Radiation Report

CDCLVP111-SEP Single-Event Effects (SEE) Radiation Report

TEXAS INSTRUMENTS

ABSTRACT

The purpose of this study is to characterize the effect of heavy-ion irradiation on the single-event effect (SEE) performance of the CDCLVP111-SEP 1:10 low-voltage positive-referenced emitter-coupled logic (LVPECL) clock distributor. This experiment utilized heavy-ions with a LET_{EFF} of 2.79 to 47.5 MeVcm² /mg irradiating five production devices in 76 experiments with a fluence of 1.00 × 10^5– 1.5 × 10^7 ions/cm^2 per run. The results demonstrate that the CDCLVP111-SEP is free of single-event latch-up (SEL) effects up to LET_{EFF} = 47.5 MeVcm² /mg.

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1 Introduction

The CDCLVP111-SEP is a radiation-hardened clock driver that distributes one differential clock pair of LVPECL inputs (CLK0, CLK1) to ten pair of differential LVPECL clock inputs (Q0, Q9) with minimal skew, additive jitter, and propagation delays for clock distribution. With an internal multiplexer, the device can accept two clock sources. By using the VBB reference voltage, the device can accept single-ended clock inputs. The output driver is specifically designed for driving 50Ω transmission lines. The CDCLVP111-SEP device is packaged on a 32pin, thermally-enhanced qual-flat-package (HLQFP). The operational temperature is specified from –55°C to 125°C. General device information and test conditions are listed in Table 1-1.

Table 1-1. Overview Information

DESCRIPTION (1)	DEVICE INFORMATION
TI Part Number	CDCLVP111-SEP
Orderable Part Number	CDCLVP111MVFPSEP
VID/SMD Number	V62/12624
Device Function	1:10 LVPECL clock distributor
Technology	RF-SiGe
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University
Heavy Ion Fluence per Run	1.00×10^5 – 1.50×10^7 ions/cm^2
Irradiation Temperature	25°C (for SET testing), and 125°C (for SEL testing)

2 Single-Event Effects (SEE)

The CDCLVP111-SEP device does not operate at high voltages or high currents; therefore, single-event burn-out (SEB) and single-event gate-rupture (SEGR) events are not expected issues. The primary single-event effect (SEE) events of interest in the CDCLVP111-SEP are single-event latch-up (SEL) and single-event transient (SET).

From a risk and impact point-of-view, 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 RF-SiGe process used for the CDCLVP111-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 that is formed between the p-substrate and n-well as well as the n+ and p+ contacts (Shoga; Binder 1986 and Bruguier; Palau 1996). The parasitic bipolar structure creates a high-conductance path (creating a steady-state current that is typically orders-of-magnitude higher than the normal operating current) between the power and ground that persists (is *latched*) until the power is removed or until the device is destroyed by the high-current state. The process modifications applied for SEL-mitigation are sufficient, as the CDCLVP111-SEP exhibits no SEL with heavy-ions of LET_{EFF} = 47.5MeVcm² /mg at a fluence of 10^7 ions/cm2 and a chip temperature of 125°C.

As the functional block diagram in Figure 2-1 shows, SETs can potentially affect the CDCLVP111-SEP in one of two primary ways:

- Local-creating temporary upsets that affect just one pair at a time
- Global-creating temporary upsets that affects all ten output pairs at a time

The global SET can be generated in the input buffers circuitry, which disrupts the currently-selected clock or affects the multiplexer select line and can potentially cause either a disruption of the clock pulse or a temporary switch to the wrong input clock. To be able to distinguish if this fail mode has occurred, set the two input clocks to different frequencies (a sudden change in clock frequency reveals that such an event has occurred). No such events were observed in any of the tests. The SET impacts the buffers in such a way that the affected clock line exhibits a positive, negative, or bipolar clock pulse disturbance whose magnitude, polarity, and duration depend on how the ionization from the SET is distributed (a function of the ion LET, location, trajectory, energy, the thickness and composition of the back-end-of-line (BEOL) stack, and so forth) and what part of the circuit is hit. The actual shape and duration of the SETs is a strong function of output capacitance and the load conditions, as well. Ultimately, SETs are only a concern if their magnitude and duration actually cause an erroneous clock pulse (extra clock pulse) or a missing clock pulse disruption which impacts the down-stream circuitry. All the observed SETs either increased or narrowed a single pulse width, created a missing pulse, or created a smaller single (runt) pulse.

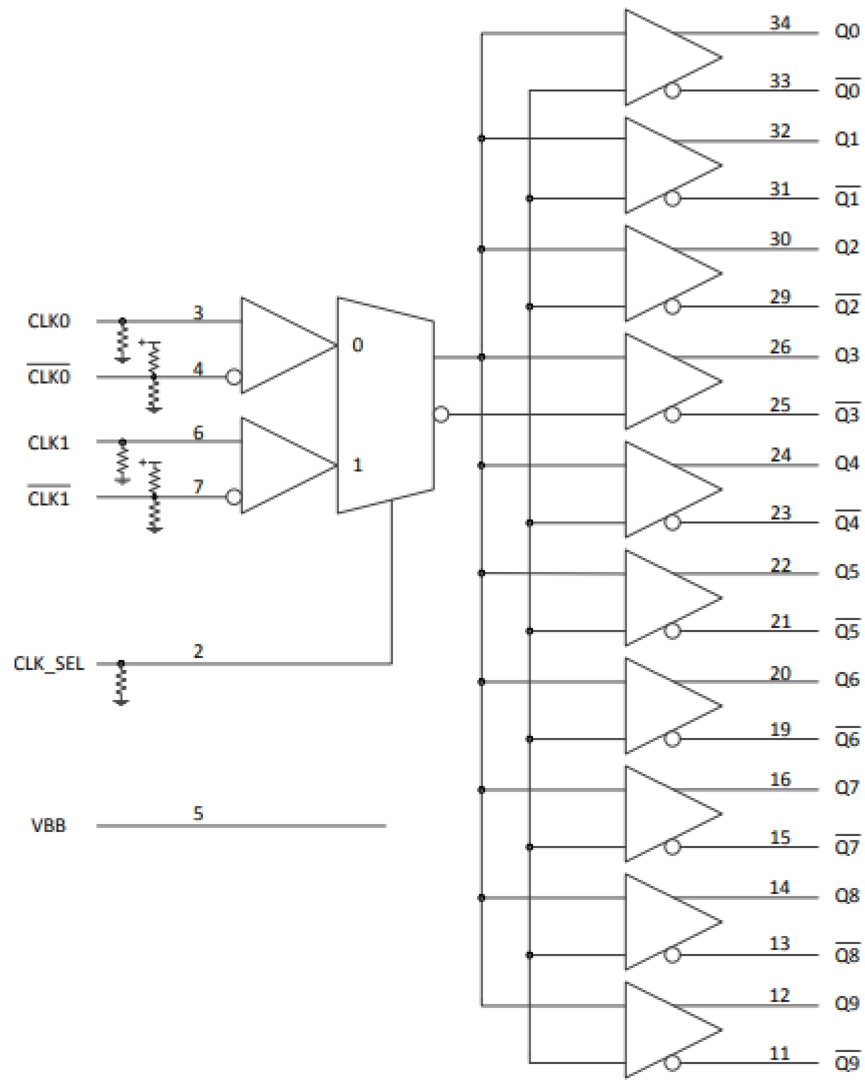

Figure 2-1. Functional Block Diagram of CDCLVP111-SEP

3 Device and Test Board Information

The CDCLVP111-SEP is packaged in a 32-pin thermally enhanced qual flat package (HLQFP) as shown in Figure 3-1. The CDCLVP111-SEP evaluation module was used to evaluate the performance and characteristics of the CDCLVP111-SEP under heavy ion radiation as shown in Figure 3-2. The schematic is shown in Figure 3-3.

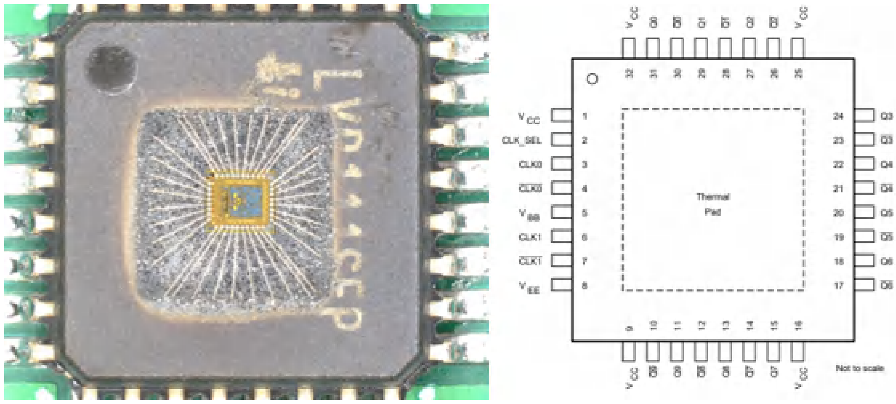

Figure 3-1. Photograph of Delidded CDCLVP111-SEP (Left) and Pinout Diagram (Right)

Note: The package was decapped to reveal the die face for all heavy-ion testing.

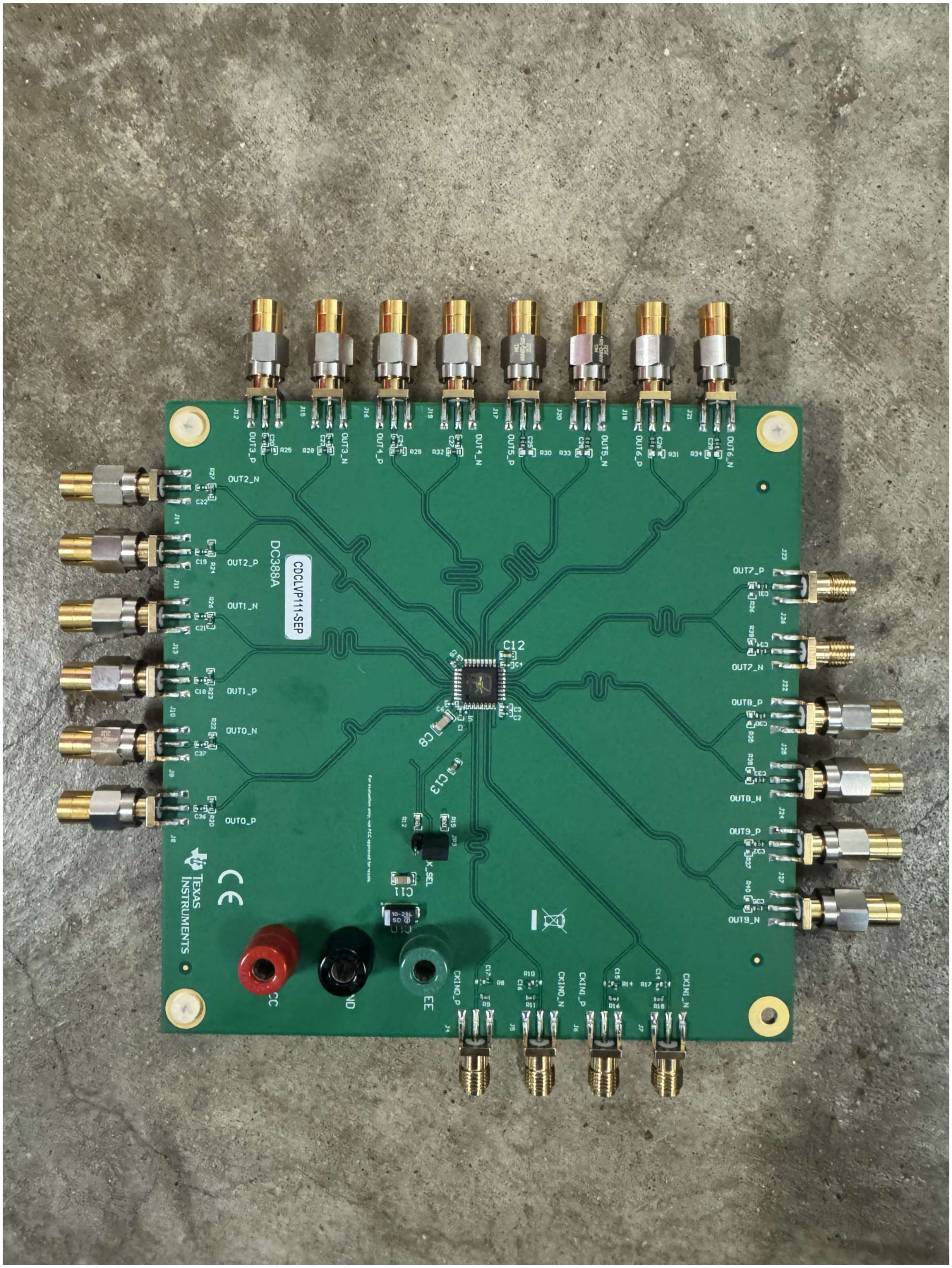

Figure 3-2. CDCLVP111-SEP EVM Top View

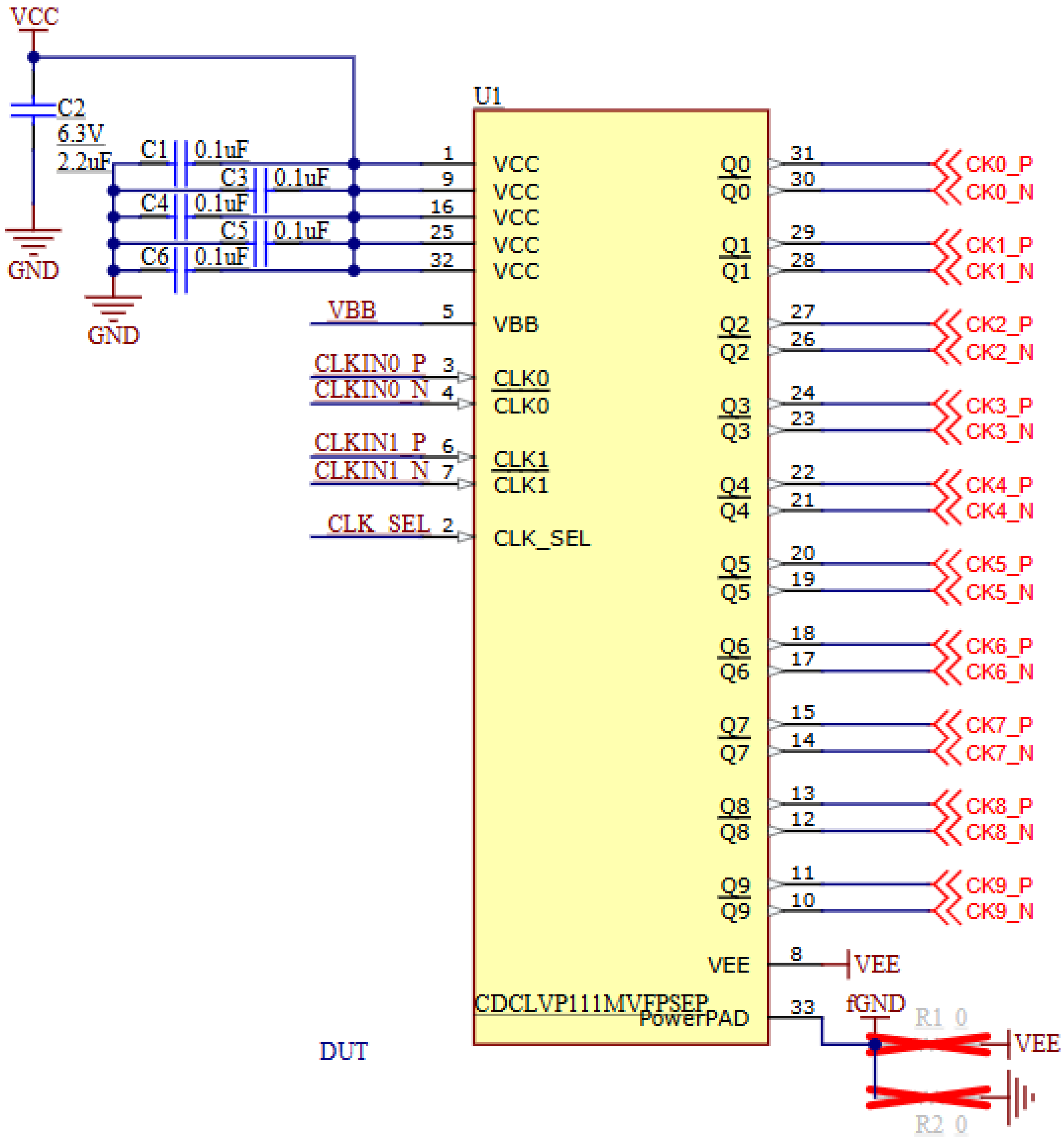

Figure 3-3. CDCLVP111-SEP EVM Schematic 1

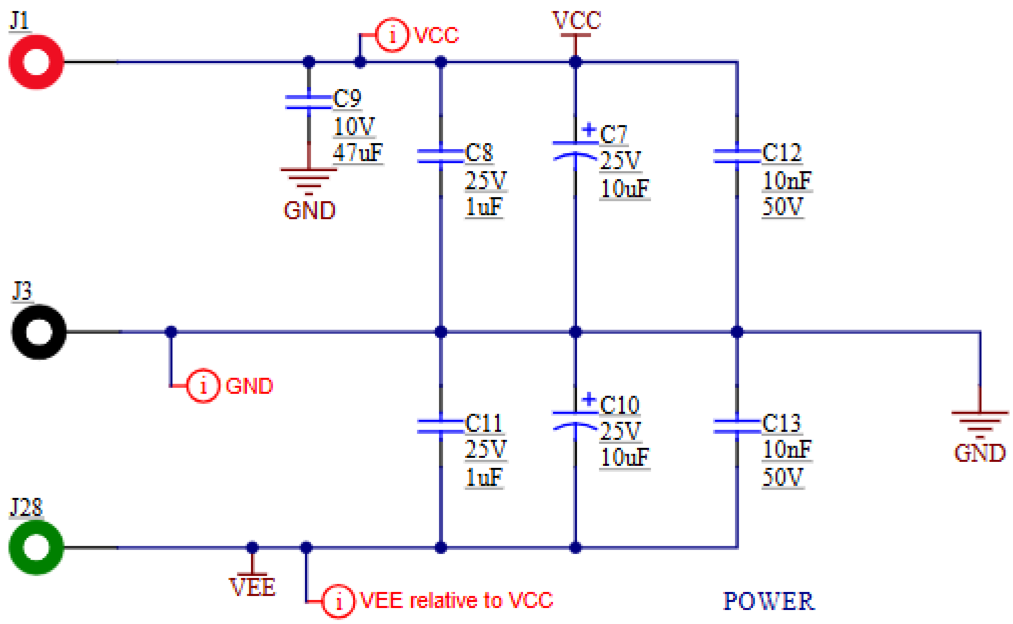

Figure 3-4. CDCLVP111-SEP EVM Schematic 2

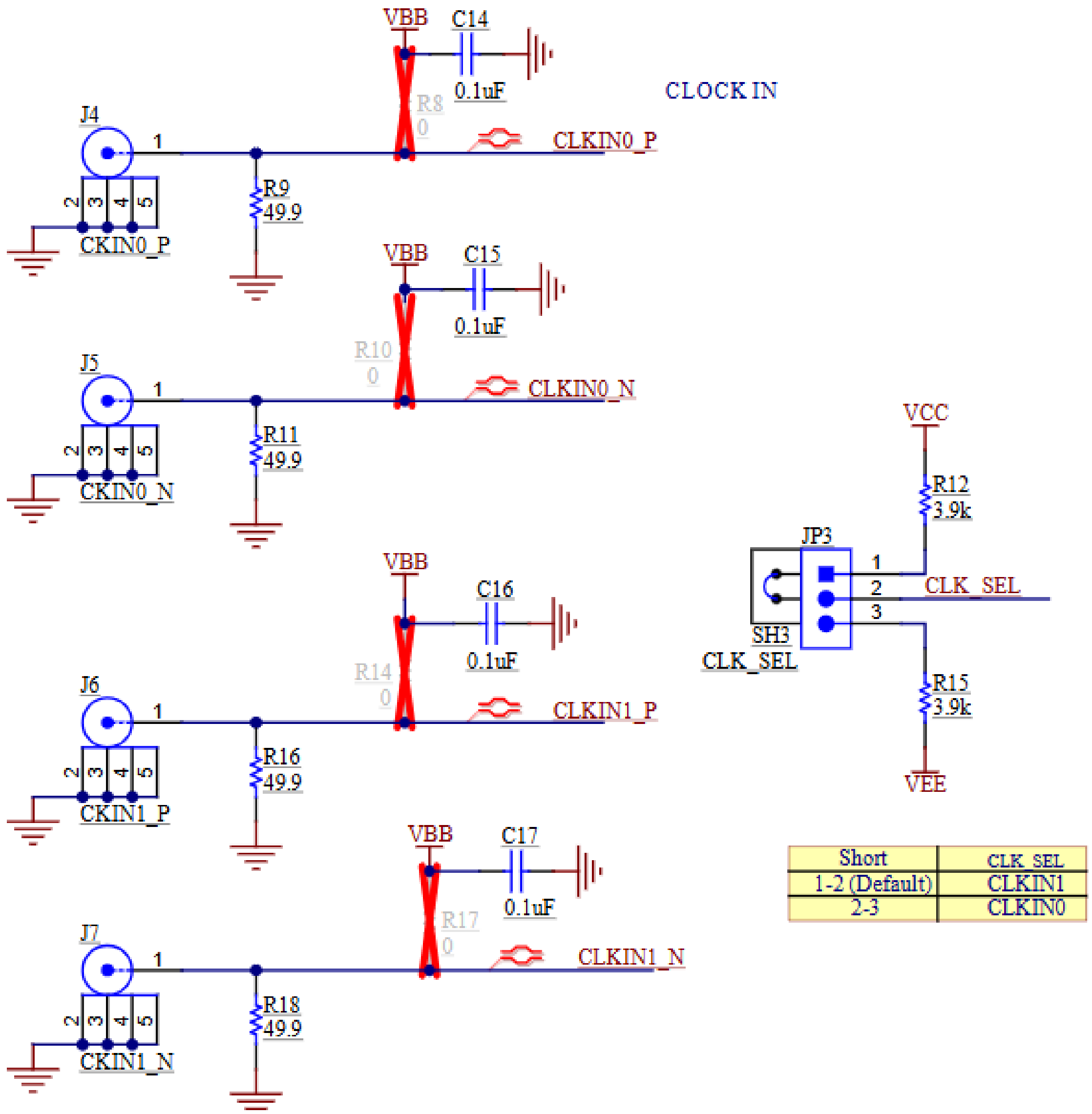

Figure 3-5. CDCLVP111-SEP EVM Schematic 3

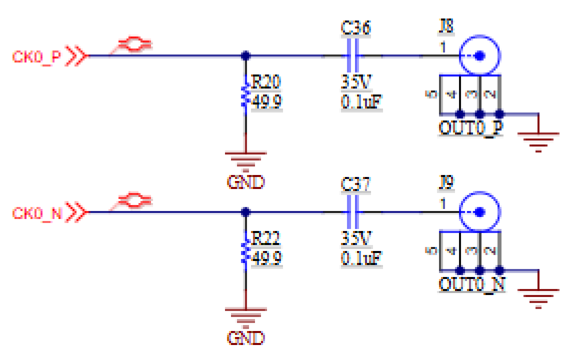

Figure 3-6. CDCLVP111-SEP EVM Schematic 4

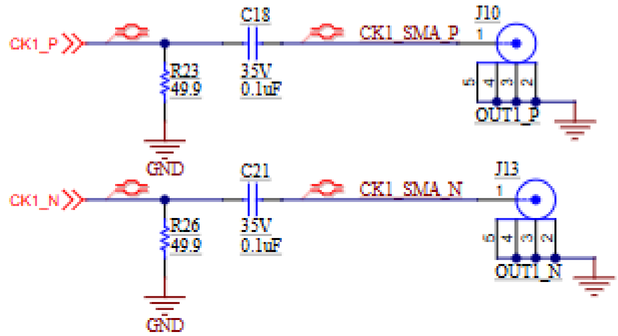

Figure 3-7. CDCLVP111-SEP EVM Schematic 5

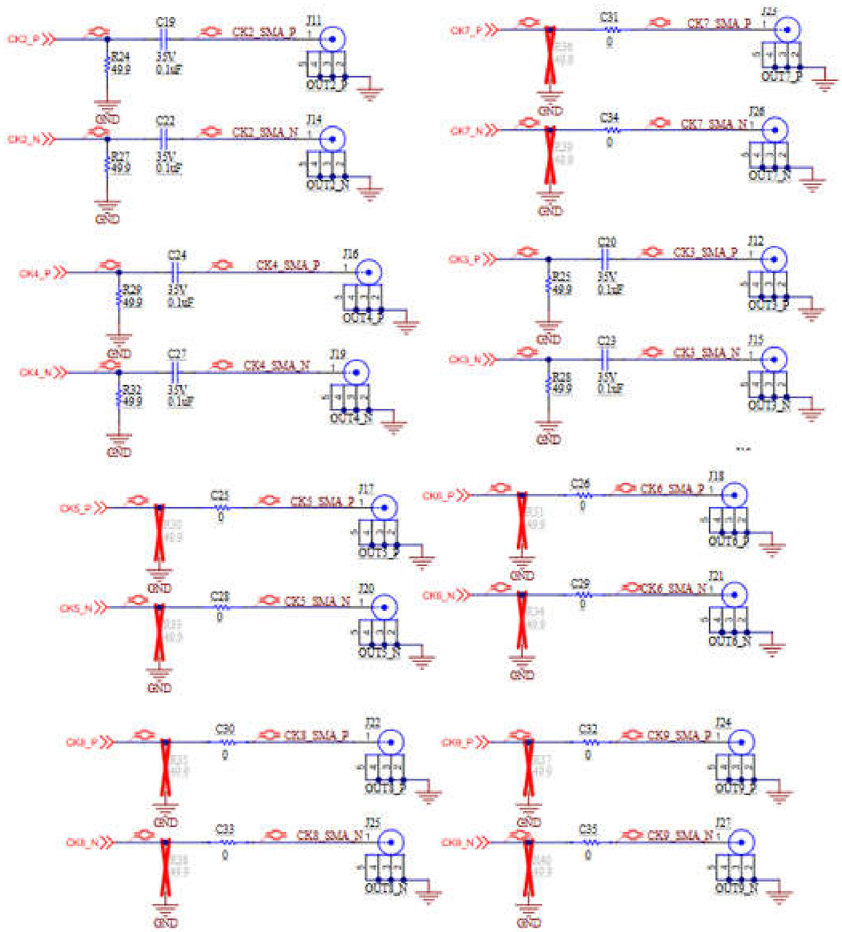

Figure 3-8. CDCLVP111-SEP EVM Schematic 6

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a K500 superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 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 1×10^5 to 1×10^6 ions/cm² × s was used to provide heavy-ion fluences of 1×10^5– 1.5×10^7 ions/cm². The TAMU facility uses a beam port that has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.

For the experiments conducted on this report, there were four ions used, ^{109}Ag, ^{84}Kr, ^{40}Ar and ^{20}Ne. ^{109}Ag was used to obtain LET_{EFF} of 47.5MeVcm²/mg. ^{84}Kr was used to obtain LET_{EFF} of 44.12 and 30.79MeVcm²/mg. ^{40}Ar was used to obtain LET_{EFF} of 12.39 and 8.68MeVcm²/mg. ^{20}Ne was used to obtain LET_{EFF} of 2.79MeVcm²/mg. The total kinetic energy for each of the ions were:

- ^{109}Ag = 1.634GeV (15MeV/nucleon)
  - Ion uniformity for these experiments was between 93% and 96%
- ^{84}Kr = 1.259GeV (15MeV/nucleon)
  - Ion uniformity for these experiments was between 93% and 96%
- ^{40}Ar = 599MeV (15MeV/nucleon)
  - Ion uniformity for these experiments was between 93% and 96%
- ^{20}Ne= 300MeV (15MeV/nucleon)
  - Ion uniformity for these experiments was between 93% and 96%

Figure 4-1 shows the CDCLVP111-SEP in front of the beam line at the TAMU facility.

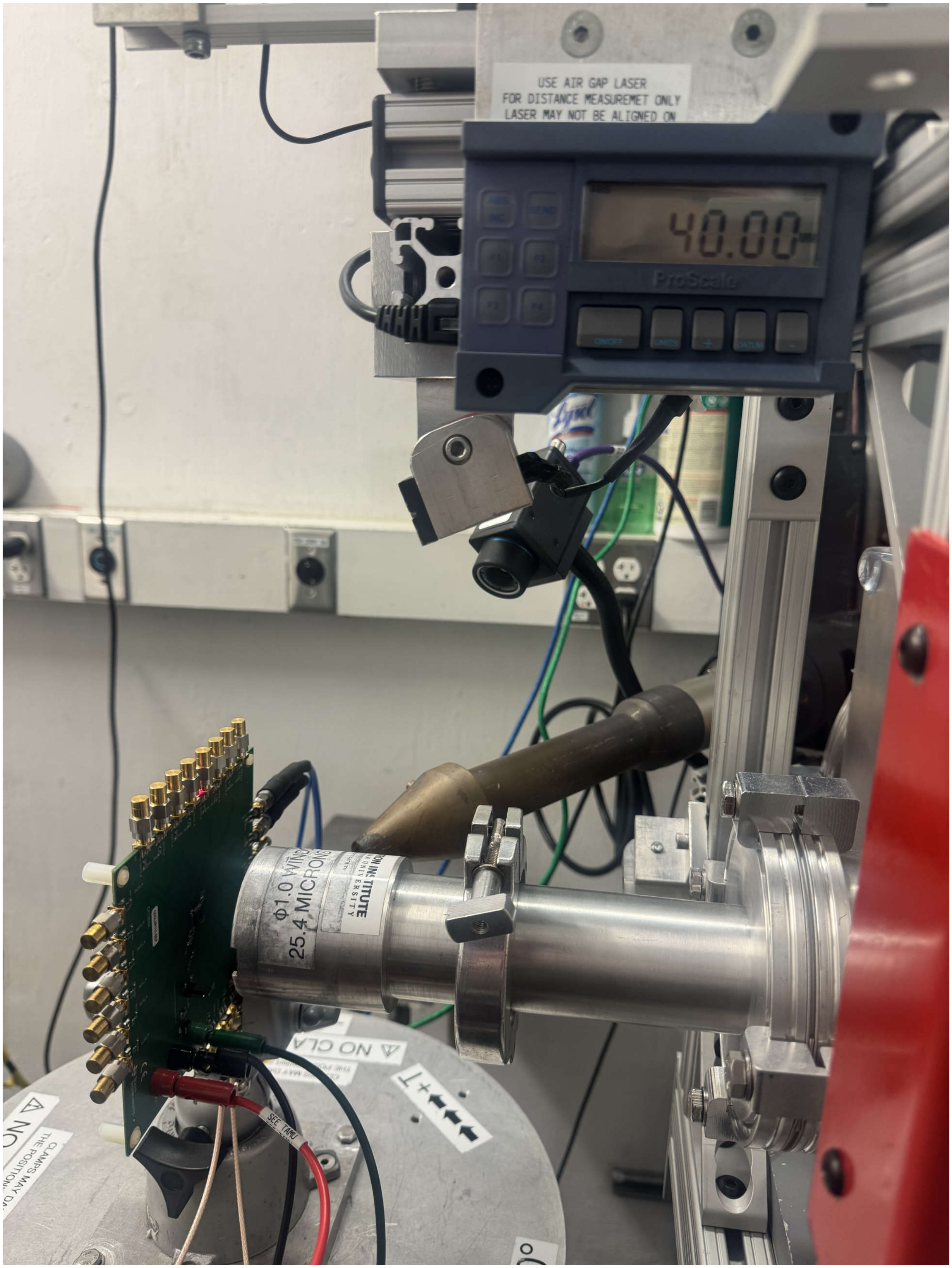

Figure 4-1. CDCLVP111-SEP EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 LET$_{EFF}$ and Range Calculation

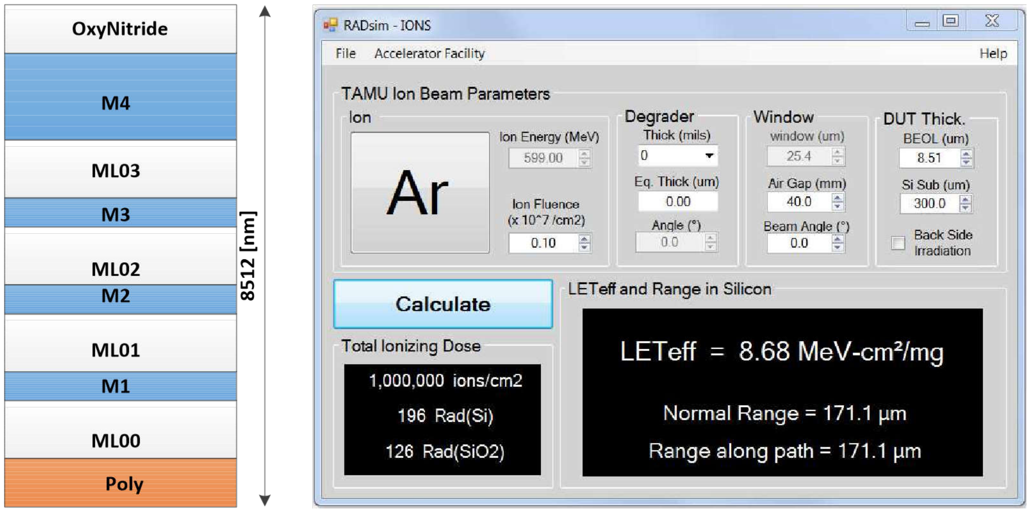

Figure 5-1. Generalized Cross-Section of the RFSiGe Technology BEOL Stack on the CDCLVP111-SEP [Left] and GUI of RADsim-IONS Application (Right)

The CDCLVP111-SEP is fabricated in the TI RFSiGe process with a back-end-of-line (BEOL) stack consisting of 4 levels of standard thickness aluminum. The total stack height from the surface of the passivation to the silicon surface is 8512 µm based on nominal layer thickness as shown in Figure 5-1.

Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the CDCLVP111-SEP, the effective LET (LET$_{EFF}$) at the surface of the silicon substrate and the range was determined with:

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

The results are shown in Ion LET$_{EFF}$ and Range in Silicon.

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

Facility	Beam Energy (MeV/ nucleon)	Ion Type	Degrader Steps (#)	Degrader Angle (°)	Copper Foil Width (µm)	Beam Port Window	Air Gap (mm)	Angle of Incidence	LET$_{EFF}$ (MeV·cm^2/ mg)	Range in Silicon (µm)
TAMU	16.3	^{109}Ag	0	0	-	1-mil Aramica	40	0	47.5	95.1
TAMU	12.59	^{84}Kr	0	0	-	1-mil Aramica	40	0	44.12	74
TAMU	12.59	^{84}Kr	0	0	-	1-mil Aramica	40	0	30.79	108.3
TAMU	5.99	^{40}A	0	0	-	1-mil Aramica	40	0	12.39	118.5
TAMU	5.99	^{40}A	0	0	-	1-mil Aramica	40	0	8.68	171.1
TAMU	3	^{20}Ne	0	0	-	1-mil Aramica	40	0	2.79	251.6

6 Test Setup and Procedures

SEE testing was performed on a CDCLVP111-SEP device, which was mounted on a high-performance evaluation board. The board was powered up using two of the four channels of an Agilent N6702A precision power supply. The twenty single-ended (ten if differential) outputs of the DUT were loaded with 50Ω to GND. The SEE events were monitored by using the Tektronix DPO7254C Digital Phosphor Oscilloscope (four-channel, 40GS/s). The scope has a 3.2μs update rate under the conditions used when collecting data at the TAMU facility. The inputs to the MUX of the CDCLVP111-SEP were provided by using two radio frequency signal generators. The differential inputs CLK0 and CLK1 was provided by means of Rohde and Schwarz SGS100A RF Source. Signals from the signal generator were connected to the board by using high-speed SMA coaxial cables model: S141MMHF- 36-2. The outputs were monitored by using two P6330 (3.5GHz of bandwidth) differential probes attached to the board by a 2.54mm pitch male header.

During the SET testing, the currents on both power supplies were monitored at all times by using an inhouse LabVIEW software GUI (PXI Rad-Test) running on a National Instruments NI-PXIe-8135 controller. This graphical user interface (GUI) also records the beam start and stop output signal on the TAMU system. The signal generators were controlled by means of the general-purpose interface bus (GPIB) protocol using their respective drivers running on the LabVIEW software. The DPO7254C device was controlled by using this front panel interface. The DPO was left on the cave at all times; however, a KVM extender was used to control it from upstairs (in the TAMU control room). TAMU provides an input signal named NIM which can be used to stop the beam after a predetermined number of events and also record the events on the system. The OUT signal of the DPO was connected to the NIM input. Figure 6-1 shows a block diagram of the setup used during the SEE testing. Table 6-1 lists the equipment setup. The device was heated using a convection heat gun aimed at the die for the SEL testing. The junction temperature was monitored by using a digital infrared camera attached as close as possible to the die.

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 CDCLVP111-SEP shows the connections, limits, and compliance values used during the testing. Figure 6-1 shows a block diagram of the setup used for SEE testing of the CDCLVP111-SEP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the CDCLVP111-SEP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{CC}	Agilent N6705C(CH # 1)	3A	100mA	2.375V and 3.8V
V_{EE}	Agilent N6705C(CH # 2)	3A	400mA	2V
CLK0	R&S SGS100A	12.75GHz	-	100MHz, 200MHz and 1200MHz
CLK1	R&S SGS100A	12.75GHz	—	100MHz
Digital Scope	DPO7254C	40G/S (2.4GHz of BW)	—	20 G/S at 2.4GHz of BW
$^{+}Q_0$,$^{-}Q_0$ and $^{+}Q_9$, $^{-}Q_9$	P6330	BW > 3.5 GHz	—	Limited By scope BW at 2.4GHz
Digital Card	PXIe 6556 (HSDIO)	200MHz	-	50MHz

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 test facility. During the heavy-ion testing, the LabVIEW control program powered up the CDCLVP111-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.

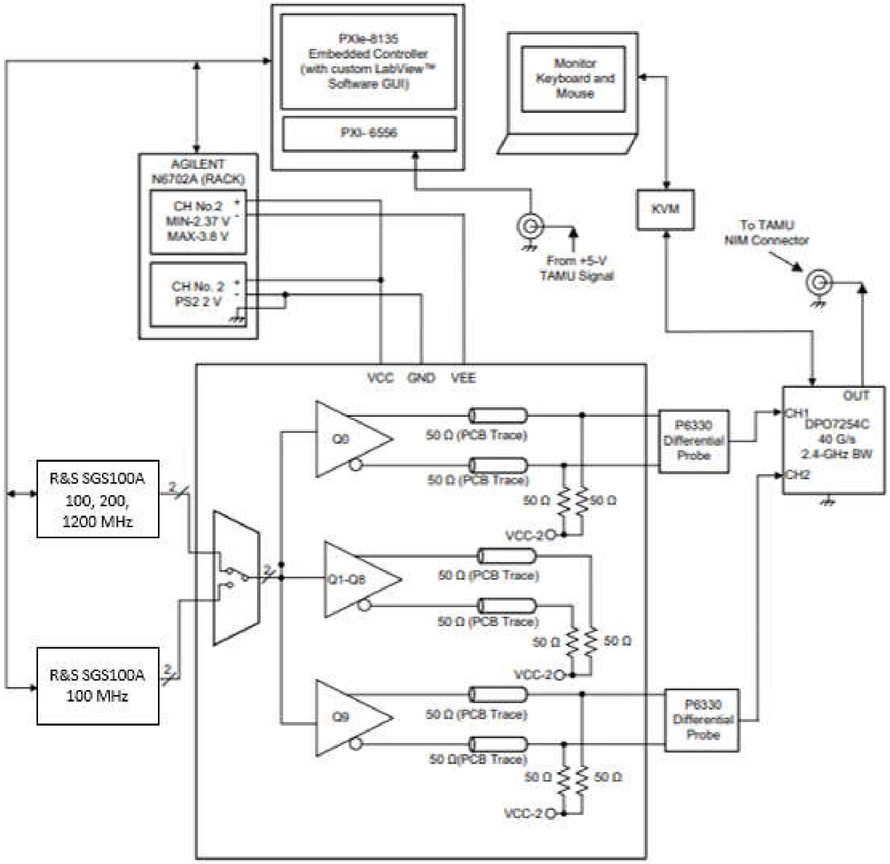

Figure 6-1. Block Diagram of the SEE Test Setup for the CDCLVP111-SEP

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 constantly monitored during testing at TAMU through an IR camera integrated into the control loop to create closed-loop temperature control.

The species used for the SEL testing was ^{109}Ag at 15MeV/nucleon. For ^{109}Ag an angle of incidence of 0° was used to achieve an LET_{EFF} of ≈ 47.5MeVcm^2/mg. The kinetic energy in the vacuum for ^{109}Ag is 1.634GeV. Flux of approximately 1.00 × 10^5- 1.15 × 10^5 ions/cm² × s and a fluence of 1.00 × 10^7– 1.50 × 10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was approximately two minutes. The three devices were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 3.8V for VCC – VEE and 2V for VEE – GND and a recommended output voltage of 400mV |VIH-VIL|. No SEL events were observed during all four runs, indicating that the CDCLVP111-SEP is SEL-free up to 47.5MeVcm^2/mg.

Table 7-1 shows the SEL test conditions and results. Figure 7-1 shows a plot of the current versus time for run number three.

Table 7-1. Summary of CDCLVP111-SEP SEL Test Condition and Results

Run #	Unit #	Temperature	Facility	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions·cm^2/mg)	Fluence (# ions)	V_{CC} - V_{EE}	V_{EE} - GND	Clock Amplitude (mV) | V_{IH}-V_{IL}|	Clock Offset (V)	SEL (# Events)
69	1	125°C	TAMU	^{109}Ag	47.5	1.05 x 10^5	1 x 10^7	3.8	2	400	0.2	0
70	1	125°C	TAMU	^{109}Ag	47.5	1.07 x 10^5	1 x 10^7	3.8	2	400	0.2	0
71	1	125°C	TAMU	^{109}Ag	47.5	1.15 x 10^5	1.5 x 10^7	3.8	2	400	0.2	0
72	1	125°C	TAMU	^{109}Ag	47.5	1 x 105	1 x 10^7	3.8	2	400	0.2	0
73	4	125°C	TAMU	^{109}Ag	47.5	1 x 10^5	1 x 10^7	3.8	2	400	0.2	0
74	4	125°C	TAMU	^{109}Ag	47.5	1.15 x 10^5	1.15 x 10^7	3.8	2	400	0.2	0
75	5	125°C	TAMU	^{109}Ag	47.5	1.07 x 10^5	1 x 10^7	3.8	2	400	0.2	0
76	5	125°C	TAMU	^{109}Ag	47.5	1.05 x 10^5	1 x 10^7	3.8	2	400	0.2	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the eight runs at 125°C (*9.24* × 10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEL} \leq 3.99 \times 10^{-8}$ cm^2/device for LET_{EFF} = 47.5MeVcm^2/mg and T = 125°C.

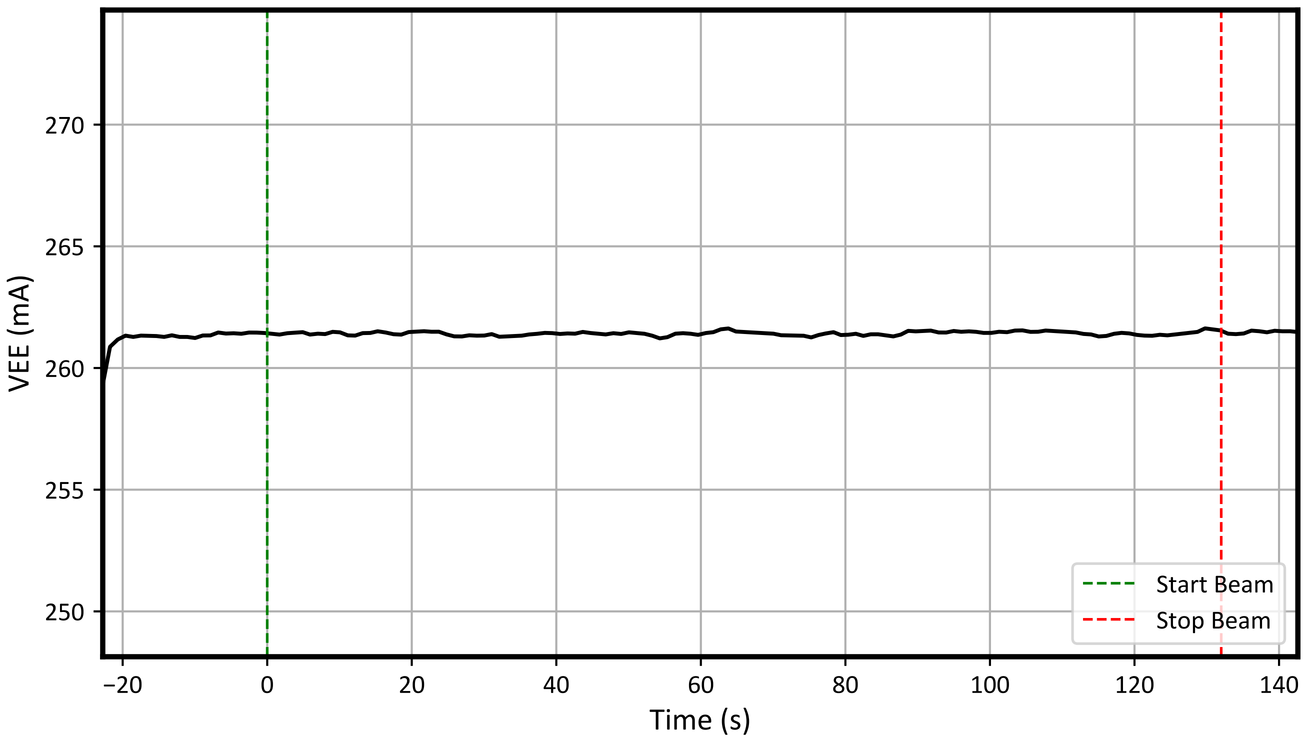

Figure 7-1. Current versus Time for Run # *71* of the CDCLVP111-SEP at T = 125°C, VEE - GND Supply

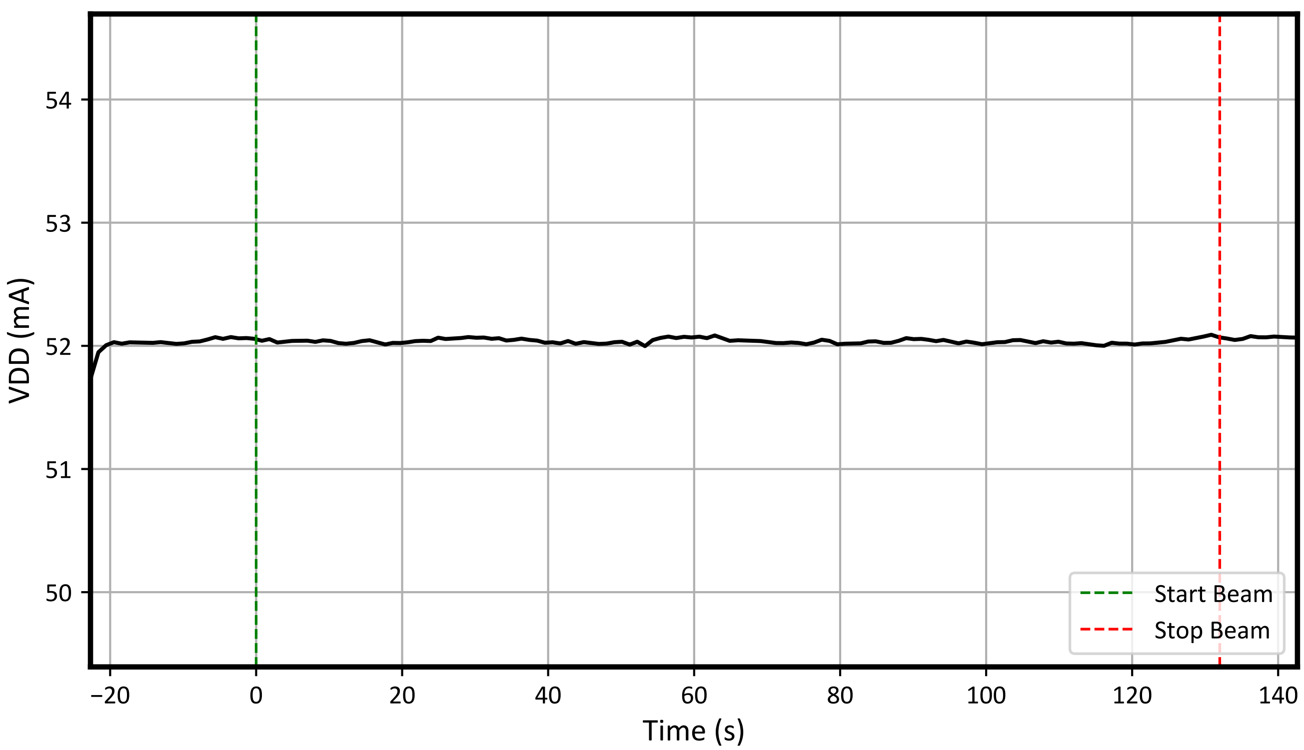

Figure 7-2. Current versus Time for Run # *71* of the CDCLVP111-SEP at T = 125°C, VCC - VEE Supply

8 Single-Event Transients (SET)

SET are defined as heavy-ion-induced transients upsets on the output Q_0 – Q_9 CDCLVP111-SEP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for the SET testing were ^{84}Kr, ^{40}Ar and ^{20}Ne for a LET_{EFF} of 2.79 – 44.12MeVcm^2/mg, for more details refer to Ion LET_{EFF} and Range in Silicon. Flux of 1 × 10^5- 1 × 10^6 ions × cm^2/s and a fluence of 1 × 10^7 ions/cm^2, per run were used for the SET characterization discussed on this chapter.

The SET characterization was performed at room temperature over two units. Several heavy-ion species were used (and some at multiple angles of incidence) to provide a LET_{EFF} ranging from 2.79 to 44.12MeV·cm^2/mg. In most cases, for each condition, two back-to-back identical runs were conducted for statistical purposes.

To capture different types of SET events, three different trigger types were used for the characterization: window, runt, and pulse width triggers (positive and negative). The purpose of each trigger mode is as follows:

- Window: Captures any deviation of the magnitude of the pulse.
- Runt: Captures any deviation from V_{OH} and V_{OL} levels. The levels are adjusted with voltages and frequency levels.
- Pulse width: Captures any deviation of the duty cycle.
  – Positive: Captures any instance where the on-time is higher than expected.
  – Negative: Captures any instance where the on-time is lower than expected.

Trigger type and signal for all scopes used is presented in Table 8-1.

Table 8-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type
DPO7254C	$Q_{0\text{-DIFF}}$	Pulse Width - Positive
		Pulse Width - Negative
		Window
		Runt
	$Q_{9\text{-DIFF}}$	Pulse Width - Positive
		Pulse Width - Negative
		Window
		Runt

Note

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.

To be able to capture events occurring in the input multiplexer, the two input clocks were set at different frequencies. The differential pair CLK0 frequency was changed between 200MHz and 1200MHz and the differential input pair CLK1 was held constant at 100MHz during all tests. Any transient event on the input multiplexer change the frequency and the pulse width trigger mode captures these events. No SET events on the input multiplexer have been observed during any of the test runs. Table 8-2 lists the clock amplitudes and offset for the MIN (2.375V) and MAX (3.800V) voltages used during the characterization.

Table 8-2. Clock Setting Used During Testing

Voltage	V_{CC}- V_{EE} (V)	V_{EE}- GND (V)	CLK $\|V_{IH}$-$V_{IL}\|$ Input Amplitude of CLK0, CLK1 (mV)	CLK Offset (V)
MIN	2.375	2	500	0.625
MAX	3.8	2	500	-0.8

Pulse Width Trigger

Figure 8-1 shows the cross-sectional plot for the positive pulse width trigger. Additionally, Figure 8-2 shows the cross-sectional plot for the positive pulse width trigger. Table 8-4 and Table 8-6 list the test conditions used for all the SET runs positive and negative pulse width trigger type, respectively. Figure 8-4 and Figure 8-5 show examples of the typical voltage versus time events for the positive and negative pulse width trigger type, respectively. All observed events were transitory and quickly recovered to normal operation. Equation 8-1 describes the cross-sectional calculation method.

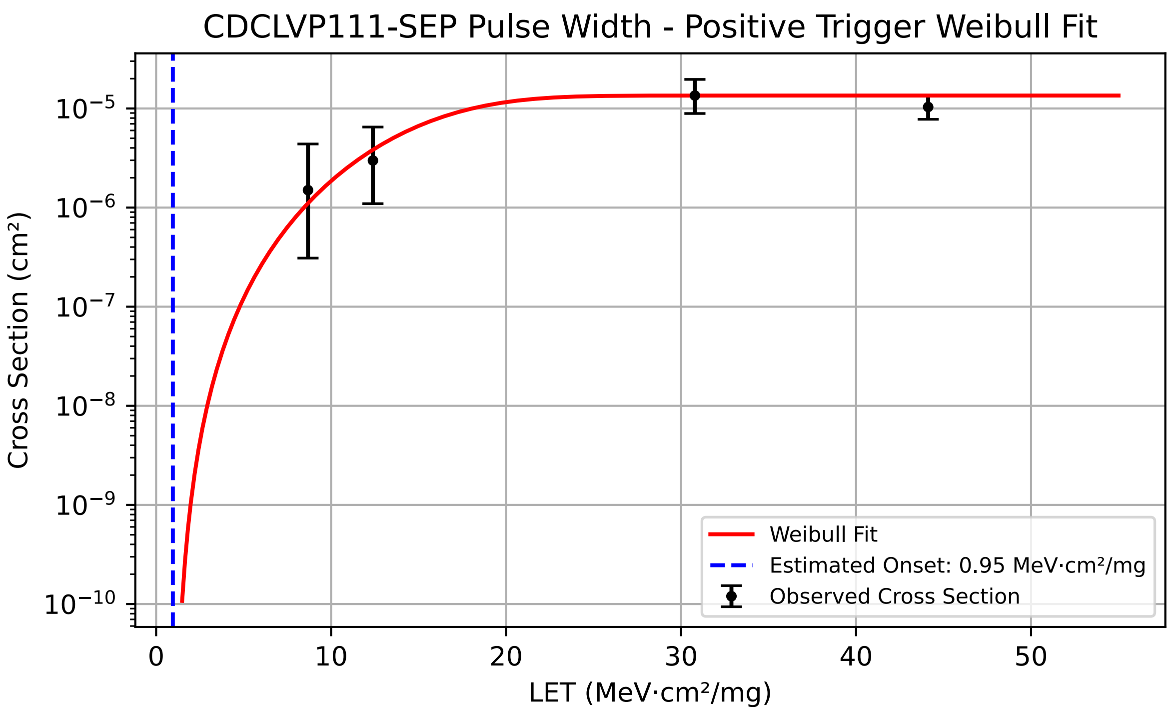

Figure 8-1. CDCLVP111-SEP Pulse Width - Positive Trigger Weibul Fit

The equation below describes the cross-sectional calculation method, which was used for all Weibull fits for all SET trigger analysis. Table 8-3 shows the Weibull parameters for positive pulse width trigger. Table 8-5 shows the Weibull parameters for the negative pulse width trigger. Table 8-8 shows the Weibull parameters for the runt trigger.

$$\sigma = \sigma_{SAT} \times \left(1 - e^{\left(-\frac{LET - Onset}{W}\right)^{S}}\right) \quad (1)$$

Table 8-3. Weibull Parameters for Postive Pulse Width Trigger

Parameter	Value
Cross-Section (cm^2)	1.35 × 10^{-5}
Onset (MeV-cm^2/mg)	0.95
W	15.69
S	3.47

Table 8-4. CDCLVP111-SEP SET Conditions for Positive Pulse Width Trigger

Run	Device	Ion	Effective LET (MeV·cm^2/mg)	Effective Fluence (Total amount of Ions)	V_{CC}- V_{EE} (V)	Trigger Settings	Number of Event
3	2	^{20}Ne	2.79	9.98 × 10^5	2.375	UL = 2.6ns ; LL = 2.46ns	0
4	2	^{40}Ar	8.68	1.00 × 10^6	2.375	UL = 2.6ns ; LL = 2.46ns	2
5	2	^{40}Ar	8.68	1.00 × 10^6	2.375	UL = 2.6ns ; LL = 2.46ns	1
6	2	40Ar	8.68	9.99 × 10^5	3.8	UL = 2.6ns ; LL = 2.46ns	0
7	2	^{40}Ar	12.39	1.01 × 10^6	2.375	UL = 2.6ns ; LL = 2.46ns	4

Table 8-4. CDCLVP111-SEP SET Conditions for Positive Pulse Width Trigger (continued)

Run	Device	Ion	Effective LET (MeV·cm²/mg)	Effective Fluence (Total amount of Ions)	V_{CC}- V_{EE} (V)	Trigger Settings	Number of Event
8	2	^{40}Ar	12.39	1.00×10^6	2.375	UL = 2.6ns ; LL = 2.46ns	2
9	2	^{84}Kr	30.79	1.00×10^6	2.375	UL = 2.6ns ; LL = 2.48ns	18
10	2	^{84}Kr	30.79	1.00×10^6	2.375	UL = 2.6ns ; LL = 2.48ns	9
11	2	^{84}Kr	44.12	1.00×10^6	2.375	UL = 2.58ns ; LL = 2.48ns	10
12	2	^{84}Kr	44.12	1.00×10^6	2.375	UL = 2.58ns ; LL = 2.48ns	13
13	3	^{84}Kr	44.12	9.99×10^5	3.8	UL = 2.6ns ; LL = 2.46ns	12
14	3	^{84}Kr	44.12	9.98×10^5	2.375	UL = 2.6ns ; LL = 2.46ns	9
15	3	^{84}Kr	44.12	2.19×10^5	2.375	UL = 2.6ns ; LL = 2.46ns	0
16	3	^{84}Kr	44.12	1.00×10^6	2.375	UL = 2.6ns ; LL = 2.46ns	10

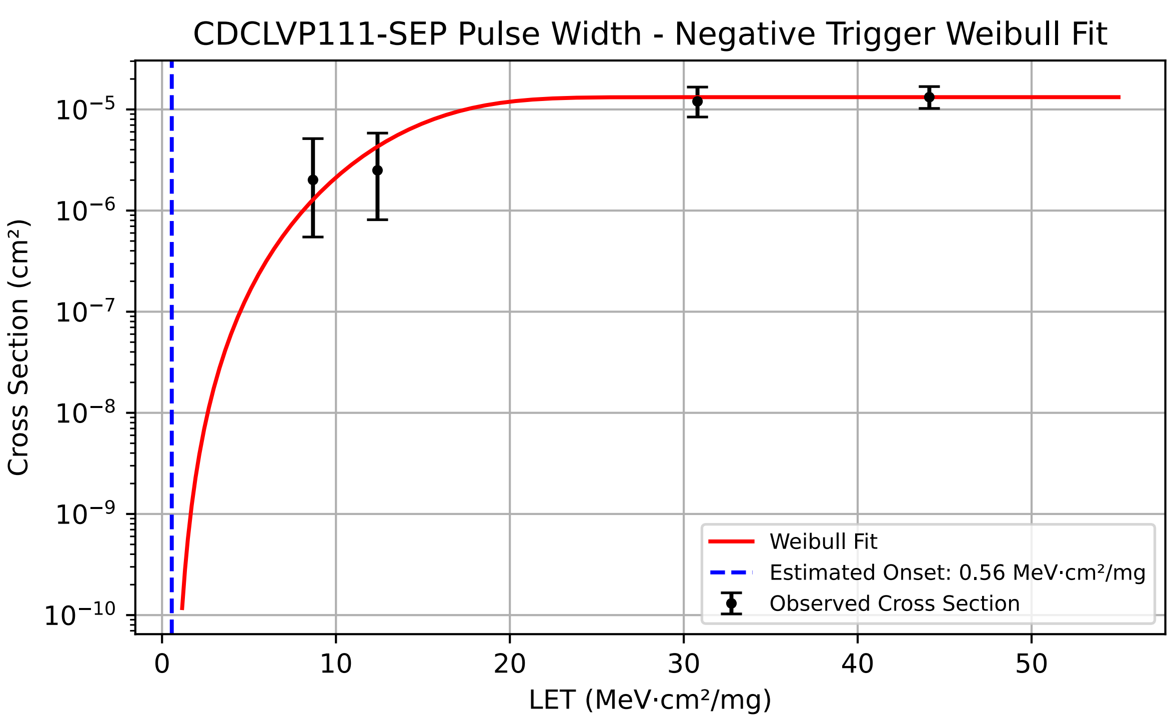

Figure 8-2. CDCLVP111-SEP Pulse Width - Negative Trigger Weibull Fit

Table 8-5. Weibull Parameters for Negative Pulse Width Trigger

Parameter	Value
Cross-Section (cm²)	1.32×10^{-5}
Onset (MeV-cm²/mg)	0.56
W	15.36

Table 8-5. Weibull Parameters for Negative Pulse Width Trigger (continued)

Parameter	Value
S	3.58

Table 8-6. CDCLVP111-SEP SET Conditions for Negative Pulse Width Trigger

Run	Device	Ion	Effective LET (MeV·cm^2/mg)	Effective Fluence (Total amount of Ions)	V_{CC}- V_{EE} (V)	Trigger Settings	Number of Event
19	2	^{40}Ar	8.68	9.96 x 10^5	2.375	UL = 2.6ns ; LL = 2.46ns	1
20	2	^{40}Ar	8.68	9.98 x 10^5	2.375	UL = 2.6ns ; LL = 2.46ns	3
21	2	^{40}Ar	12.39	1.00 x 10^6	2.375	UL = 2.6ns ; LL = 2.46ns	2
22	2	^{40}Ar	12.39	1.00 x 10^6	2.375	UL = 2.6ns ; LL = 2.46ns	3
23	2	^{84}Kr	30.79	1.00 x 10^6	2.375	UL = 2.58ns ; LL = 2.48ns	11
24	2	^{84}Kr	30.79	9.96 x 10^5	2.375	UL = 2.58ns ; LL = 2.48ns	13
25	2	^{84}Kr	30.79	1.00 x 10^6	2.375	UL = 2.58ns ; LL = 2.48ns	12
26	2	^{84}Kr	44.12	9.98 x 10^5	2.375	UL = 2.6ns ; LL = 2.46ns	15
27	2	^{84}Kr	44.12	1.00 x 10^6	2.375	UL = 2.6ns ; LL = 2.46ns	15
28	3	^{84}Kr	44.12	1.00 x 10^6	3.8	UL = 2.6ns ; LL = 2.46ns	10
29	3	^{84}Kr	44.12	9.98 x 10^5	2.375	UL = 2.6ns ; LL = 2.46ns	14
30	3	^{84}Kr	44.12	1.00 x 10^6	2.375	UL = 2.6ns ; LL = 2.46ns	12

Window Trigger

No SET was observed at the minimum voltage, maximum voltage and 200MHz clock frequency. However, the user can calculate the 99% confidence upper-bound cross section by using the MFTF method as described in Section A.2 and combining (or summing) the fluence of the all runs performed under the same conditions (see Equation 8-2 and Equation 8-1). The SET conditions and event results are shown in Table 8-7.

$$\sigma_{SET\_at\_MinVoltage\_and\_200MHz} \leq 1.23 \times 10^{-6}\ at\ LET = 44.12\ MeV \cdot cm^2/mg\ and\ T = 25°C \tag{2}$$

$$\sigma_{SET\_at\_MaxVoltage\_and\_200MHz} \leq 1.84 \times 10^{-6}\ at\ LET = 44.12\ MeV \cdot cm^2/mg\ and\ T = 25°C \tag{3}$$

Table 8-7. CDCLVP111-SEP SET Conditions for Window

Run	Device	Ion	Effective LET (MeVcm^2/mg)	Effective Fluence (Total amount of Ions)	V_{CC}- V_{EE} (V)	Trigger Settings	Number of Events
33	2	^{20}Ne	2.79	1.00 × 10^6	2.375	UL = 810mV ; LL = -830mV	0
34	2	^{20}Ne	2.79	9.99 × 10^5	2.375	UL = 810mV ; LL = -830mV	0
35	2	^{40}Ar	12.39	1.00 × 10^6	2.375	UL = 810mV ; LL = -830mV	0
36	2	^{40}Ar	12.39	1.00 × 10^6	2.375	UL = 810mV ; LL = -830mV	0

Table 8-7. CDCLVP111-SEP SET Conditions for Window (continued)

Run	Device	Ion	Effective LET (MeVcm^2/mg)	Effective Fluence (Total amount of Ions)	V_{CC}- V_{EE} (V)	Trigger Settings	Number of Events
37	2	^{84}Kr	30.79	9.97 × 10^5	2.375	UL = 810mV ; LL = -830mV	0
38	2	^{84}Kr	30.79	9.95 × 10^5	2.375	UL = 810mV ; LL = -830mV	0
39	2	^{84}Kr	44.12	1.00 × 10^6	2.375	UL = 852mV ; LL = -850mV	0
40	2	^{84}Kr	44.12	1.00 × 10^6	2.375	UL = 852mV ; LL = -850mV	0
41	3	^{84}Kr	44.12	1.00 × 10^6	3.8	UL = 1.12V ; LL = -1.12V	0
42	3	^{84}Kr	44.12	9.98 × 10^5	3.8	UL = 1.12V ; LL = -1.12V	0
43	3	^{84}Kr	44.12	9.96 × 10^5	2.375	UL = 810mV ; LL = -770mV	0

Runt Trigger

Figure 8-3 shows the cross-sectional plot for the runt trigger. Table 8-8 lists the parameters for the Weibul Fit for runt trigger. Table 8-9 list the test conditions used for all the SET runs with Runt trigger type.

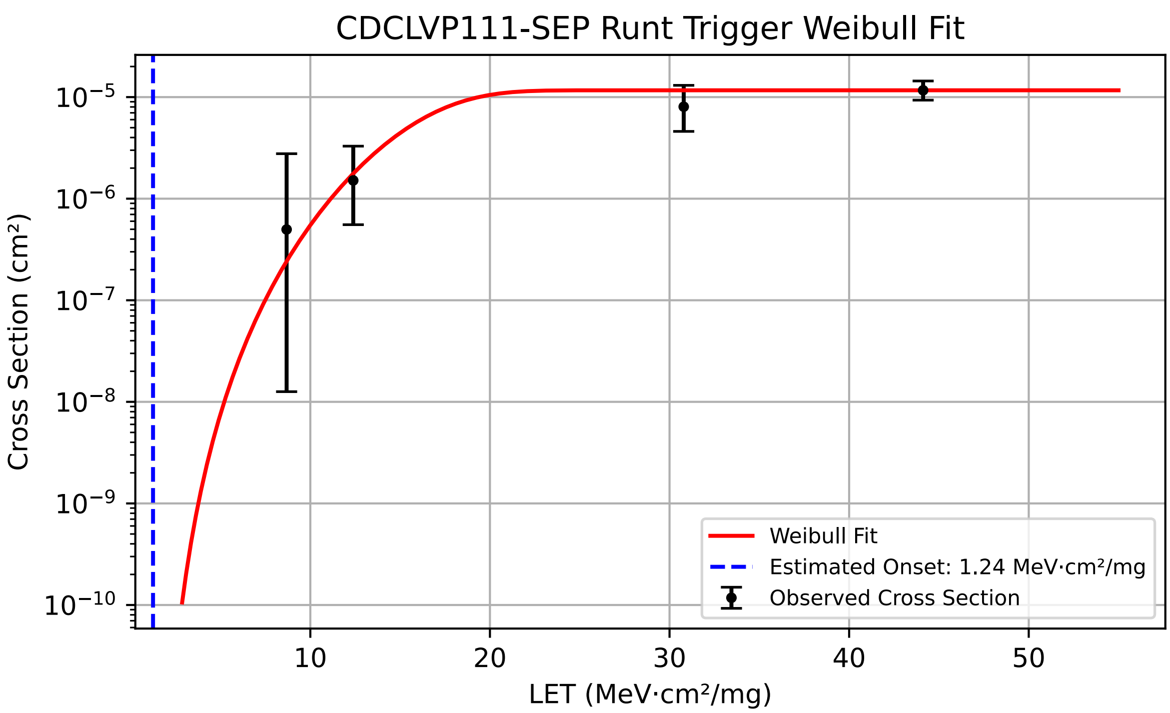

Figure 8-3. CDCLVP111-SEP Runt Trigger Weibull FIt

Table 8-8. Weibull Parameters for Runt Trigger

Parameter	Value
Cross-Section (cm^2)	1.17 × 10^{-5}
Onset (MeV-cm^2/mg)	1.24
W	15.91

Table 8-8. Weibull Parameters for Runt Trigger (continued)

Parameter	Value
s	5.08

Table 8-9. CDCLVP111-SEP SET Conditions for Runt Trigger

Run	Device	Ion	Effective LET (MeVcm²/mg)	Effective Fluence (Total amount of Ions)	V_{CC}- V_{EE} (V)	Trigger Settings	Number of Events
48	2	^{20}Ne	2.79	1.00×10^6	2.375	UL = 610mV; LL = -630mV	0
49	2	^{20}Ne	2.79	1.00×10^6	2.375	UL = 610mV; LL = -630mV	0
50	2	^{40}Ar	8.68	1.00×10^6	2.375	UL = 450mV; LL = -400mV	1
51	2	^{40}Ar	8.68	1.01×10^6	2.375	UL = 450mV; LL = -400mV	0
52	2	^{40}Ar	12.39	9.97×10^5	2.375	UL = 610mV; LL = -630mV	0
53	2	^{40}Ar	12.39	1.02×10^6	2.375	UL = 610mV; LL = -630mV	2
54	2	^{40}Ar	12.39	1.00×10^6	2.375	UL = 450mV; LL = -400mV	4
55	2	^{40}Ar	12.39	9.97×10^5	2.375	UL = 450mV; LL = -400mV	0
56	2	^{84}Kr	30.79	9.96×10^5	2.375	UL = 350mV; LL = -290mV	8
57	2	^{84}Kr	30.79	9.97×10^5	2.375	UL = 350mV; LL = -290mV	8
58	2	^{84}Kr	44.12	1.00×10^6	2.375	UL = 740mV; LL = -680mV	1
59	2	^{84}Kr	44.12	1.00×10^6	2.375	UL = 350mV; LL = -290mV	3
60	2	^{84}Kr	44.12	1.00×10^6	2.375	UL = 350mV; LL = -290mV	5
61	3	^{84}Kr	44.12	3.67×10^5	3.8	UL = 350mV; LL = -290mV	20
62	3	^{84}Kr	44.12	1.00×10^6	3.8	UL = 710mV; LL = -730mV	55
63	3	^{84}Kr	44.12	1.00×10^6	2.375	UL = 810mV; LL = -770mV	0
64	3	^{84}Kr	44.12	1.00×10^6	2.375	UL = 610mV; LL = -630mV	3
65	3	^{84}Kr	44.12	1.00×10^6	2.375	UL = 610mV; LL = -630mV	2

Time Domain SET Examples

The positive pulse-width trigger events in Figure 8-4 only show a small deviation from the normal clock output. The negative pulse-width trigger event captured in Figure 8-5 shows a violation of the negative pulse width (time), which can also be considered as a V**OL** violation. Some events captured with the runt trigger are also captured with the pulse-width trigger and vice versa. Figure 8-6 shows this behavior where a runt event can also be interpreted as a positive pulse-width violation.. At 200MHz all events recover within just one clock cycle; however, at 1.2GHz, two clock cycles are required for recovery. The events were local 54.55% of the time, affecting only the differential pair Q0. The other 45.45% of the time, the event has a global effect on the Q0 and Q9 differential pair.

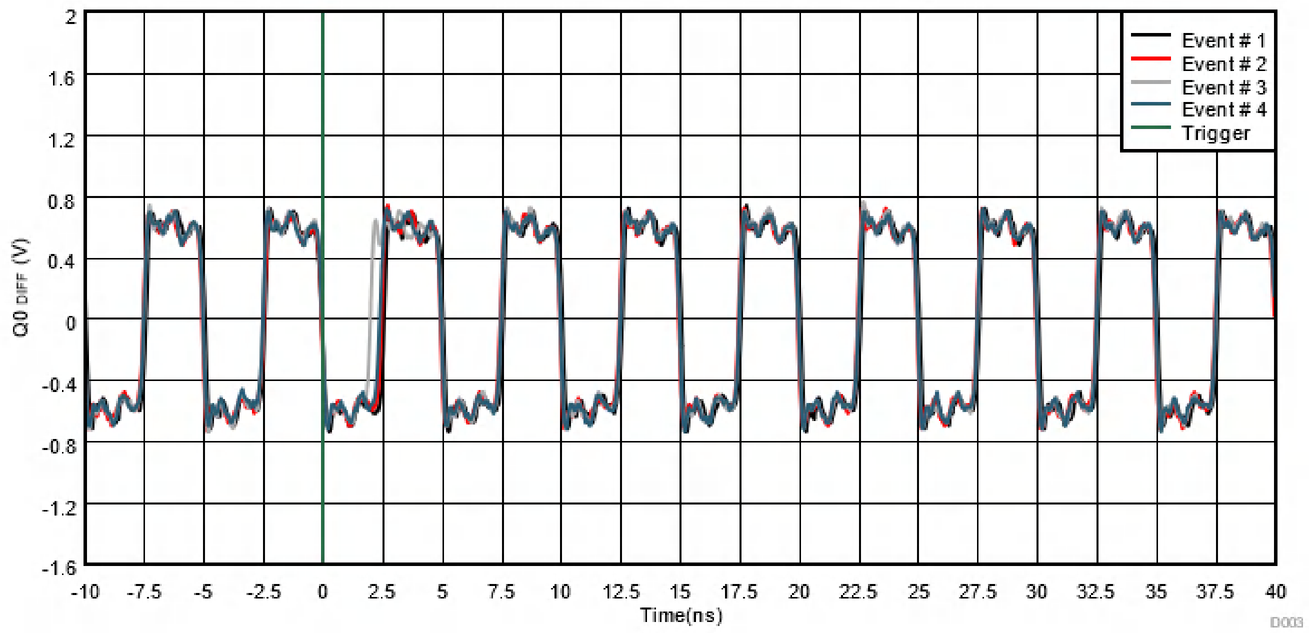

Figure 8-4. Time Domain Plot of Events on Run 7 Positive Pulse Width Trigger

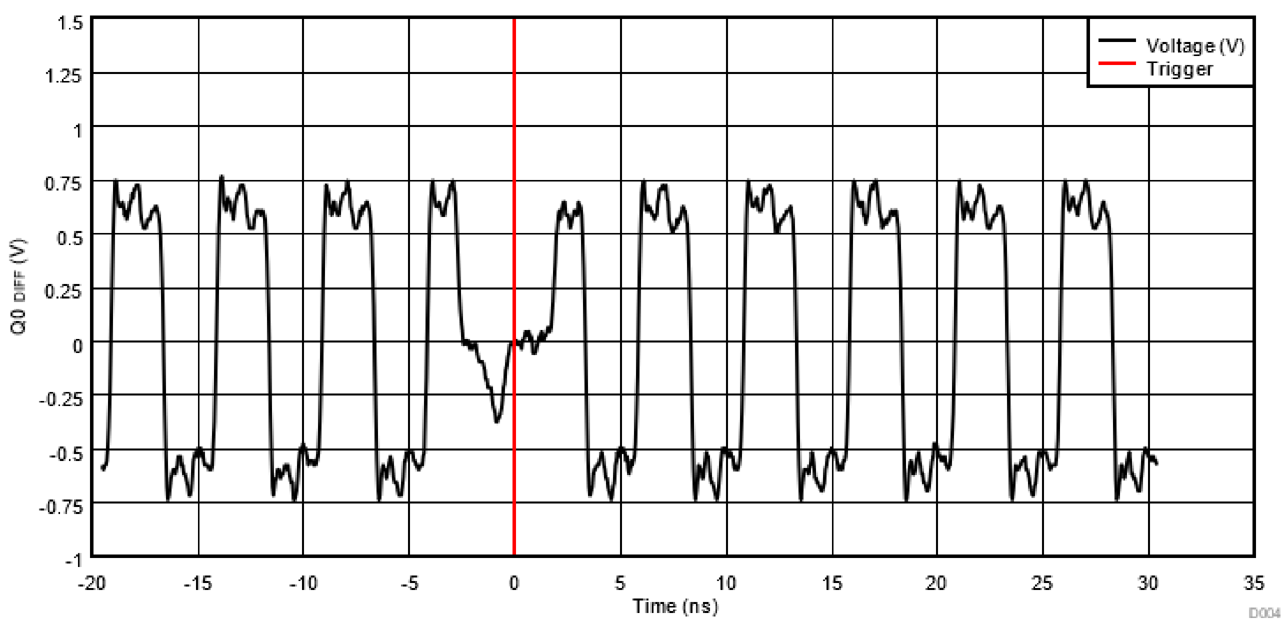

Figure 8-5. Time Domain Plot of Event 2 on Run 32 Negative Pulse Width Trigger

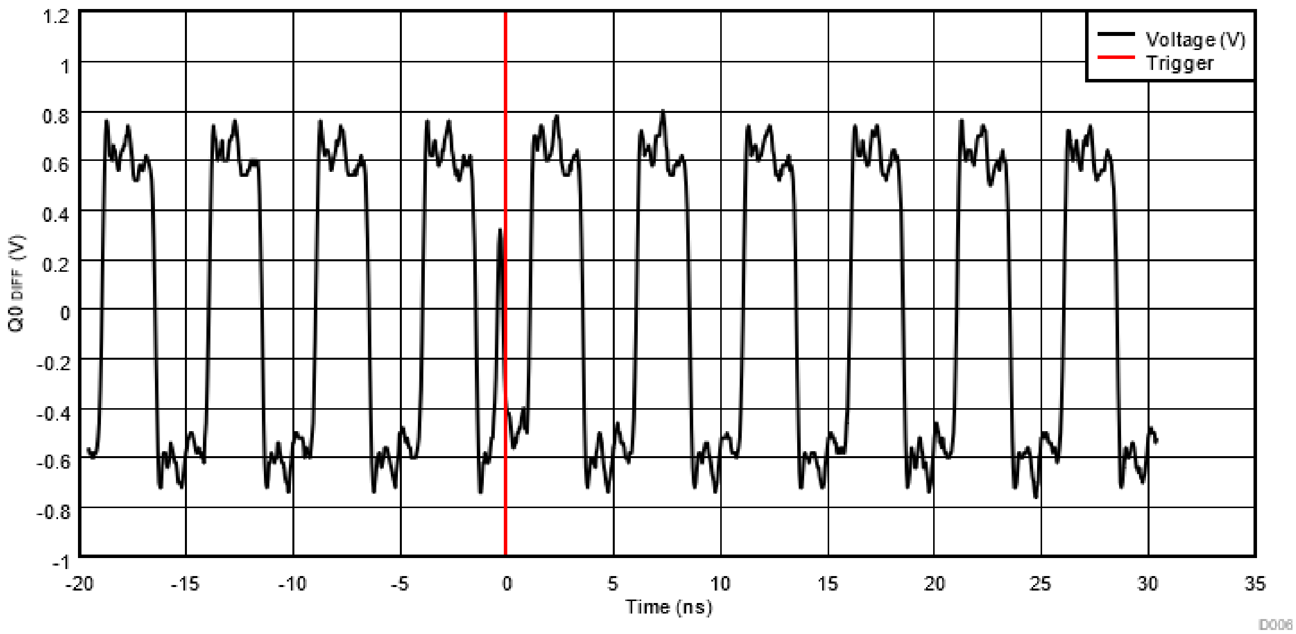

Figure 8-6. Time Domain Plot of Event 6 on Run 56 Runt Trigger

9 Summary

The goal of this study was to characterize the effect of heavy-ion irradiation on the single-event effect (SEE) performance of the CDCLVP111-SEP 1:10 LVPECL Clock Distributor. Table 9-1 shows a tabulated summary of the results of all of the SEE testing. Heavy-ions with LET_{EFF} ranging from 2.79 to 47.5MeVcm^2/mg were used to irradiate four production devices in 76 experiments with heavy-ion fluences ranging from 1×10^6 to 1×10^7 ions/cm^2 per run. The results demonstrate that the CDCLVP111-SEP is SEL free up to LET_{EFF} = 47.5MeVcm^2/mg.

The results demonstrate that SET occurs at a low onset but with a small saturation cross section. All of the observed SET events were also transitory, recovering fully within one clock cycle of the event. The presented summary is based on the characterization based at 200MHz, minimum voltage, and mean cross-sectional value.

Table 9-1. Summary of Results for all SEE Testing for CDCLVP111-SEP

LET (MeV·cm^2/mg)	SET				SEL
	Window	Runt	Pulse Width Positive	Pulse Width Negative	
2.79	SET - Free	SET - Free	SET - Free	SET - Free	-
8.681	SET - Free	≤ 4.98 × 10^{-7}	≤ 1× 10^{-6}	≤ 2.06 × 10^{-6}	-
12.39	SET - Free	≤ 1.52 × 10^{-6}	≤ 2.99 × 10^{-6}	≤ 2.5 × 10^{-6}	-
30.79	SET - Free	≤ 8.29 × 10^{-6}	≤ 1.35 × 10^{-6}	≤ 1.22 × 10^{-6}	-
44.12	SET - Free	≤ 1.21 × 10^{-6}	≤ 1.04 × 10^{-6}	≤ 1.45 × 10^{-6}	-
47.5	-	-	-	-	SEL - Free

A References

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