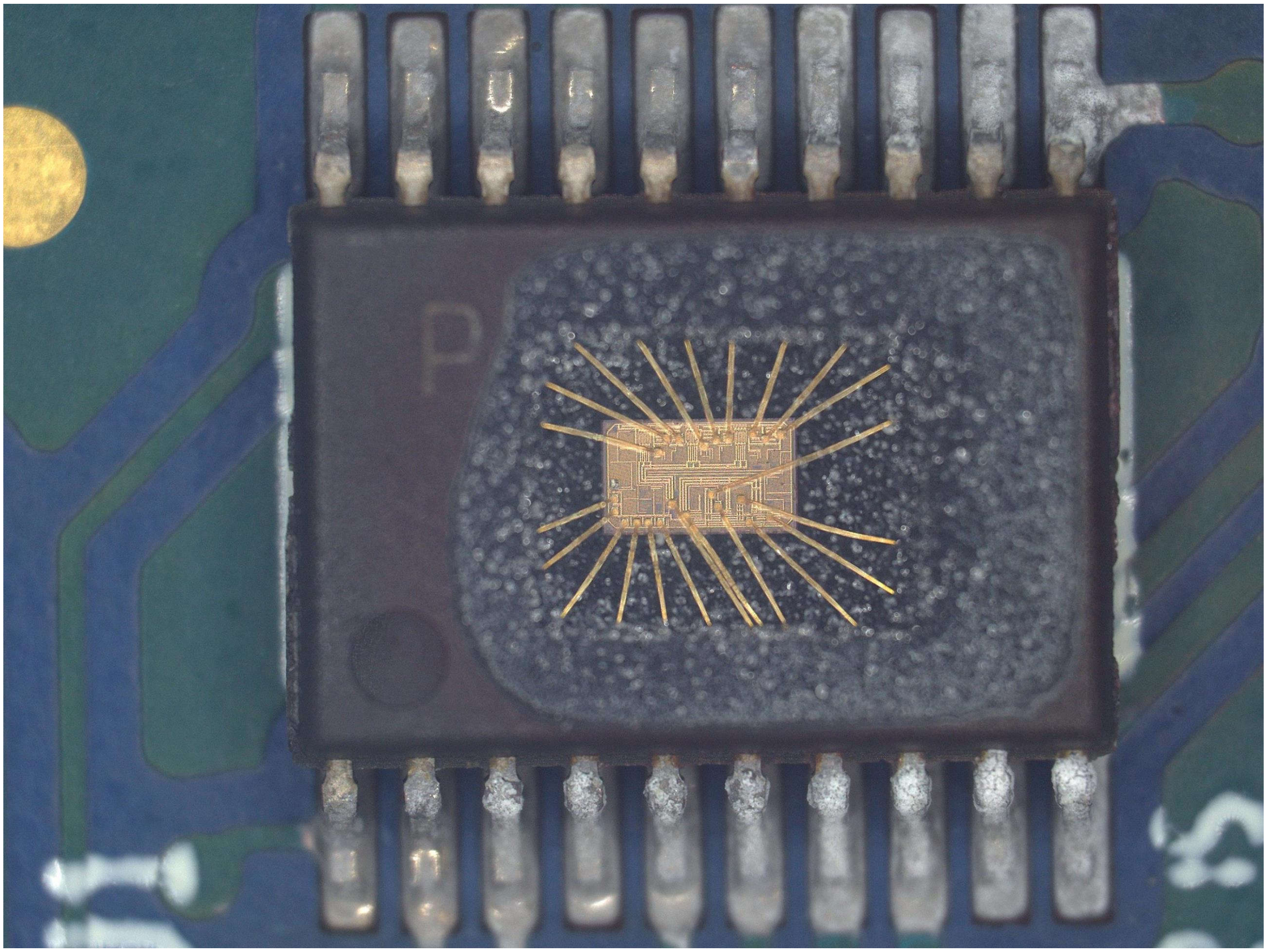

Figure 3-1. Photograph of Delidded DRV8351-SEP

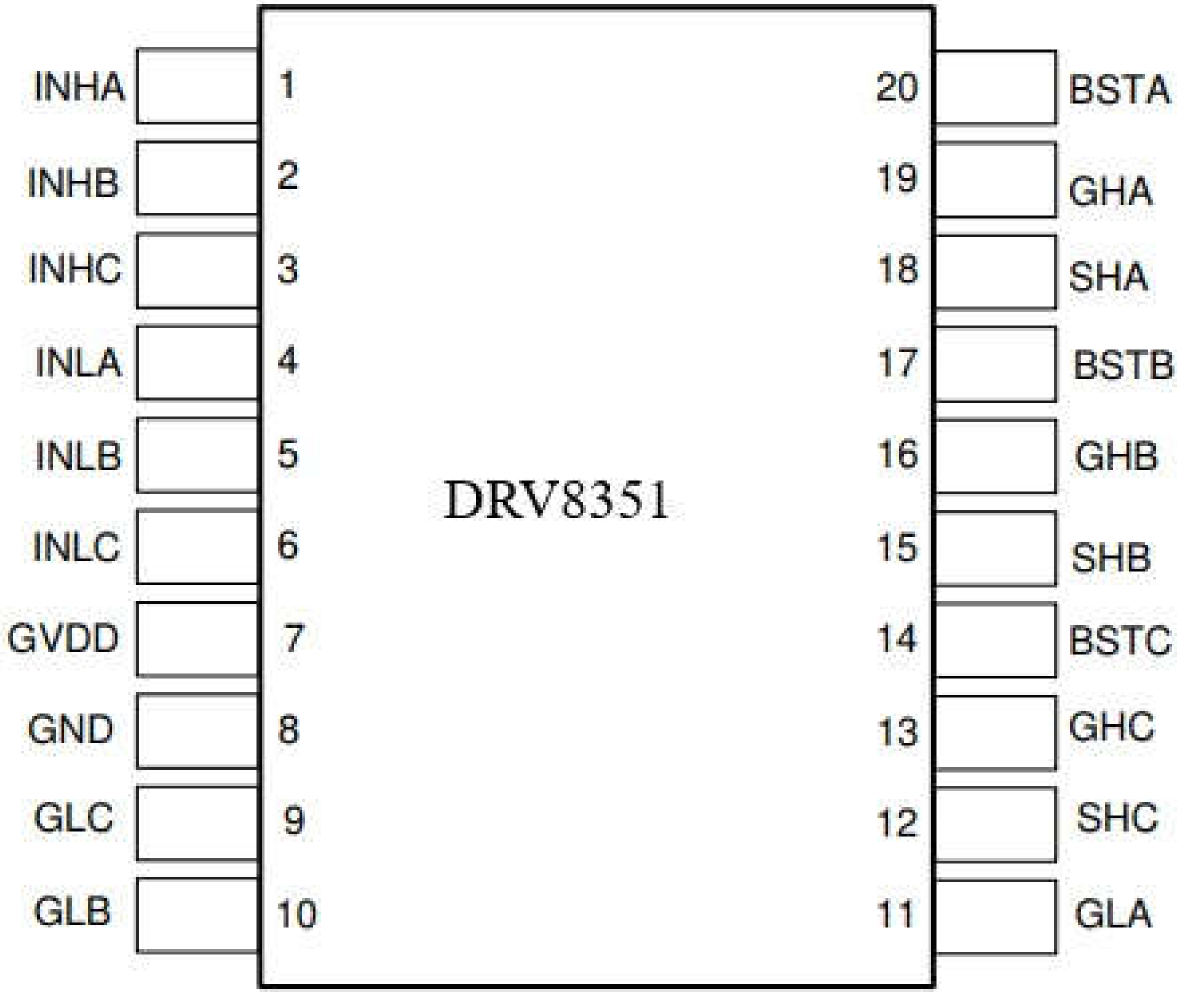

Figure 3-2. Pinout Diagram

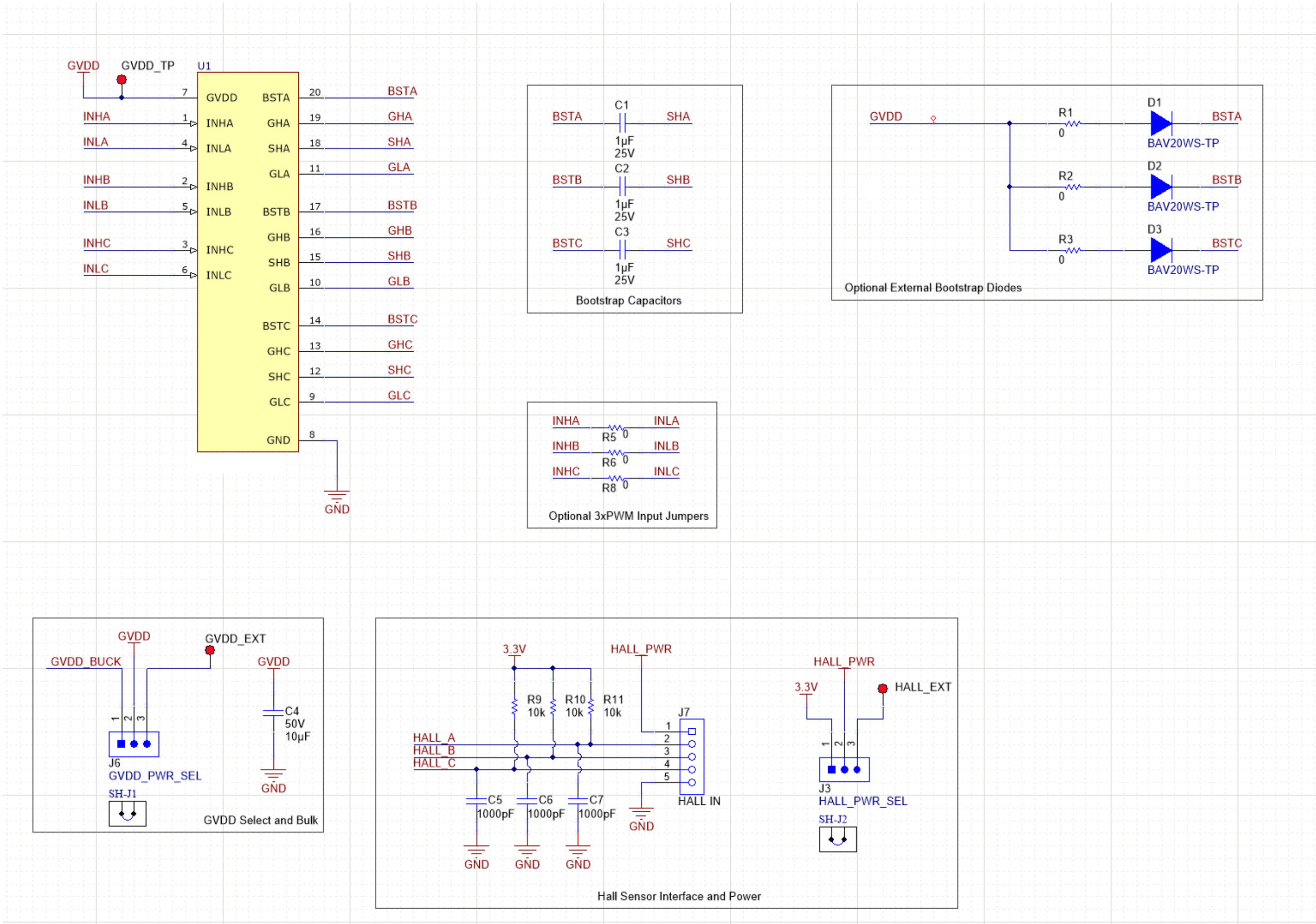

Figure 3-3. DRV8351-SEP Evaluation Board Schematics - Device

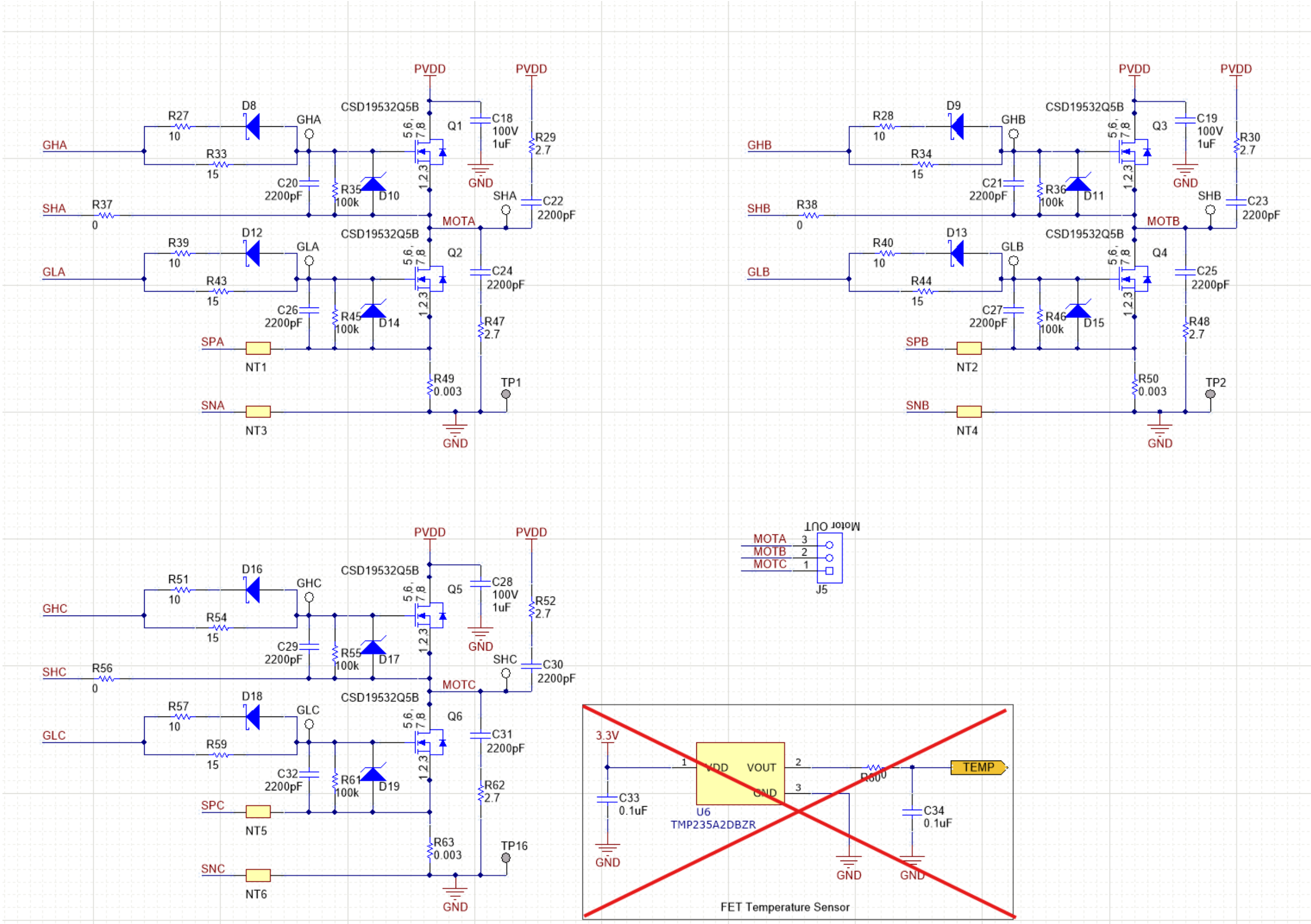

Figure 3-4. DRV8351-SEP Evaluation Board Schematics - Power Stage

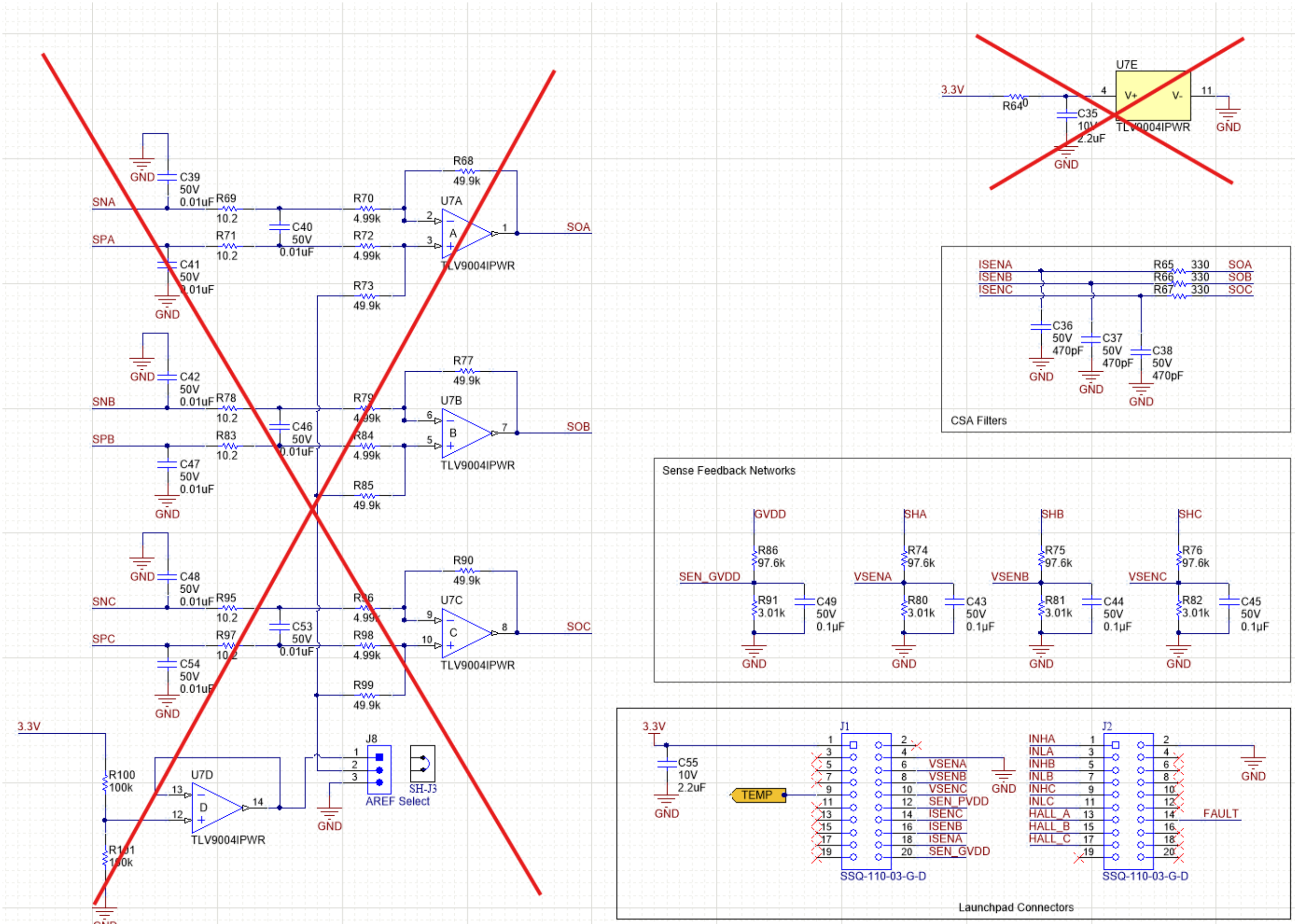

Figure 3-5. DRV8351-SEP Evaluation Board Schematics - Sense Feedback/USB2ANY

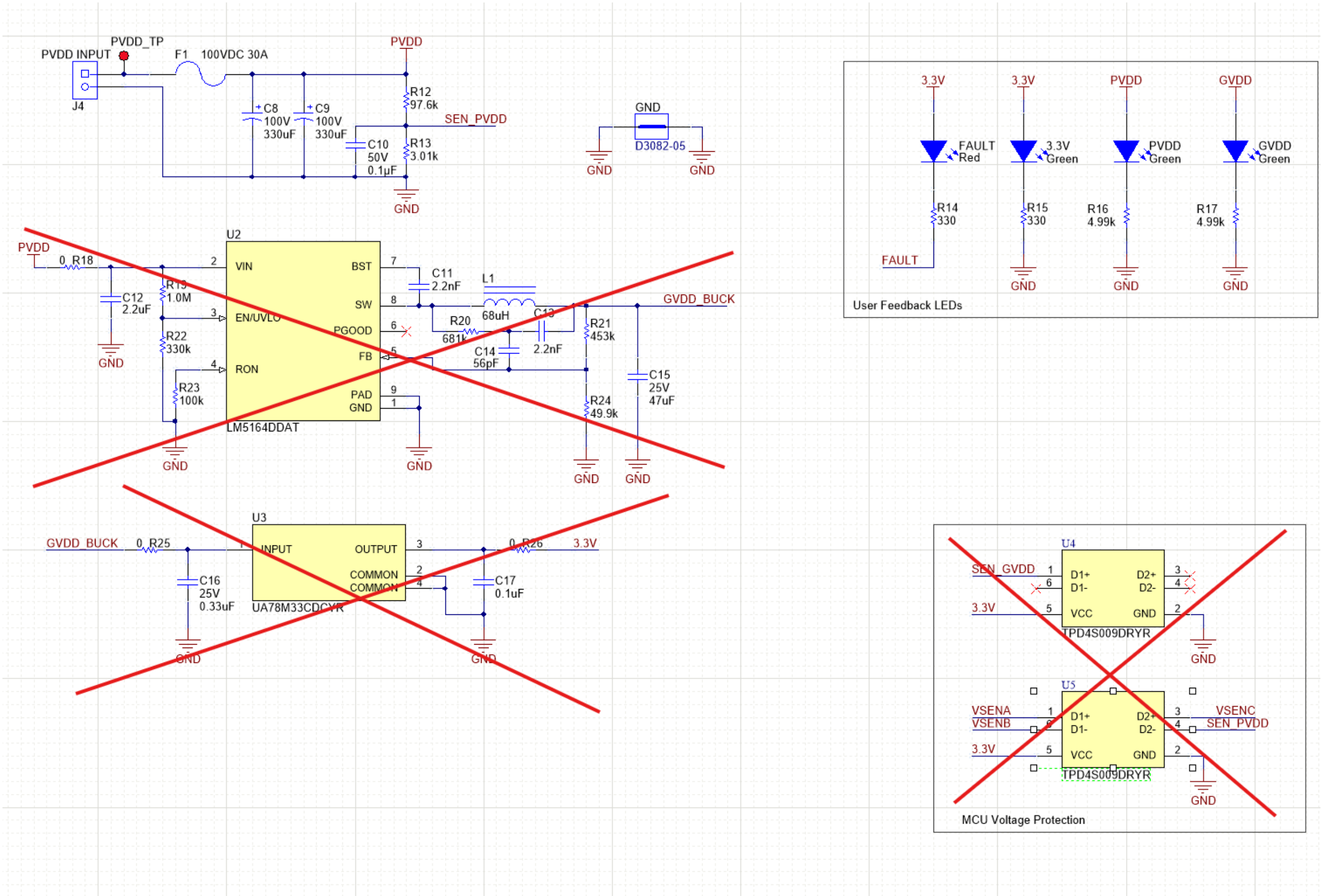

Figure 3-6. DRV8351-SEP Evaluation Board Schematics - Input Power

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 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 1.02×10^4 to 1.12×10^5 ions / $cm^2 \times s$ were used to provide heavy-ion fluences of 9.97×10^6 to 1.00×10^7 ions / cm^2.

For the experiments conducted on this report, there were three ions used, ^{109}Ag, ^{84}Kr, and ^{63}Cu. ^{109}Ag was used to obtain LET_{EFF} of 43 and 48MeV × cm^2 / mg. ^{84}Kr was used to obtain LET_{EFF} of 30.6MeV × cm^2 / mg. ^{63}Cu was used to obtain LET_{EFF} of 20.3MeV × cm^2 / mg. The total kinetic energies for each of the ions were:

- ^{109}Ag = 1.634 GeV (15 MeV/nucleon)
- ^{84}Kr = 1.259GeV (15MeV / nucleon
- ^{63}Cu = 0.944GeV (15MeV / nucleon)

Figure 4-1 shows the DRV8351-SEP Evaluation Board used for the data collection 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. The in-air gap between the device and the ion beam port window was maintained between 10 - 40mm for all runs to achieve different effective LETs.

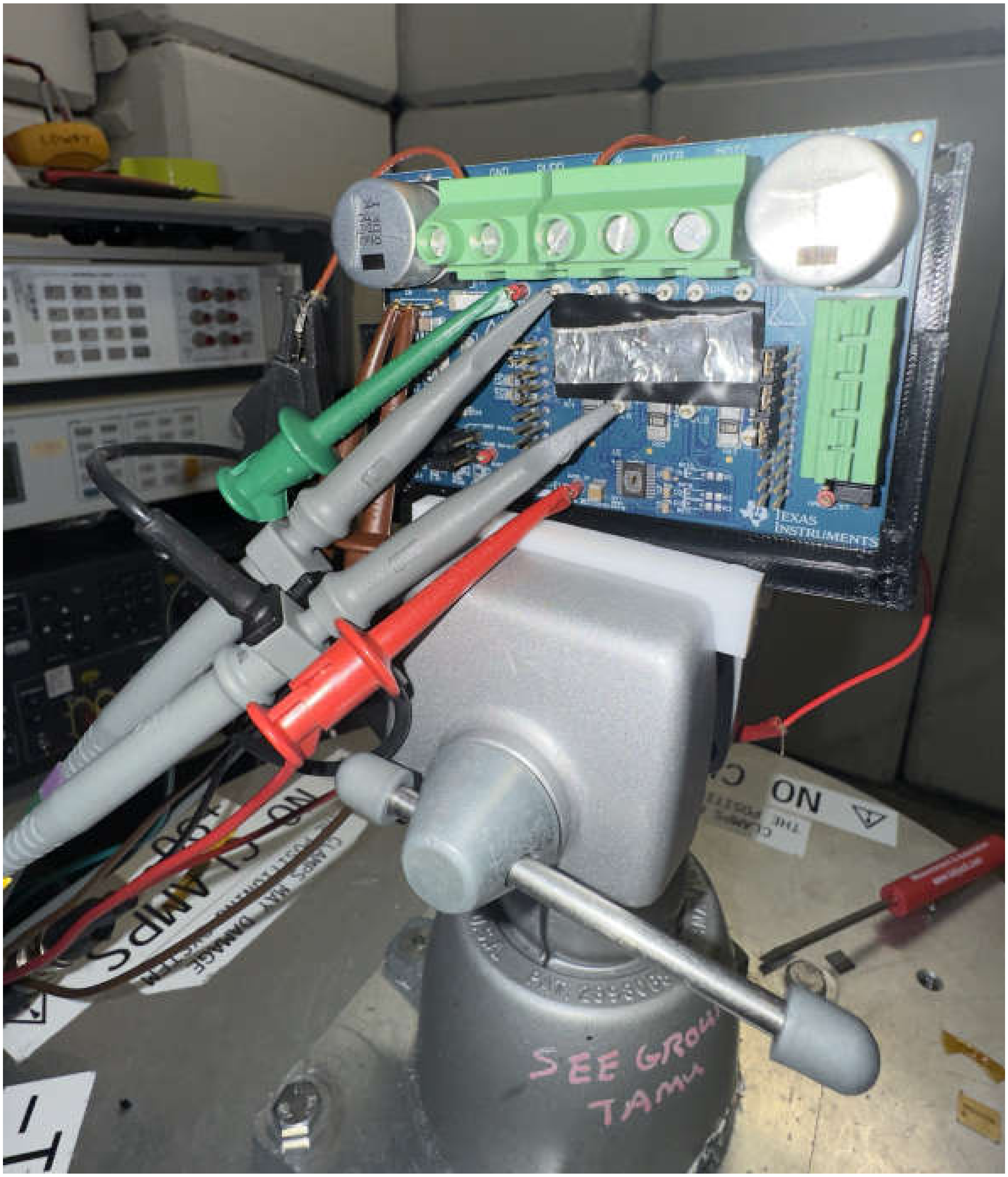

Figure 4-1. Evaluation Board in Front of the Heavy-Ion Beam Exit Port

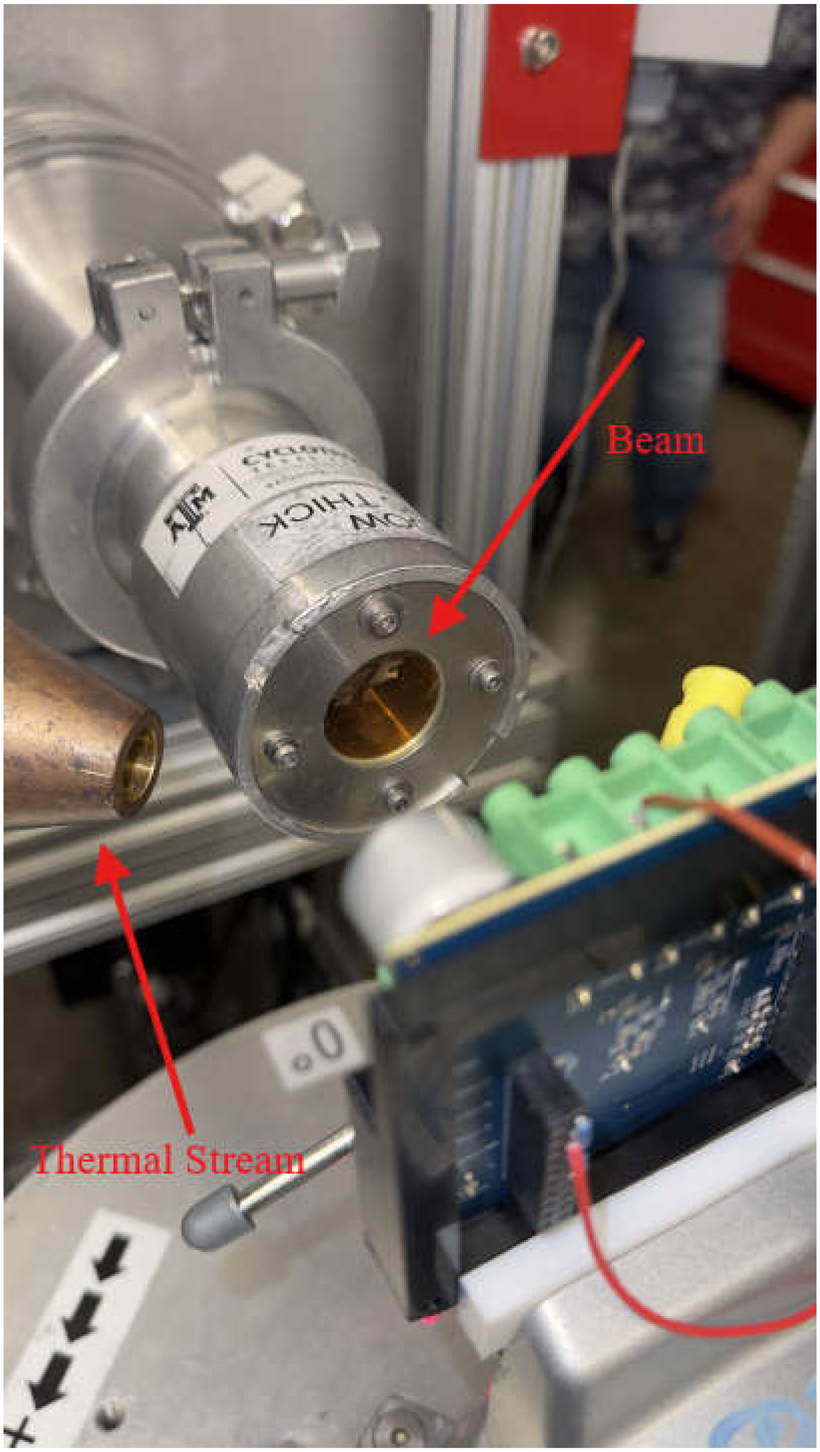

Figure 4-2. Output of Beam

5 Depth, Range, and LET$_{EFF}$ Calculation

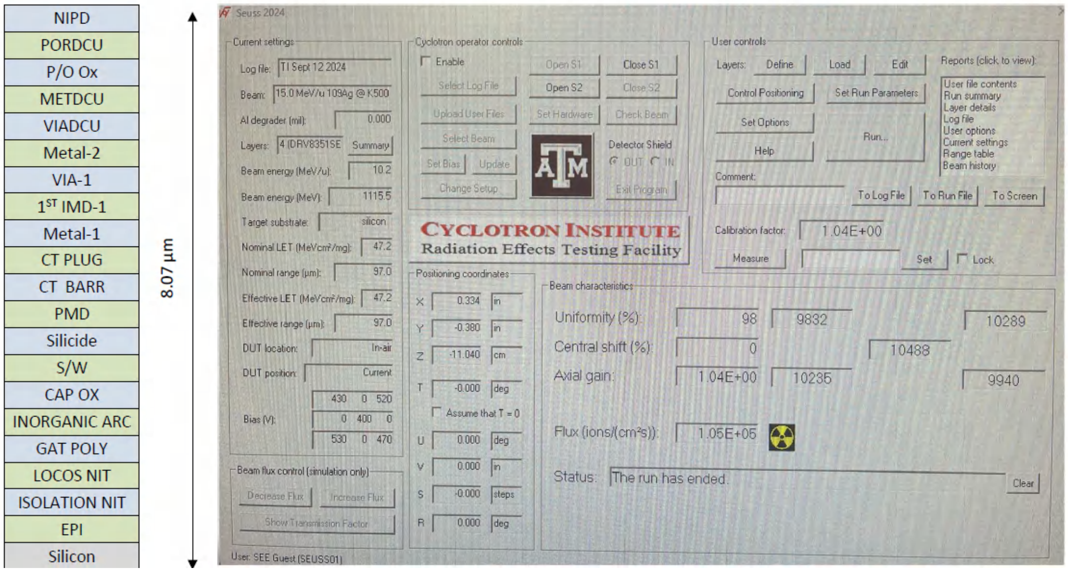

Figure 5-1. Generalized Cross-Section Stack on the DRV8351-SEP and Application Used to Determine Ion Parameters

The DRV8351-SEP is fabricated in the TI LBC9 process with 2LM + METDCU back-end-of-line (BEOL) stack. The total stack height from the surface of the passivation to the silicon surface is 8.07µm based on nominal layer thickness as shown in Figure 5-1. Accounting for energy loss through the 1mil thick Aramica beam port window, the 40mm air gap, and the BEOL stack over the DRV8351-SEP, the effective LET (LET$_{EFF}$) at the surface of the silicon substrate and the depth was determined with the SEUSS 2020 Software (provided by the Texas A&M Cyclotron Institute and based on the latest SRIM-2013 [7] models). The results are shown in Ion LET$_{EFF}$, Depth, and Range in Silicon.

Table 5-1. Ion LET$_{EFF}$, Depth, and Range in Silicon

Ion Type	Beam Energy (MeV / nucleon)	Angle of Incidence	Degrader Steps (Number)	Degrader Angle	LET$_{EFF}$ (MeV × cm^2/ mg)
^{109}Ag	15	0	0	0	48
^{109}Ag	15	0	0	0	43
^{84}Kr	15	0	0	0	30.6
^{63}Cu	15	0	0	0	20.2

6 Test Setup and Procedures

There were three input supplies used to power the DRV8351-SEP which provided PVDD, GVDD, INH/INL. The PVDD for the device was provided through channel 1of an NI PXIe 4137-1 and ranged from 10V to 15V for SET. The GVDD for the device was provided by Channel 2 of an NI PXIe 4137-2 and ranged from 10V to 40V SET. INH/INL were provided by a National Instruments NI PXIe-5433 2-channel AWG.

The primary signals monitored on the EVM were GH, GL and SH. This was done so using two instruments. The first was a NI PXIe-5110 which triggered (based on SH), pulse-width at 10% outside width. The second instrument was a NI PXIe-5172 oscilloscope which triggered from a window on GL, when GL went below or above it's expected switching voltage by 3V. This card was also monitoring GH and SH.

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 MXI controller and NI PXIe-8381 remote control module.

Table 6-1 lists 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 DRV8351-SEP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the DRV8351-SEP

Pin Name	Equipment Used	Capability	Compliance	Range of Values Used
PVDD	PXIe-4137	200V, 1A	0.4A	10V to 40V
GVDD	PXIe-4137	200V, 1A	0.4A	10V to 15V
SHx	PXIe-5110	100MS / s	—	20MS / s
INHx/INLx	PXIe-5433 (CH # 0&1)	$24V_{PK-PK}$, 80MHz	—	0V to 5V, 20kHz to 200kHz
GLx/GHx/SHx	PXIe-5172-4	250MS/s	---	20MS / s

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to verify 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 DRV8351-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, the NI scope cards continuously monitored the signals. When the output exceeded the pre-defined 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 or SEB/SEGR events occurred during any of the tests.

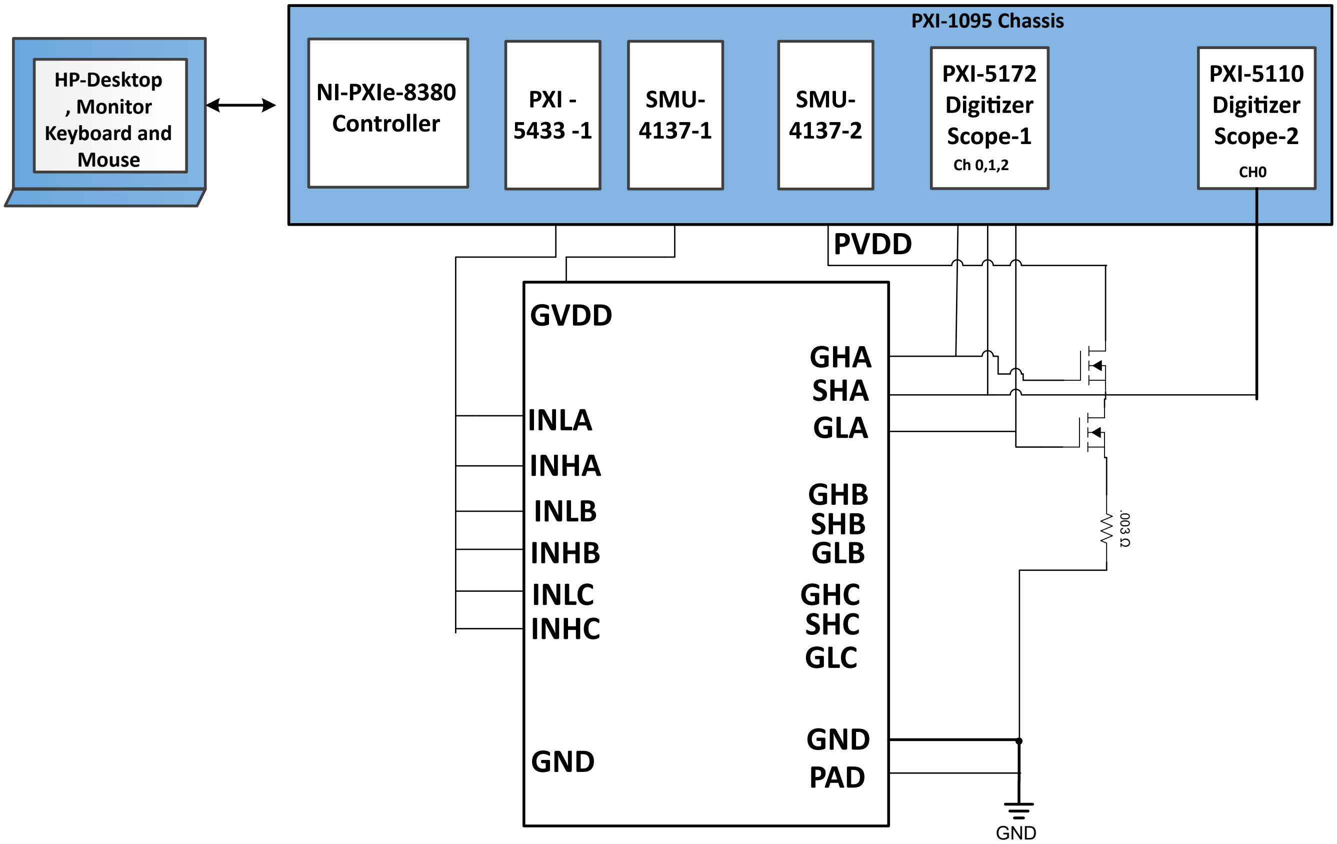

Figure 6-1. Block Diagram of the SEE Test Setup for the DRV8351-SEP

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 verified using thermal camera prior to exposure to heavy ions.

The species used for the SEL testing was Silver (^{109}Ag at 15MeV / nucleon). For the ^{109}Ag ion an angle of incidence of 0° was used to achieve an LET_{EFF} = 47.2MeV × cm^2 / mg (for more details, see Ion LET_{EFF}, Depth, and Range in Silicon). The kinetic energy in the vacuum for Silver is 1.634 GeV. Flux of approximately 10^5 ions / cm^2× s and a fluence of approximately 10^7 - 10.5^7 ions / cm^2 per run was used. Run duration to achieve this fluence was approximately 100 seconds. No SEL events were observed on GVDD on any run. PVDD hits the current clamp of 400mA under certain conditions, specifically when we took frequency above 150kHz. The spikes in current show in the graphs below always seemed to recover back to nominal current draw assuming frequency was under 125kHz. Table 7-1 shows the SEL test conditions and results.

Table 7-1. Summary of DRV8351-SEP SEL Test Condition and Results

Device	Board Number	Run Number	Ion	LET_{EFF} (MeV × cm^2 / mg)	Flux (ions × cm^2 / mg)	Fluence (Number of ions)	Frequency	Phase	GVDD	PVDD	GVDD Pre Beam_Current (mA)	GVDD Post Beam_Current (mA)	PVDD Pre Beam_Current (mA)	PVDD PostBeam_Current (mA)
DRV8351-SEP	11	23	^{109}Ag	47.2	1.01E5	1E7	20kHz	A	15	42.5	12.13	11.92	16.37	16.44
DRV8351-SEP	10	20	^{109}Ag	47.2	7.8E4	1E7	20kHz	B	15	42.5	12.22	12.81	15.81	15.94
DRV8351-SEP	13	29	^{109}Ag	47.2	1.07E5	1E7	20kHz	C	15	42.5	11.74	12.32	15.2	15.54
DRV8351-SEP	1	2	^{109}Ag	47.2	1.12E5	1E7	125kHz	A	15	42.5	66.35	66.45	88.86	88.81
DRV8351-SEP	2	7	^{109}Ag	47.2	1.17E5	1.5E7	125kHz	B	15	42.5	63.09	63.07	86.04	86.01
DRV8351-SEP	13	30	^{109}Ag	47.2	1.07E7	1E7	125kHz	C	15	42.5	63.35	63.31	86.98	86.91

Using the MFTF method shown in *Single-Event Effects (SEE) Confidence Interval Calculations* and combining (or summing) the fluences of the four runs at 125°C (4 × 10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{SEL} \leq 5.68 \, x \, 10^{-8} \, cm^2/device \, for \, LET_{EFF} = 48 \, MeV \cdot cm^2/mg \, and \, T = 125°C \quad (1)$$

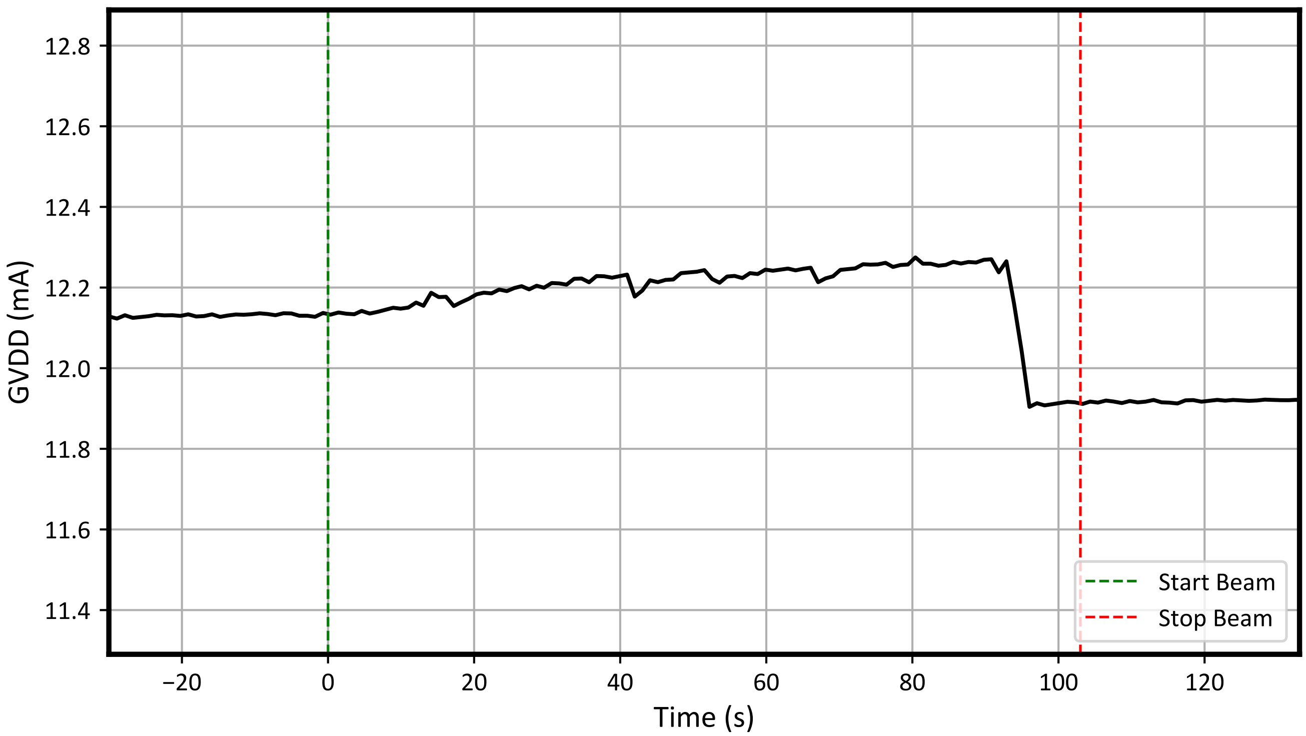

Figure 7-1. SEL Run 23 (f_{sw} = 20kHz) - GVDD

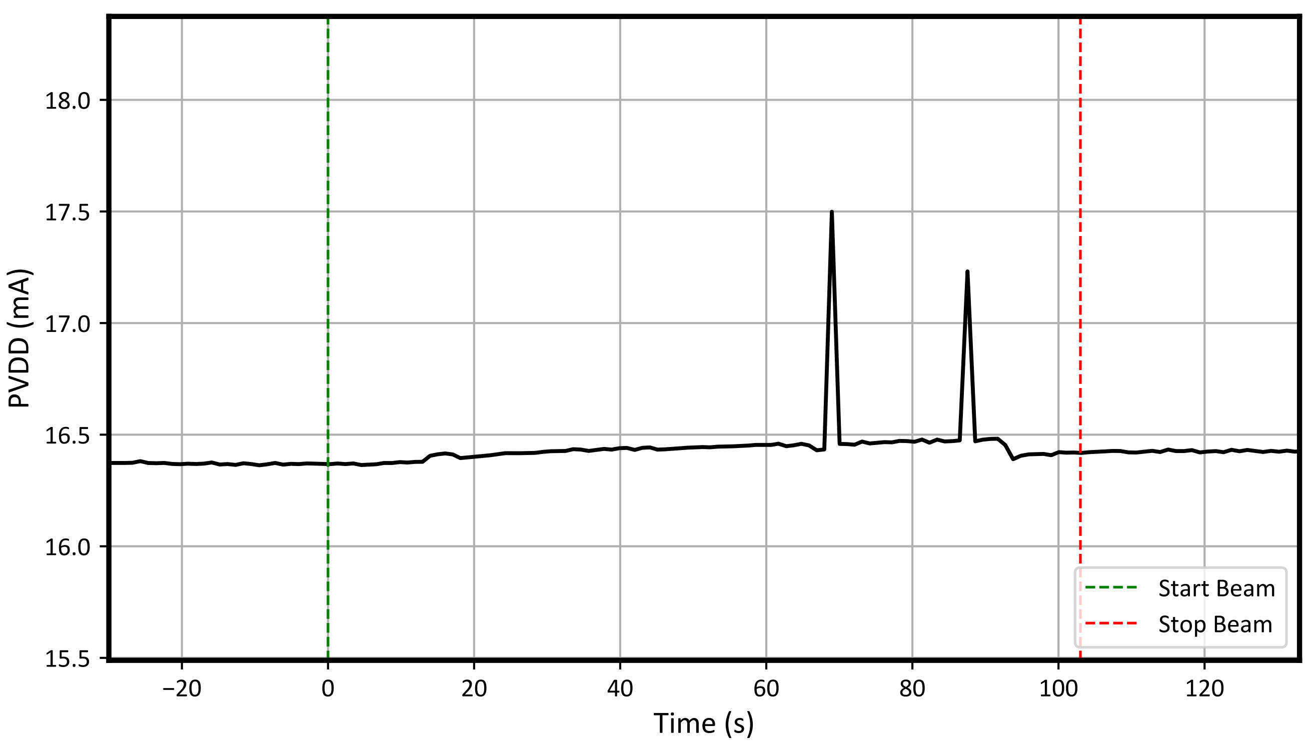

Figure 7-2. SEL Run 23 (f_{sw} = 20kHz) - PVDD

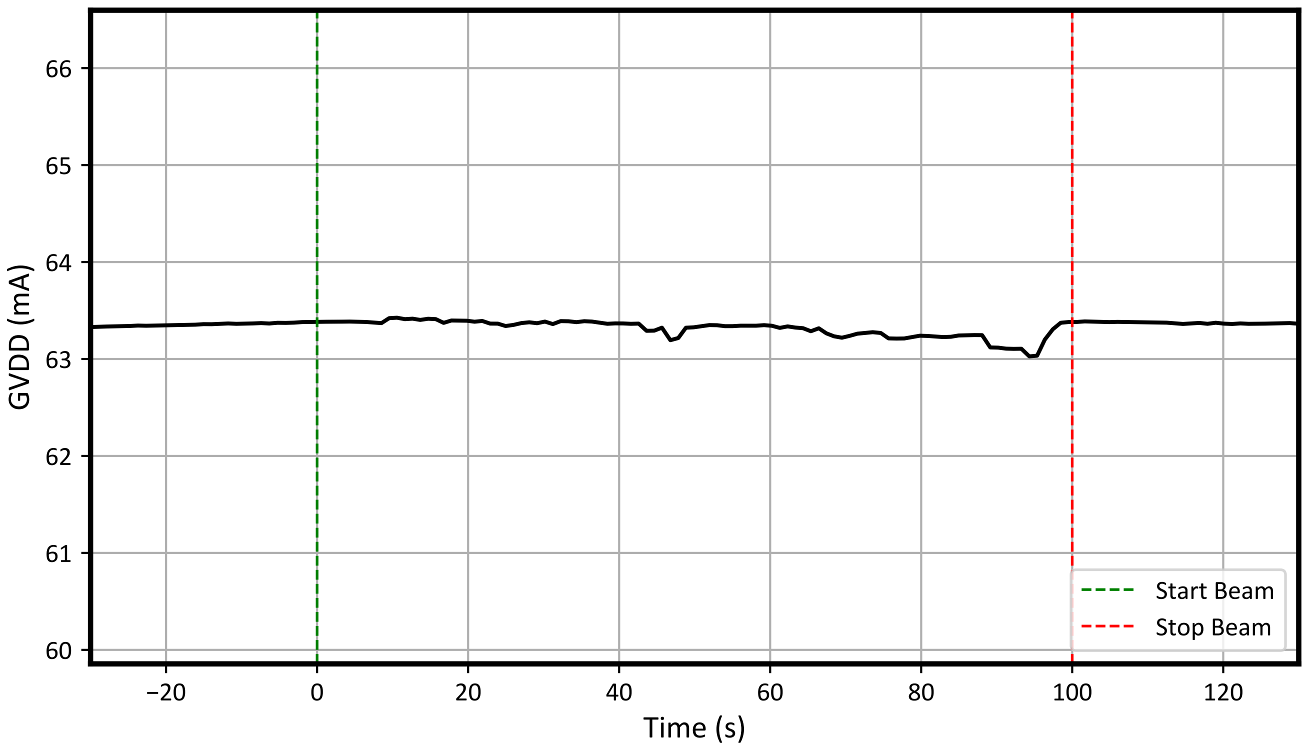

Figure 7-3. SEL Run 30(f_{sw} = 125kHz) - GVDD

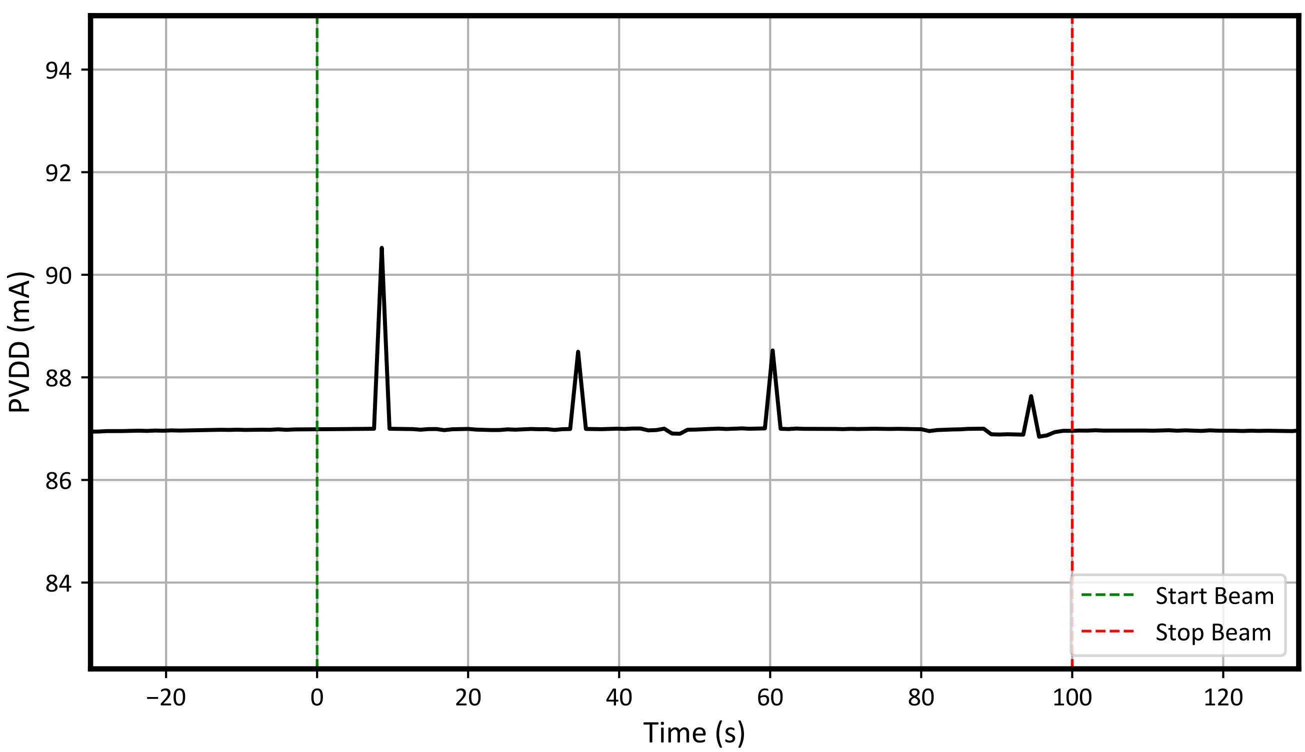

Figure 7-4. SEL Run 30(f_{sw} = 125kHz) - PVDD

7.2 Single-Event Burnout (SEB)

During the SEB characterization, the device was tested at room temperature of approximately 25°C. The device was tested with INL = 5V and INH = 0V. For the SEB-OFF mode the the device did exhibit some cross conduction, as well as GL dropping to zero volts and then recovering.

The species used for the SEB testing was Silver (^{109}Ag at 15MeV / nucleon). For the ^{109}Ag ion an angle of incidence of 0° was used to achieve an LET_{EFF} = 47.2MeV × cm^2 / mg (for more details, see Ion LET_{EFF}, Depth, and Range in Silicon). The kinetic energy in the vacuum for this ion is 1.634 GeV (15-MeV / amu line). Flux of approximately 10^5 ions / cm^2 × s and a fluence of approximately 10^7 ions / cm^2 was used for the run. Run duration to achieve this fluence was approximately 100 seconds. The DRV8351-SEP was powered with PVDD = 40V, GVDD = 15V. The inputs were biased such that the low side inputs were held at 5V while the high side inputs were tied to ground, this maintained that the bootstrap capacitor were charged. The goal was to look for transients on either GH or GL for unexpected behavior. It was observed that we had cross conduction events similar to our SET results. Additionally it was seen that the low side GL would drop down to ~2V then recovering back to nominal value.Summary of DRV8351-SEP SEB Test Condition and Results shows the SEB/SEGR test conditions and results.

Table 7-2. Summary of DRV8351-SEP SEB Test Condition and Results

Device	Board Number	Run Number	Ion	LET_{EFF} (MeV × cm^2 / mg)	Flux (ions × cm^2/ mg)	Fluence (number of ions)	Input Bias	Phase	GVDD	PVDD	Number of Transients GL	Number of Transients GH
DRV8351-SEP	7	12	^{109}Ag	47.2	1.04E5	1E7	INLx = 5V | INHx = 0V	A	15	42.5	127	97
DRV8351-SEP	8	14	^{109}Ag	47.2	1.02E5	9.95E6	INLx = 5V | INHx = 0V	B	15	42.5	30	117
DRV8351-SEP	9	16	^{109}Ag	47.2	1.04E5	1.04E5	INLx = 5V | INHx = 0V	C	15	42.5	38	93

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations*, the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{SEB} \leq 1.23 \, x \, 10^{-7} \, cm^2/device \; for \; LET_{EFF} = 48 \, MeV \cdot cm^2/mg \; and \; T = 25°C \quad (2)$$

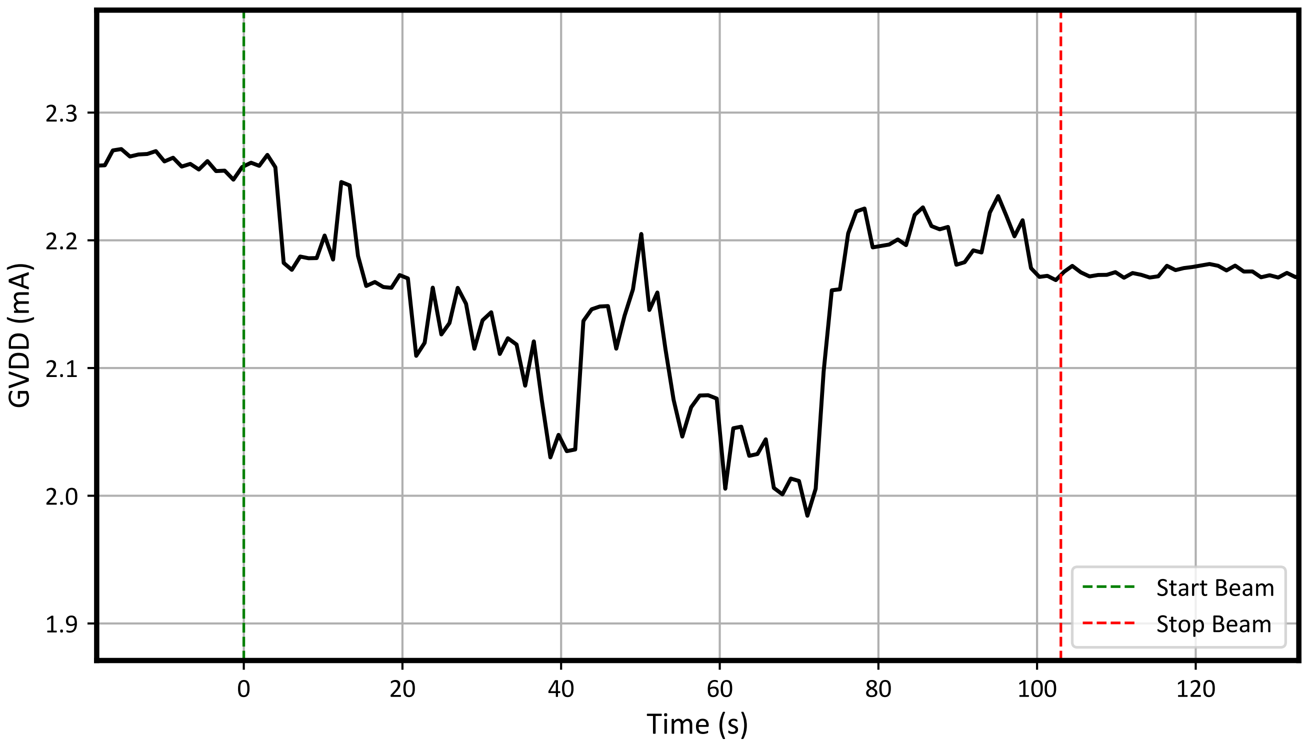

Figure 7-5. SEB on Run 14 (INH = 0V, INL = 5V) | GVDD

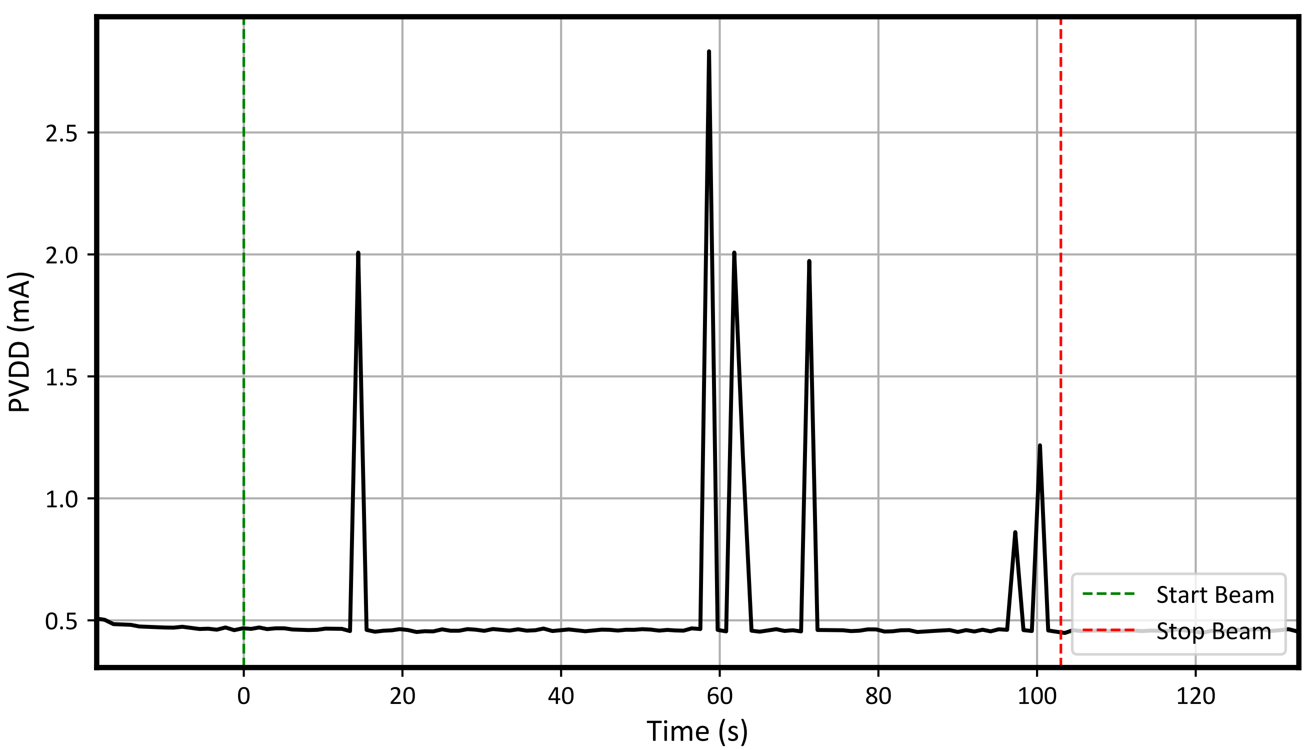

Figure 7-6. SEB on Run 14 (INH = 0V, INL = 5V) | PVDD

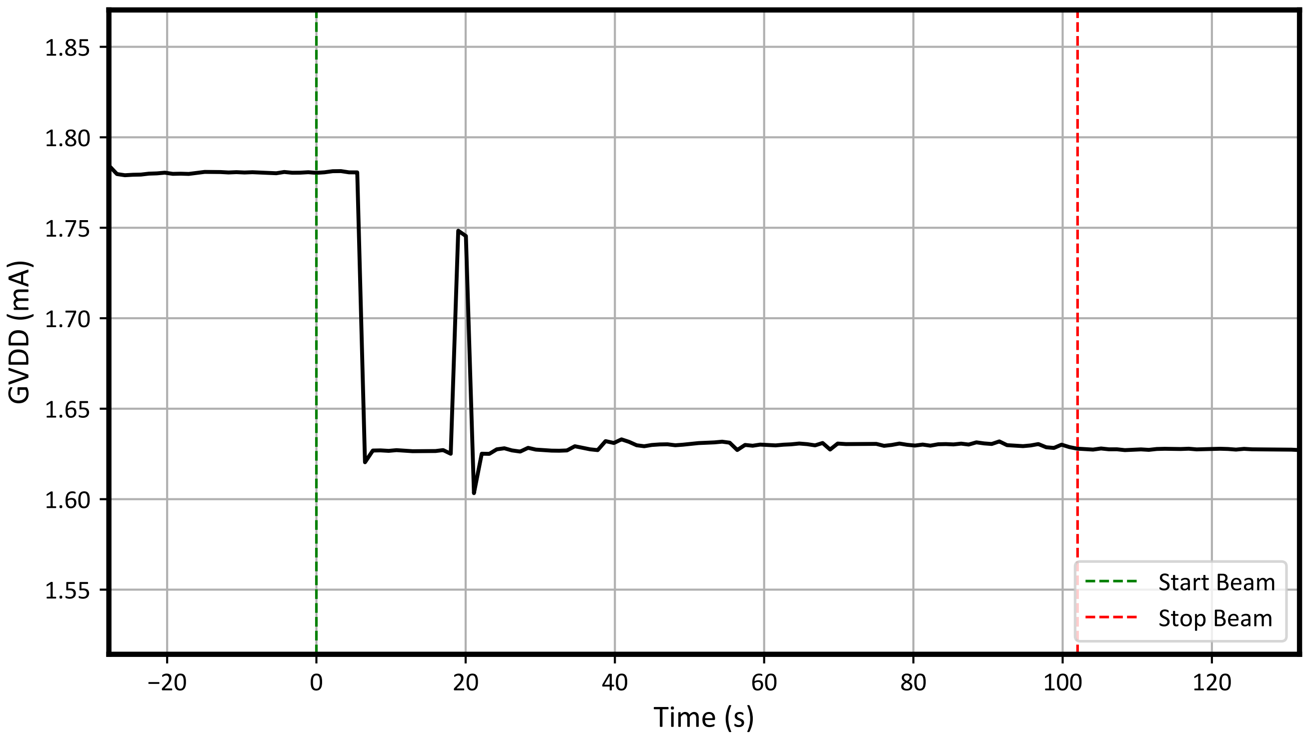

Figure 7-7. SEB On Run 12 (INH = 0V, INL = 5V) | GVDD

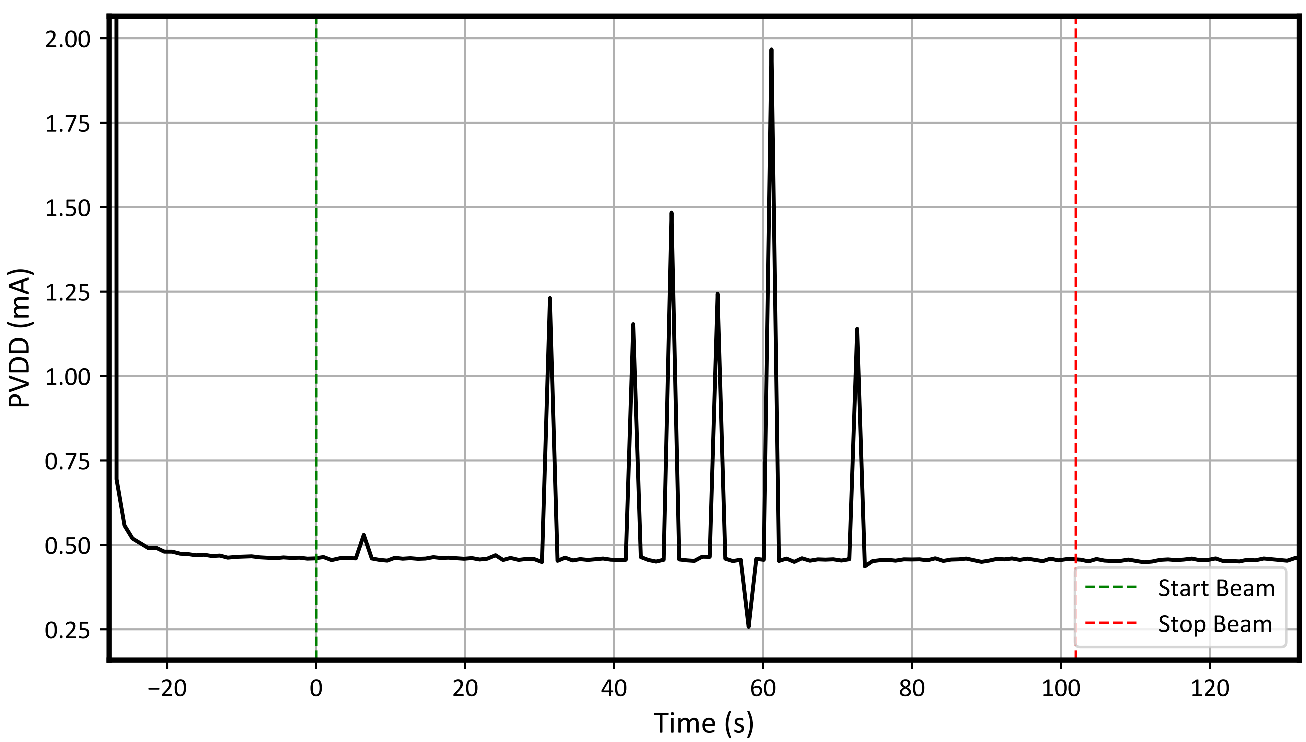

Figure 7-8. SEB On Run 12 (INH = 0V, INL = 5V) | PVDD

8 Single-Event Transients (SET)

The primary focus of SETs were heavy-ion-induced transient upsets on the output signals GH,GL, and SH. SET testing was done at room temperature across three ion species, ^{109}Ag, ^{84}Kr , and ^{63}Cu which produced a range of LET_{EFF} of 20.3 to 47.2MeV × cm^2 / mg for more details, see Ion LET_{EFF}, Depth, and Range in Silicon. GH, GL, and SH were monitored by a single scope, a NI PXIe-5172. Additionally a NI PXIe-5110 was monitoring SH. During PWM, the PXIe 5172 was configured to trigger based on an *outside* window width measurement. As for the PXIe 5110, the pulse width trigger for the output signal was 10%. The window for the 5172 was set to trigger on GL, if it went +/- 2V out of it's expected switching condition this would be counted as a trigger. As for the 5110, if the pulse width was +/- 10% off from the expected pulse width, this would be counted as a trigger.

Table 8-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
PXIe-5172	GL	Window	±2V	4000	20MS / s
PXIe-5110	SH	Pulse Width	± 10%	4000	20MS / s

Table 8-2. Summary of DRV8351-SEP SET Test Condition and Results

Device	Board Number	Run Number	Ion	LET_{EFF} (MeV × cm^2 / mg)	Flux (ions × cm^2/ mg)	Fluence (number of ions)	Frequency	Phase	GVDD	PVDD	Number of Transients GL	Number of Transients SH
DRV8351-SEP	7	10	Ag	47.2	1E5	1E7	20kHz	A	15	42.5	72	14
DRV8351-SEP	8	13	Ag	47.2	1E5	1E7	20kHz	B	15	42.5	22	65
DRV8351-SEP	9	15	Ag	47.2	1E5	1E7	20kHz	C	15	42.5	16	46
DRV8351-SEP	11	22	Ag	47.2	1.1E5	1E7	200kHz	A	15	42.5	51	50
DRV8351-SEP	10	18	Ag	47.2	8.4E4	1E7	200kHz	B	15	42.5	60	49
DRV8351-SEP	9	17	Ag	47.2	9.66E4	9.96E6	200kHz	C	15	42.5	161	69
DRV8351-SEP	4	11	Kr	30.6	9.76E4	1E7	20kHz	A	13	30	54	10
DRV8351-SEP	4	14	Kr	30.6	1.1E5	1E7	20kHz	A	10	20	145	90
DRV8351-SEP	4	16	Kr	30.6	1.01E5	1E7	20kHz	A	10	10	158	60
DRV8351-SEP	8	18	Cu	20.3	1.07E5	1E7	20kHz	A	13	30	84	16
DRV8351-SEP	8	19	Cu	20.3	1.07E5	1E7	20kHz	A	10	20	120	84
DRV8351-SEP	8	20	Cu	20.3	1.12E5	1E7	20kHz	A	10	45	118	109

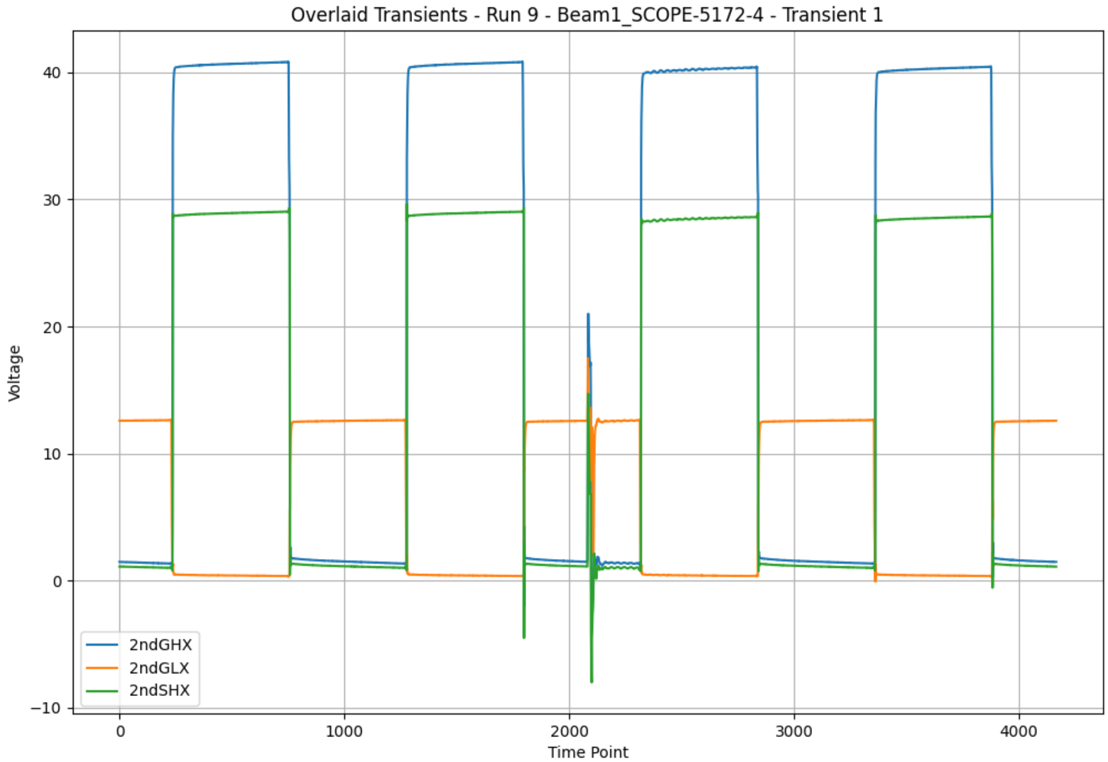

Figure 8-1. Cross Conduction SET Run 9 Zoomed Out (f_{sw} = 20kHz) 47.2MeV

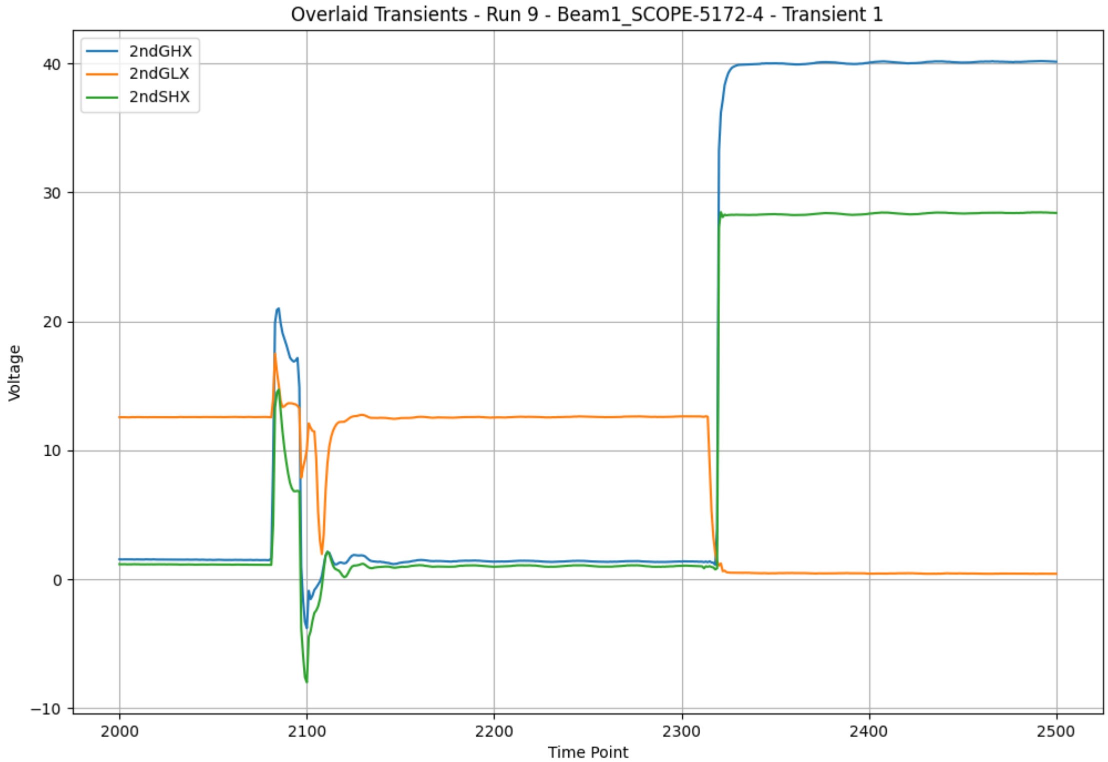

Figure 8-2. Cross Conduction SET Run 9 Zoomed in 1 (f_{sw} = 20kHz) 47.2MeV

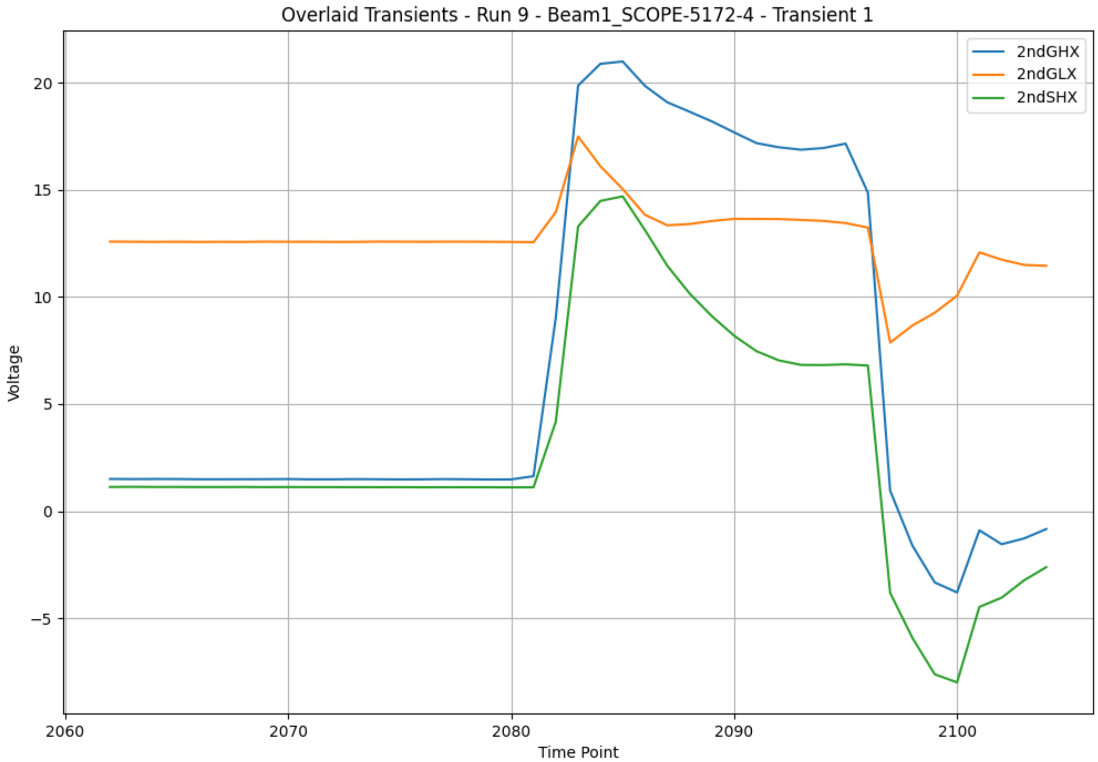

Figure 8-3. Cross Conduction SET Run 9 Zoomed in 2 (f_{sw} = 20kHz) 47.2MeV

9 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 shown in *Heavy Ion Orbital Environment Single-Event Effects Estimations*. Assume a minimum shielding configuration of 100mils (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 and the SEB, the event rate calculation for the SEL and the SEB is shown on Table 9-1 and Table 9-2, respectively.

Table 9-1. 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)	48	4.50×10^{-4}	5.68×10^{-8}	2.55×10^{-11}	1.06×10^{-3}	1.07×10^{8}
GEO		1.48×10^{-3}		8.38×10^{-11}	3.49×10^{-3}	3.27×10^{7}

Table 9-2. SEB 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)	48	4.50×10^{-4}	1.23×10^{-7}	5.54×10^{-11}	2.31×10^{-3}	4.95×10^{7}
GEO		1.48×10^{-3}		1.82×10^{-10}	7.56×10^{-3}	1.51×10^{7}

10 Summary

The purpose of this study was to characterize the effect of heavy-ion irradiation on the single-event effect (SEE) performance of the DRV8351-SEP 40V Three Phase Half-Bridge Gate driver. Heavy-ions with LET_{EFF} =20 to 48MeV × cm^2 / mg were used for the SEE characterization campaign. Flux of approximately 10^5 ions / cm^2 × s and fluences of approximately 10^7 ions / cm^2 per run were used for the characterization. The SEE results demonstrated that the DRV8351-SEP exhibits cross confuction events that are explained in more detail in the sections above. The cross conduction events did not seem to damage the device or the MOSFETS. SEL and SEB LET_{EFF} = 48MeV × cm^2 / mg and across the full electrical specifications. Transients at LET_{EFF} = 48MeV × cm^2 / mg on GL/GH/SH are presented and discussed. CREME96-based worst week event-rate calculations for LEO(ISS) and GEO orbits for the DSEE and SET are presented for reference.

A 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.
2. G. Bruguier and J. M. Palau, "Single particle-induced latchup", *IEEE Trans. Nucl. Sci., Vol. 43(2)*, Mar. 1996, pp. 522-532.
3. G. H. Johnson, J. H. Hohl, R. D. Schrimpf and K. F. Galloway, "Simulating single-event burnout of n-channel power MOSFET's," in IEEE Transactions on Electron Devices, vol. 40, no. 5, pp. 1001-1008, May 1993.
4. J. R. Brews, M. Allenspach, R. D. Schrimpf, K. F. Galloway,J. L. Titus and C. F. Wheatley, "A conceptual model of a single-event gate-rupture in power MOSFETs," in IEEE Transactions on Nuclear Science, vol. 40, no. 6, pp. 1959-1966, Dec. 1993.
5. G. H. Johnson, R. D. Schrimpf, K. F. Galloway, and R. Koga,“Temperature dependence of single event burnout in n-channel power MOSFETs [for space application],” IEEE Trans. Nucl. Sci., 39(6), Dec. 1992, pp.1605-1612.
6. Texas A&M University, *Cyclotron Institute Radiation Effects Facility*, webpage.
7. James F. Ziegler, *"The Stopping and Range of Ions in Matter" (SRIM) software simulation tool*, webpage.
8. D. Kececioglu, “Reliability and Life Testing Handbook”, Vol. 1, PTR Prentice Hall, New Jersey,1993, pp. 186-193.
9. Vanderbilt University, *CREME-MC*, webpage.
10. A. J. Tylka, J. H. Adams, P. R. Boberg, et al.,"CREME96: A Revision of the Cosmic Ray Effects on Micro-Electronics Code", *IEEE Trans. on Nucl. Sci., Vol. 44(6)*, Dec. 1997, pp. 2150-2160.
11. A. J. Tylka, W. F. Dietrich, and P. R. Boberg, "Probability distributions of high-energy solar-heavy-ion fluxes from IMP-8: 1973-1996", *IEEE Trans. on Nucl. Sci.,Vol. 44(6)*, Dec. 1997, pp. 2140-2149.