Radiation Report

SN54SC8T165-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 SN54SC8T165-SEP. SEE performance was verified at minimum (1.2V) and maximum (5.5V) operating conditions. Heavy-ions with an LET_{EFF} of 50MeV-cm^2/ mg were used to irradiate three production devices with a fluence of 1×10^7 ions / cm^2. The results demonstrate that the SN54SC8T165-SEP is SEL-free up to LET_{EFF} = 50MeV-cm^2 / mg as 125°C. SET performance at minimum and maximum operating voltages saw no excursions ≥ |1%| , as shown and discussed in this report.

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1 Overview

The SN54SC8T165-SEP is a radiation-tolerant, 1.2V to 5.5V 8-bit shift registers with 3-state output and logic level shifter. The input is designed with a lower threshold circuit to support up translation for lower voltage CMOS inputs (for example, 1.2V input to 1.8V output or 1.8V input to 3.3V output). In addition, the 5V tolerant input pins enable down translation (for example, 3.3V to 2.5V output).

For more information, see the SN54SC8T165-SEP product page.

Table 1-1. Overview Information

Description	Device Information
TI Part Number	SN54SC8T165-SEP
Orderable Part Number	SN54SC8T165MPWTSEP
VID Number	V62/25625
Device Function	Radiation-tolerant, 1.2V to 5.5V, Parallel-Load 8-Bit Shift Registers
Technology	LBC9
Exposure Facility	Facility for Rare Isotope Beams (FRIB) at Michigan State University – FRIB Single Event Effects (FSEE) Facility
Heavy Ion Fluence per Run	1×10^7 ions / cm^2
Irradiation Temperature	25°C (for SET testing) and 125°C (for SEL testing)

2 Single-Event Effects (SEE)

The primary single-event effect (SEE) event of interest in the SN54SC8T165-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 (LBC9) process used for SN54SC8T165-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 SN54SC8T165-SEP exhibited no SEL with heavy-ions up to an LET_{EFF} of 50MeV-cm^2 / mg at a fluence of 1×10^7 ions / cm^2 and a chip temperature of 125°C.

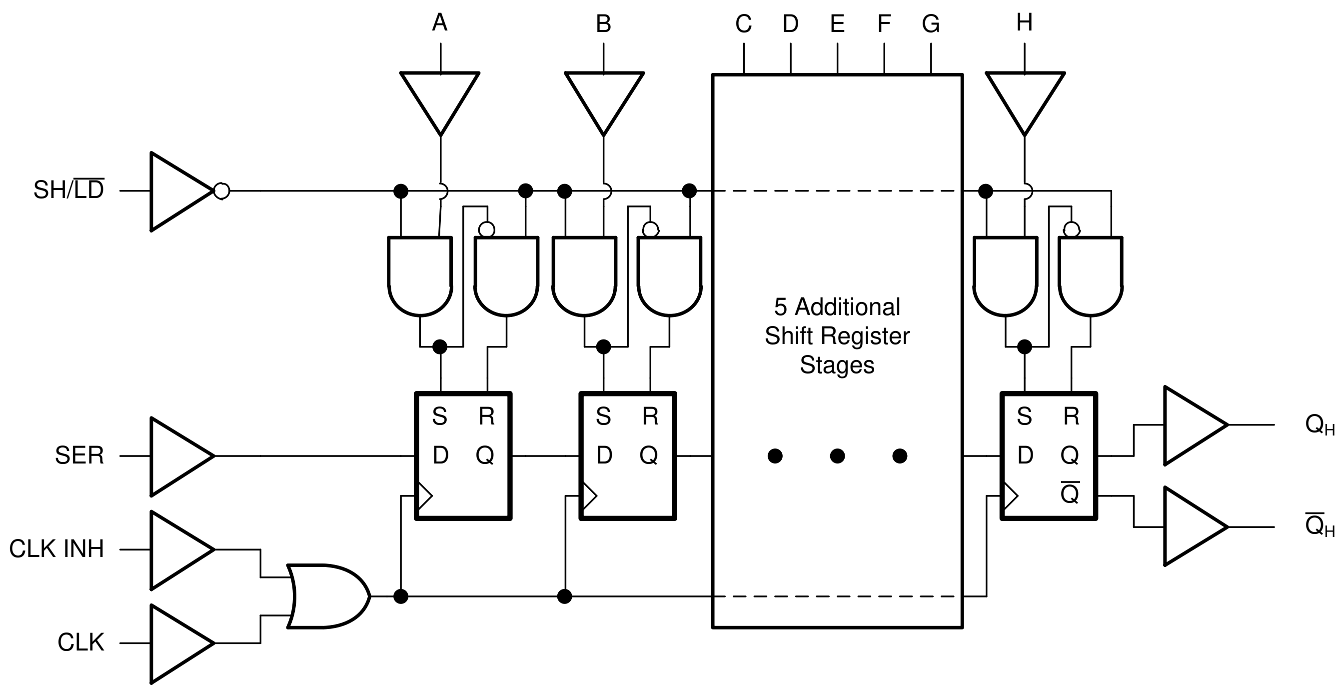

Figure 2-1. Functional Block Diagram of the SN54SC8T165-SEP

3 Test Device and Test Board Information

The SN54SC8T165-SEP is a packaged 16-pin, TSSOP plastic package shown in the pinout diagram in Figure 3-1. Figure 3-2 shows the device with the package cap 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 diagram used for Single-Event Latch-up (SEL) testing. Figure 3-5 and Figure 3-6 show the bias diagrams used for Single-Event Transient (SET) testing.

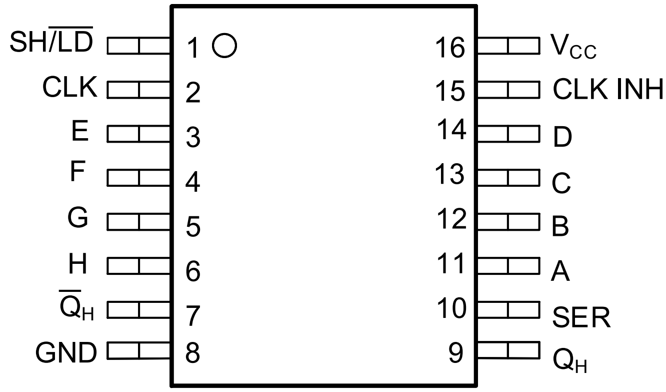

Figure 3-1. SN54SC8T165-SEP Pinout Diagram

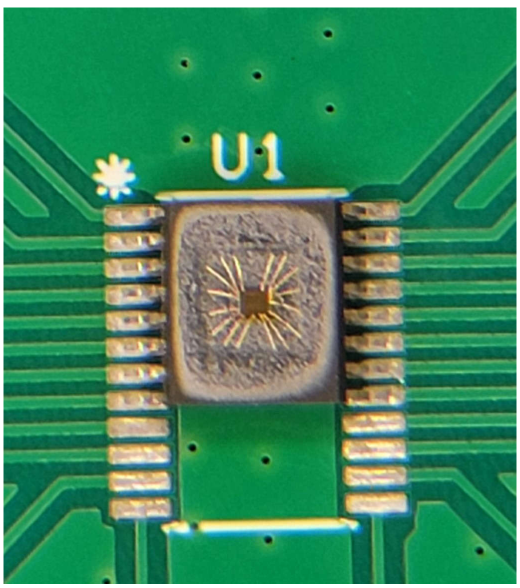

Figure 3-2. Photo of SN54SC8T165-SEP Package Decapped

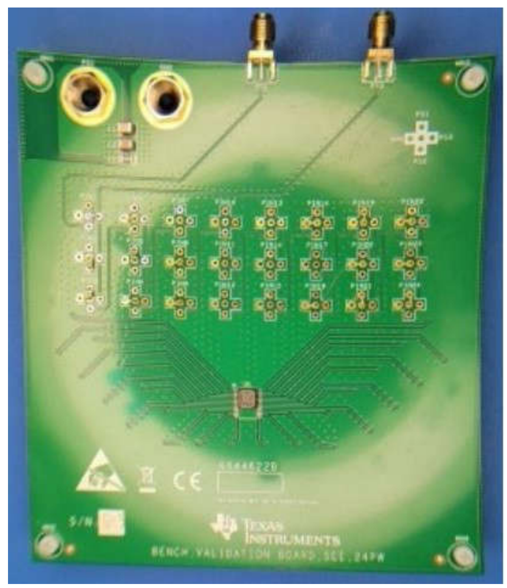

Figure 3-3. SN54SC8T165-SEP Evaluation Board (Top View)

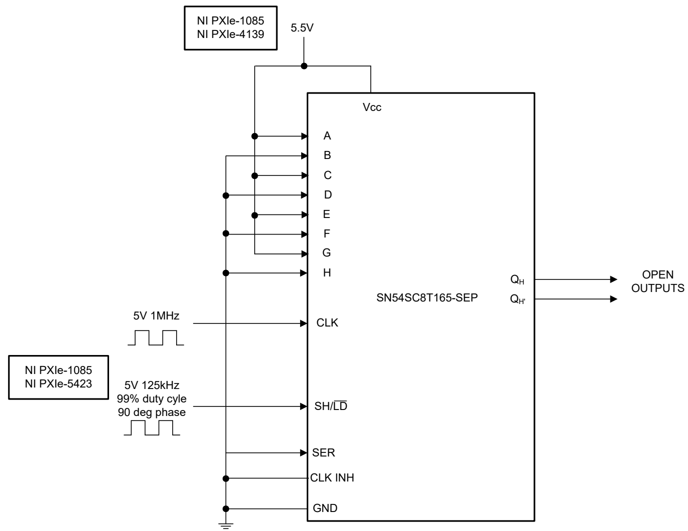

Figure 3-4. SN54SC8T165-SEP SEL Bias Diagram

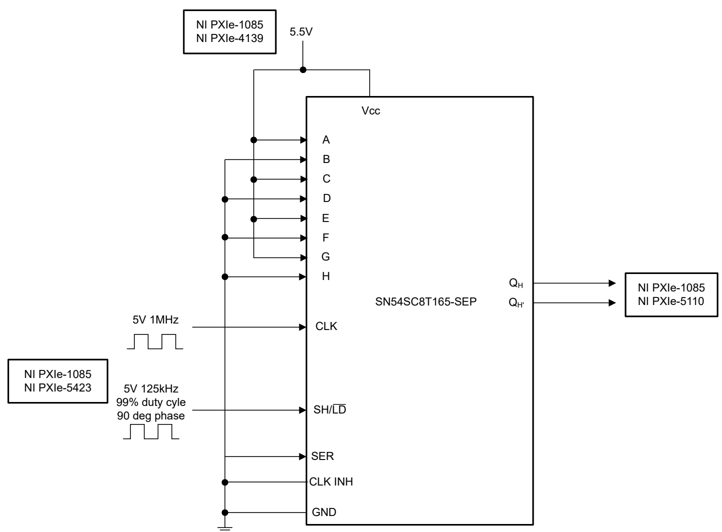

Figure 3-5. SN54SC8T165-SEP SET 5.5V Bias Diagram

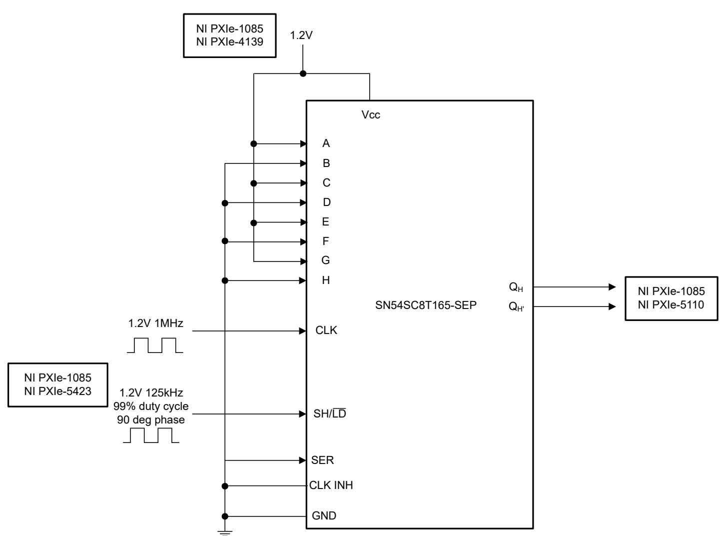

Figure 3-6. SN54SC8T165-SEP SET 1.2V Bias Diagram

4 Irradiation Facility and Setup

The heavy ion species used for the SEE studies on this product were provided and delivered by the Facility for Rare Isotope Beams (FRIB) at Michigan State University (FRIB Single Event Effects (FSEE) Facility's linear accelerator.) The FSEE Facility has a dedicated beamline built on the FRIB linac infrastructure with a user experimental station at the end of the FSEE beamline. Ion beams are delivered with high uniformity over a 1-inch diameter exposure area using a thin vacuum window. For this study, ion flux of 1 × 10^5 ions / cm^2-s was used to provide heavy ion fluence of 1 × 10^7 ions / cm^2 using ^{129}Xe ion at a linac energy of 25 MeV / μ. Ion beam uniformity for all tests was 96.16%.

Figure 4-1 shows one of the three SN54SC8T165-SEP test boards used for experiments at the MSU facility. The in-air gap between the device and the ion beam port window was maintained at 70mm for all runs.

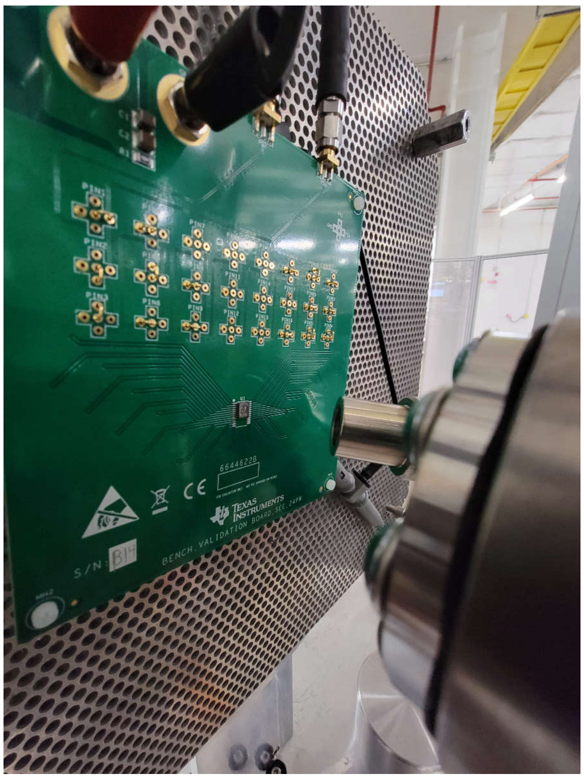

Figure 4-1. SN54SC8T165-SEP Evaluation Board at the MSU Facility

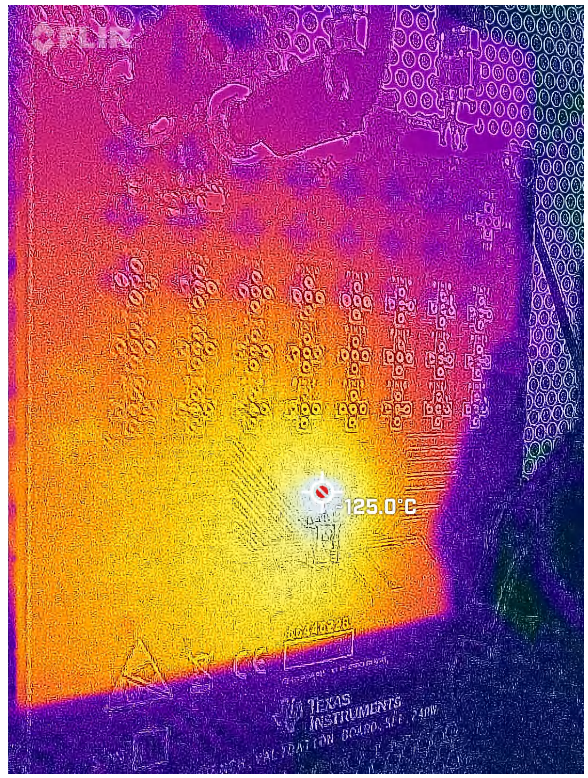

Figure 4-2. SN54SC8T165-SEP Thermal Image for SEL

5 Results

5.1 SEL Results

During SEL characterization, the device was heated using forced hot air, maintaining device temperature at 125°C. A FLIR (FLIR ONE Pro LT) thermal camera was used to validate die temperature to make sure the device was accurately heated (see Figure 4-2.) The species used for SEL testing was a Xenon (^{129}Xe) ion at 25MeV / μ with an angle-of-incidence of 0° for an LET_{EFF} of 50MeV-cm^2/ mg. A fluence of approximately 1 × 10^7 ions / cm^2 was used for each run.

The three devices were powered up and exposed to the heavy-ions using the maximum recommended supply voltage of 5.5V using a National Instruments™ PXI Chassis PXIe-4139 and a 5V, 1MHz and 125kHz square wave input using a National Instruments™ PXI Chassis PXIe-5423 function generator. The run duration to achieve this fluence was approximately 100 seconds. As listed in Table 5-1, no SEL events were observed during the nine runs, indicating that the SN54SC8T165-SEP is SEL-free. Figure 5-1, Figure 5-2, and Figure 5-3 show the plots of current versus time for runs two, eighteen, and twenty-six, respectively.

Table 5-1. Summary of SN54SC8T165-SEP SEL Test Conditions and Results

Run Number	Unit Number	Distance (mm)	Temperature (°C)	Ion	Angle	Flux (ions × cm^2 / mg)	Fluence (Number of ions)	LET_{EFF} (MeV × cm^2/mg)	Did an SEL Event Occur?
2	B12	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
3	B12	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
4	B12	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
17	B15	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
18	B15	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
19	B15	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
24	B14	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
25	B14	70	125	Xe	0°	1.00E+05	1.00E+07	50	No
26	B14	70	125	Xe	0°	1.00E+05	1.00E+07	50	No

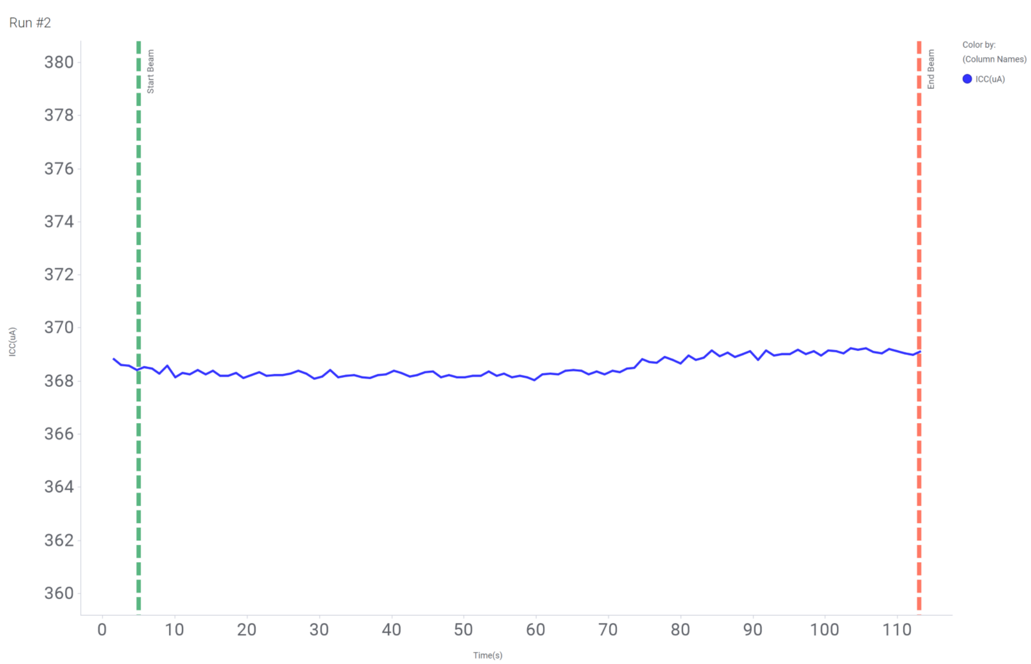

Figure 5-1. Current versus Time for Run 2 of the SN54SC8T165-SEP at T = 125°C

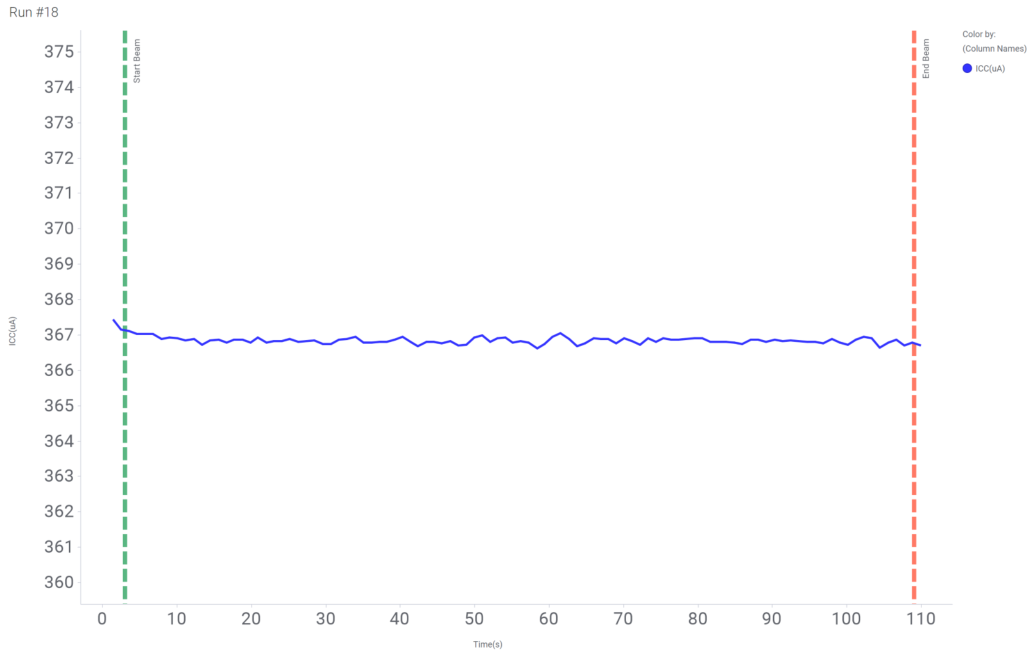

Figure 5-2. Current versus Time for Run 18 of the SN54SC8T165-SEP at T = 125°C

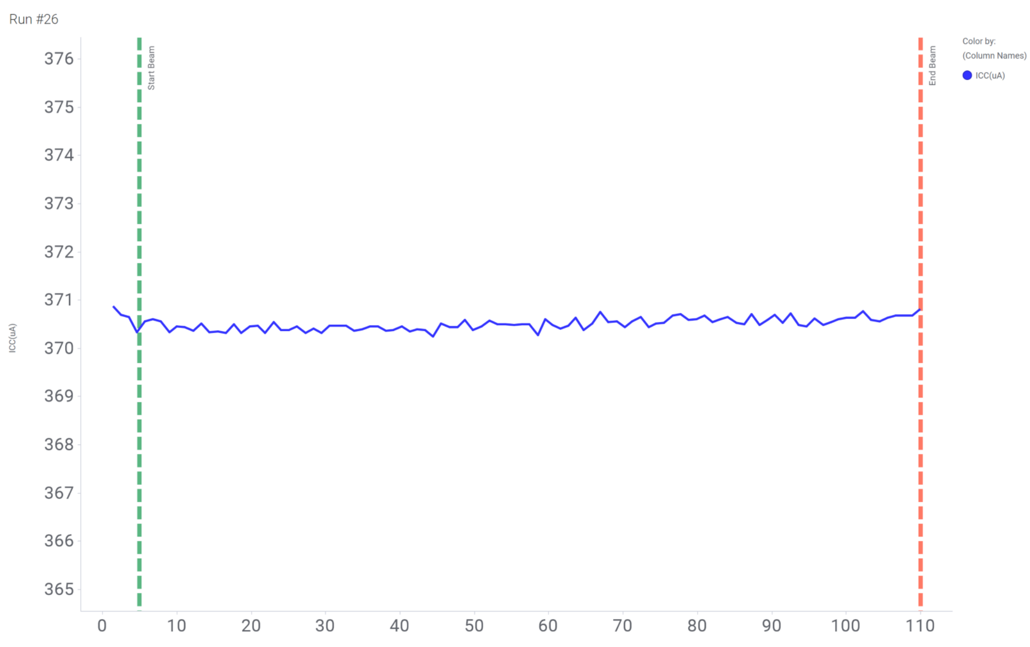

Figure 5-3. Current versus Time for Run 26 of the SN54SC8T165-SEP at T = 125°C

No SEL events were observed, indicating that the SN54SC8T165-SEP is SEL-immune at LET_{EFF} = 50MeV-cm^2 / mg and T = 125°C. Using the MFTF method shown in Single-Event Effects (SEE) Confidence Internal Calculations , the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{SEL} \leq 4.10 \times 10^{-8} cm^2/\text{device for } LET_{EFF} = 50\ MeV \cdot cm^2/mg \text{ and } T = 125°C \quad (1)$$

5.2 Single-Event Transients (SET)

SETs are defined as heavy-ion-induced transient upsets on output pin Q_H of the SN54SC8T165-SEP. SET testing was performed at room temperature (no external temperature control applied). The species used for the SET testing was ^{129}Xe for a LET_{EFF} = 50MeV × cm^2 / mg. Flux of approximately 10^5 ions / cm^2 × s and a fluence of approximately 10^7 ions / cm^2 were used for the SET runs.

Three units were tested across multiple input conditions to determine the worst-case setup for SETs. The unit was tested with V_{CC} of 1.2V and 5.5V and a rising edge window trigger of ±1%, ±2%, ±3% and ±5%. All combinations of VCC and window triggers showed no transient upsets, as listed in Table 5-2

To capture SETs, one NI PXI-5110 scope card was used to continuously monitor the output voltage on pin Q_H. The NI scope was programmed to a sample rate of 100M samples per second (S/s) and recorded 2k samples, with a 20% pretrigger reference, in case of an event (trigger). Under heavy-ions, the SN54SC8T165-SEP did not exhibit any transient upsets.

Table 5-2. Summary of SN54SC8T165-SEP SET Test Condition and Results

Run Number	Unit Number	Voltage Level	Ion	LET_{EFF} (MeV × cm^2/mg)	FLUX (ions × cm^2/ mg)	Fluence (Number ions)	Window Trigger	SET Upsets
9	B12	5.5V	Xe	50	1.00E+05	1.00E+07	5%	0
10	B12	5.5V	Xe	50	1.00E+05	1.00E+07	3%	0
11	B12	5.5V	Xe	50	1.00E+05	1.00E+07	2%	0
12	B12	5.5V	Xe	50	1.00E+05	1.00E+07	1%	0
13	B12	1.2V	Xe	50	1.00E+05	1.00E+07	5%	0
14	B12	1.2V	Xe	50	1.00E+05	1.00E+07	3%	0
15	B12	1.2V	Xe	50	1.00E+05	1.00E+07	2%	0
16	B12	1.2V	Xe	50	1.00E+05	1.00E+07	1%	0
20	B15	5.5V	Xe	50	1.00E+05	1.00E+07	2%	0
21	B15	5.5V	Xe	50	1.00E+05	1.00E+07	1%	0
22	B15	1.2V	Xe	50	1.00E+05	1.00E+07	2%	0
23	B15	1.2V	Xe	50	1.00E+05	1.00E+07	1%	0
27	B14	5.5V	Xe	50	1.00E+05	1.00E+07	1%	0
28	B14	1.2V	Xe	50	1.00E+05	1.00E+07	1%	0

5.3 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*. 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.) Using the 95% upper-bounds for the SEL and the SET, the event rate calculations for the SEL are listed in Table 5-3 and Table 5-4, respectively. Note that this number is for reference since no SEL or SET events were observed.

Table 5-3. SEL Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2 / mg)	CREME96 Integral FLUX (per day / cm^2)	σSAT (cm^2)	Event Rate (per day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	50	3.80×10^{-4}	4.10×10^{-8}	1.56×10^{-11}	6.48×10^{-4}	1.76×10^{8}
GEO		1.23×10^{-3}		5.04×10^{-11}	2.10×10^{-3}	5.43×10^{7}

Table 5-4. SET Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2 / mg)	CREME96 Integral FLUX (per day / cm^2)	σSAT (cm^2)	Event Rate (per day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	50	3.80×10^{-4}	2.63×10^{-8}	1.00×10^{-11}	4.17×10^{-4}	2.74×10^{8}
GEO		1.23×10^{-3}		3.24×10^{-11}	1.35×10^{-3}	8.45×10^{7}

MTBE is the mean-time-between-events in years at the given event rates. These rates clearly demonstrate the SEE robustness of the SN54SC8T165-SEP in two harshly conservative space environments. Customers using the SN54SC8T165-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.

6 Summary

The purpose of this study was to characterize the effects of heavy-ion irradiation on the single-event latch-up (SEL) performance of the SN54SC8T165-SEP radiation-tolerant, 1.2V to 5.5V parallel-load 8-bit shift registers. SEE performance was verified at minimum (1.2V) and maximum (5.5V) operating conditions. Heavy-ions with an LET_{EFF} of 50MeV-cm^2/ mg were used to irradiate three production devices with a fluence of 1 × 10^7 ions / cm^2. The results demonstrate that the SN54SC8T165-SEP is SEL-free up to LET_{EFF} = 50MeV-cm^2/ mg as 125°C. SET performance for the minimum and maximum operating voltage saw no excursions ≥ |1%|, as shown and discussed in this report. CREME96-based worst week event-rate calculations for LEO(ISS) and GEO orbits for the SEL and SET 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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3. Texas A&M University, *Texas A&M University Cyclotron Institute Radiation Effects Facility*, webpage.
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8. 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.