Radiation Report

TMP9R00-SP Single-Event Effects (SEE) Radiation Test Report

ABSTRACT

This report characterizes the effects of heavy-ion irradiation on the single-event effect (SEE) performance of the TMP9R00-SP 9-channel temperature sensor. Heavy ions with a LET_{EFF} of 76 MeV-cm^2 /mg was used to irradiate the devices with a fluence of 1 × 107 ions/cm^2. The results demonstrate that the TMP9R00-SP is SEL-free up to LET_{EFF} = 76 MeV-cm^2 /mg at 125°C, and a dynamic SET cross section is presented.

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1 Introduction

The TMP9R00-SP device is a radiation-hardened, high-accuracy, low-power 8-channel remote temperature sensor monitor with a built-in local temperature sensor. The remote temperature sensors are typically low-cost discrete NPN or PNP transistors, or substrate thermal transistors or diodes that are integral parts of microprocessors, analog-to-digital converters (ADC), digital-to-analog converters (DAC), microcontrollers, or field-programmable gate arrays (FPGA). Temperature is represented as a 13-bit digital code for both local and remote sensors, giving a resolution of 0.0625°C. The two-wire serial interface accepts the SMBus communication protocol with up to four different pin-programmable addresses.

Table 1-1 lists general device information and test conditions. See the TMP9R00-SP Product Page for more detailed technical specifications, user-guides, and application notes.[1]

Table 1-1. Overview Information

Description	Device Information(1)
TI Part Number	TMP9R00-SP
SMD Number	5962R2021401VXC
Device Function	Remote and Local Digital Temperature Sensor
Technology	LCB8LV
Exposure Facility	Facility for Rare Isotope Beams, Michigan State University
Heavy Ion Fluence per Run	1×10^6 – 1×10^7 ions/cm^2
Irradiation Temperature	25°C (SET) and 125°C (SEL)

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2 SEE Mechanisms

The primary SEE events of interest in the TMP9R00-SP are single-event latch-up (SEL), single-event burn-out (SEB) and single-event transient (SET). From a risk and impact point-of-view, the occurrence of an SEL and SEB is potentially the most destructive SEE event and the biggest concern for space applications. In mixed technologies such as the LBC8LV process used for the TMP9R00-SP, the CMOS circuitry introduces a potential for SEL and SEB susceptibility. SEL can occur if excess current injection caused by the passage of an energetic ion is high enough to trigger the formation of a parasitic cross-coupled PNP and NPN bipolar structure (formed between the p-sub and n-well and n+ and p+ contacts). 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 TMP9R00-SP exhibited no SEL with heavy ions up to an LET_{EFF} of 75 MeV-cm^2/mg at a fluence of 10^7 ions/cm^2 and a chip temperature of 125°C. This study was performed to evaluate the cross section and transient effects with a bias voltage of 1.7 V and 2.0 V. To capture different SET signature events, the trigger was set with ±1.5° variance. Heavy ions with LET_{EFF} 69, 48, and 8 MeV-cm^2/mg were used to irradiate the devices. Flux of 10^4 ions/s-cm^2 and fluence of 10^6 ions/cm^2 were used during the exposure at room temperature. The output temperature data was processed and analyzed.

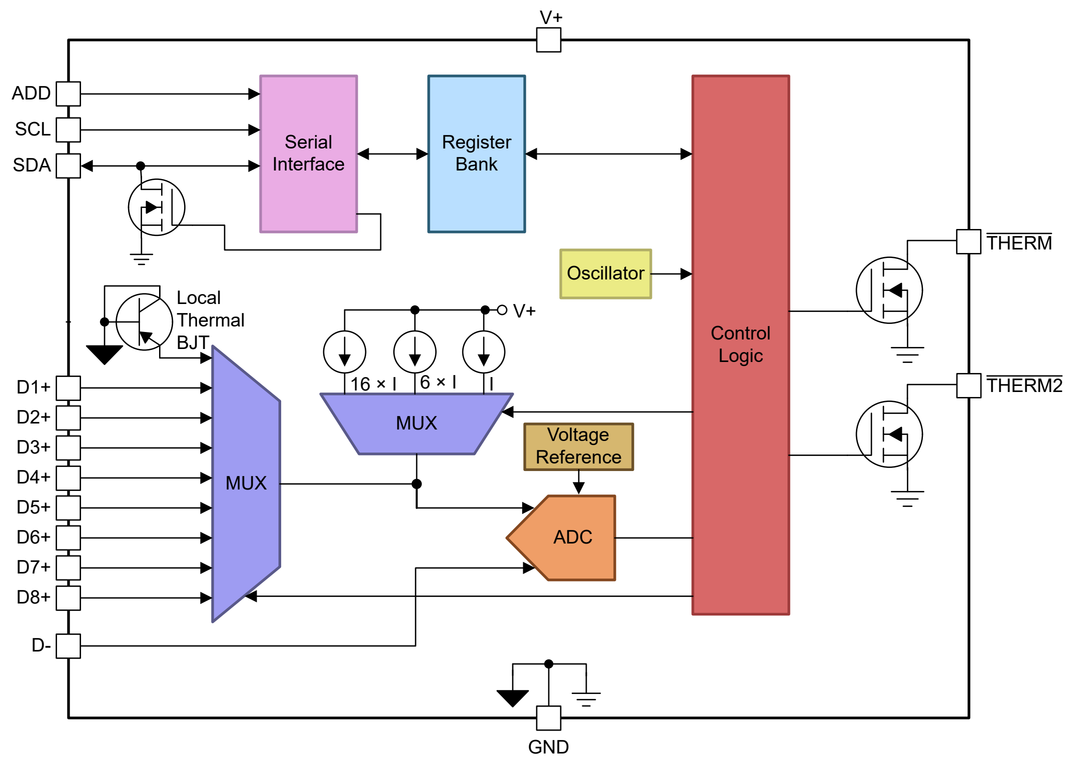

Figure 2-1. Functional Block Diagram of the TMP9R00-SP

2.1 Test Device and Test Board Information

The TMP9R00-SP is packaged in a 16-pin, thermally enhanced, dual-ceramic flat-pack package (CFP) shown with the pinout in Figure 2-2.

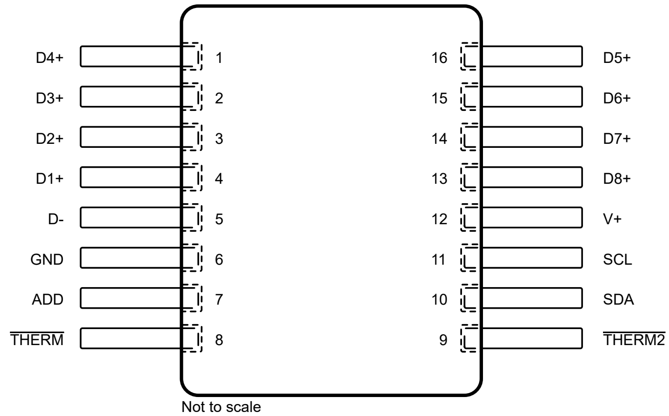

Figure 2-2. TMP9R00-SP HKT Package 16-Pin CFP Top View

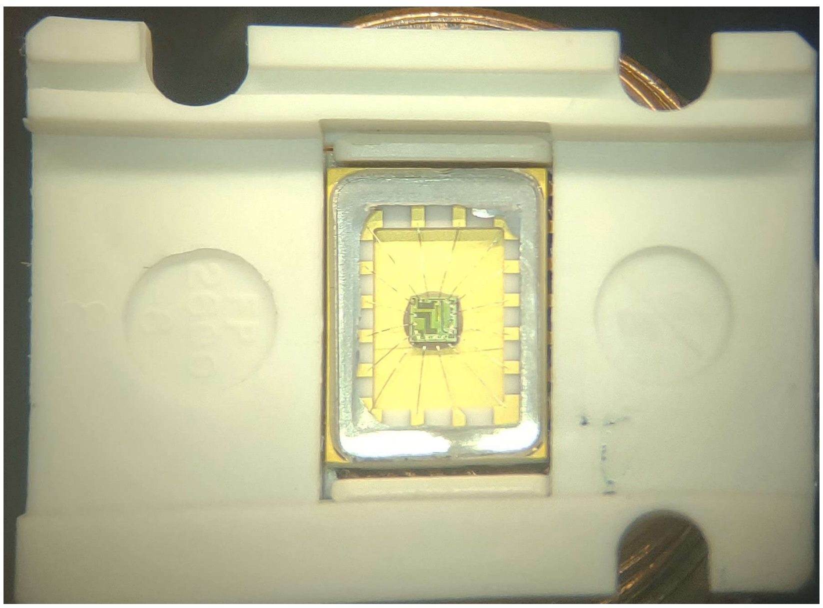

Figure 2-3. Delidded TMP9R00-SP

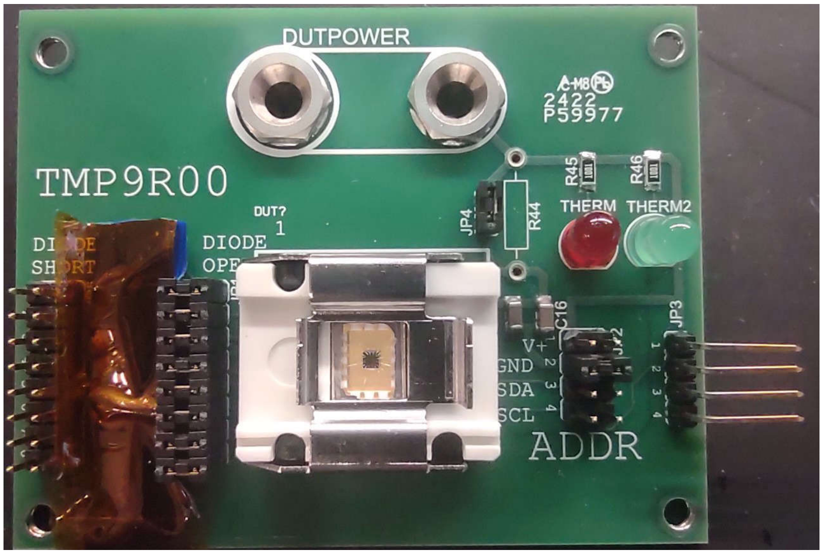

Figure 2-4. TMP9R00-SP Board Top View

3 Irradiation Facility and Setup

The heavy ion species used for the SEL 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. The ion species for SET testing were provided by the MSU Facility for Rare Isotope Beams using a heavy-ion particle accelerator.

Ion beams are delivered with high uniformity over a 1-in diameter circular cross-sectional area for the in-air station. Uniformity is achieved by means of magnetic defocusing. The intensity of the beam is regulated over a broad range spanning several orders of magnitude. For the bulk of these studies, ion fluxes between 10^4 and 10^5 ions/s-cm^2 were used to provide heavy-ion fluences between 10^6 and 10^7 ions/cm^2. For these experiments Thulium (Tr), Xenon (Xe), and Argon (Ar) ions were used. The air space between the device and the ion beam port window was maintained at 70 mm for all runs. For more information on the effective LET range and depth for the experiments, see Table 3-1.

Table 3-1. Ions and LET_{EFF} Used for SEE Characterization

Ion Type	Angle of Incidence	FLUX (ions·cm^2/mg)	FLUENCE (# ions)	LET_{EFF} (MeV-cm^2/mg)
Tr	0°	1.00×10^5	1.00×10^7	66
Tr	29°	1.00×10^5	1.00×10^7	75
Xe	0°	1.00×10^4	1.00×10^6	69
Xe	0°	1.00×10^4	1.00×10^6	48
Ar	0°	1.00×10^4	1.00×10^6	8

3.1 SEL Results

During SEL characterization, the device was heated using forced hot air, maintaining the die temperature at 125°C. The temperature was monitored by means of a K-type thermocouple attached as close as possible to the die. The species used for the SEL testing was a Thulium ion with angle of incidence at 0° and 29° for an LET_{EFF} = 66 and 75 MeV-cm^2/mg. A flux of approximately 10^5 ions/cm^2 -s and a fluence of approximately 10^7 ions were used for all runs. The V_{CC} voltage was set to the recommended maximum at 2.0 V. No SEL events were observed during both runs, as shown in Table 3-2. The resulting graph of current vs time is detailed in Figure 3-1.

Table 3-2. TMP9R00-SP SEL Conditions Using Tr with Angle = 0° and 29°

Run #	Distance (mm)	Temperature (°C)	Ion Type	Angle of Incidence	Flux (ions·cm^2/mg)	Fluence (ions/cm^2)	LET_{EFF} (MeV-cm^2/mg)
1	40	125	Tr	0°	1.00 × 10^5	1.00 × 10^7	66
2	40	125	Tr	29°	1.00 × 10^5	1.00 × 10^7	75

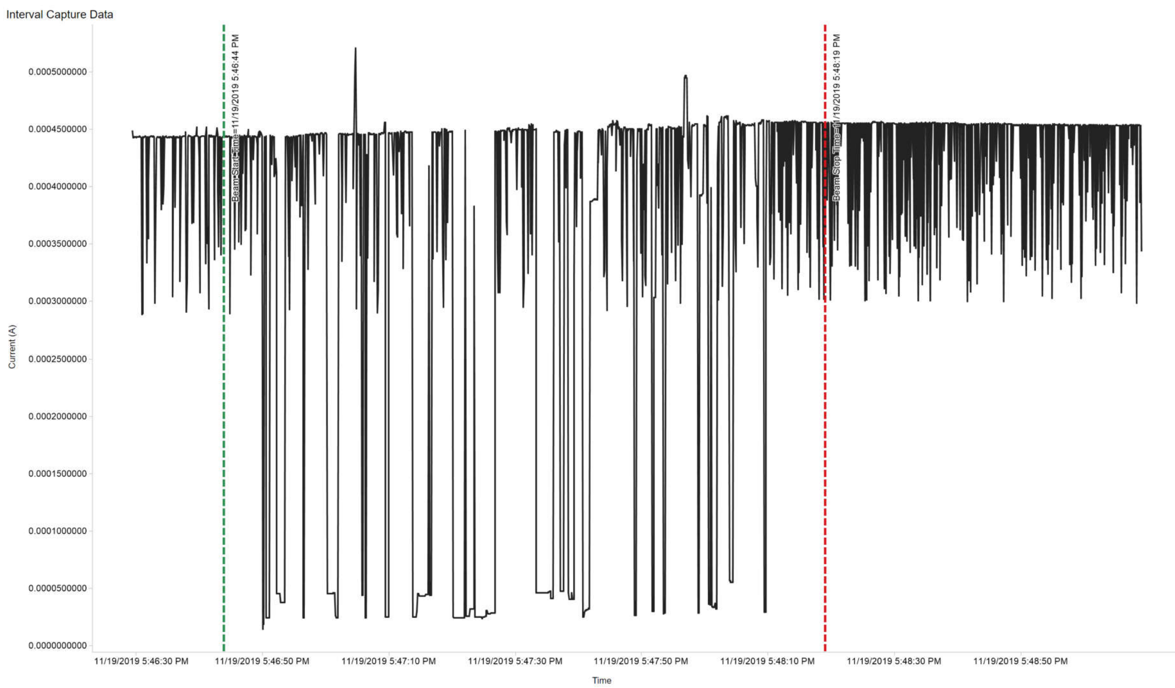

Figure 3-1. Current vs Time for V_{CC} Supply During SEL Run #2

3.2 SET Results

In the case of the TMP9R00-SP, SETs were categorized as heavy-ion induced events that create a fully recoverable transient (±1.5°C) on the temperature output. Such variations were monitored and captured in software, and a data point was recorded any time the trigger condition was achieved. All SET data was collected at room temperature with a 70-mm air gap. Events are recorded separately for the local channel and each remote channel.

Initial temperature readings were recorded for the local channel and each remote channel. All device registers were read in 350-ms intervals and the current temperature readings were compared with the initial readings to record all events that exceeded ±1.5°C. To make sure that previous transients were not affecting subsequent register reads, a device reset was issued between each measurement. The TMP9R00-SP registers can be software reset by setting bit 15 of the Software Reset register (20h) to 1. This software reset restores the power-on-reset state to all TMP9R00-SP registers and aborts any conversion in progress.

Table 3-3. Summary of TMP9R00-SP SET Results

Run #	Ion Type	Angle of Incidence	LET_{EFF} ($MeV \cdot cm^2/mg$)	Flux ($ions \cdot cm^2/mg$)	Fluence ($ions/cm^2$)	V+ (V)	Total # of Events
19	Xe	0°	69	1.00×10^4	1.00×10^6	2	**13**
20	Xe	0°	69	1.00×10^4	1.00×10^6	1.7	**11**
21	Xe	0°	69	1.00×10^4	1.00×10^6	1.7	**25**
22	Xe	0°	48	1.00×10^4	1.00×10^6	2	**8**
23	Xe	0°	48	1.00×10^4	1.00×10^6	2	**17**
24	Xe	0°	48	1.00×10^4	1.00×10^6	1.7	**8**
26	Xe	0°	48	1.00×10^4	1.00×10^6	1.7	**8**
28	Ar	0°	8	1.30×10^4	1.00×10^6	2	**0**
29	Ar	0°	8	1.30×10^4	1.00×10^6	2	**1**
30	Ar	0°	8	1.30×10^4	1.00×10^6	2	**1**
31	Ar	0°	8	1.00×10^4	1.00×10^6	2	**0**
32	Ar	0°	8	1.00×10^4	1.00×10^6	2	**0**
33	Ar	0°	8	1.00×10^4	1.00×10^6	2	**0**
34	Ar	0°	8	1.00×10^4	1.00×10^6	2	**0**
35	Ar	0°	8	1.00×10^4	1.00×10^6	1.7	**0**
36	Ar	0°	8	1.00×10^4	1.00×10^6	1.7	**0**
37	Ar	0°	8	1.00×10^4	1.00×10^6	1.7	**0**
38	Ar	0°	8	1.00×10^4	1.00×10^6	1.7	**0**

Table 3-4. SET Results by Channel

Run #	Local Channel	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
19	0	1	1	4	3	0	1	2	1
20	0	2	0	1	3	1	2	0	2
21	1	1	0	2	3	3	4	4	7
22	0	1	1	1	2	1	1	1	0
23	0	3	1	2	2	1	2	3	3
24	0	3	1	0	0	1	0	1	2
26	0	1	2	0	3	1	0	0	1
28	0	0	0	0	0	0	0	0	0
29	0	0	1	0	0	0	0	0	0
30	0	0	0	0	0	0	0	1	0
31	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0

3.2.1 Histogram of Temperature Events Exceeding ±1.5°C

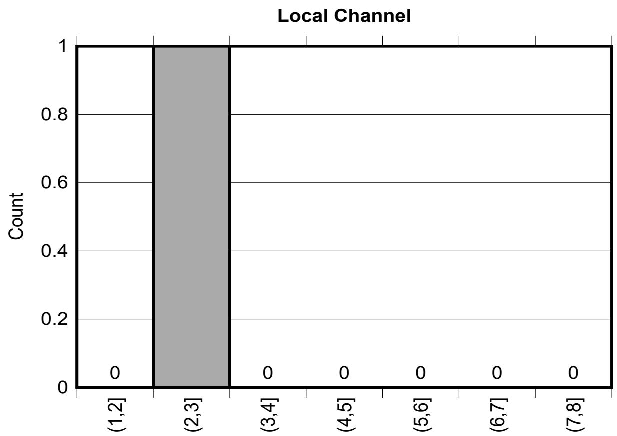

Figure 3-2. Local Channel

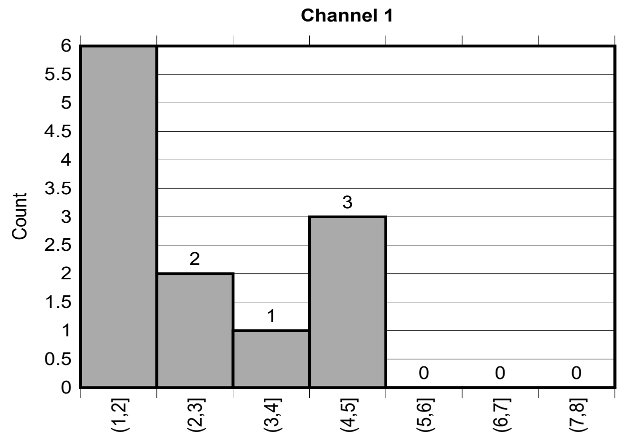

Figure 3-3. Channel 1

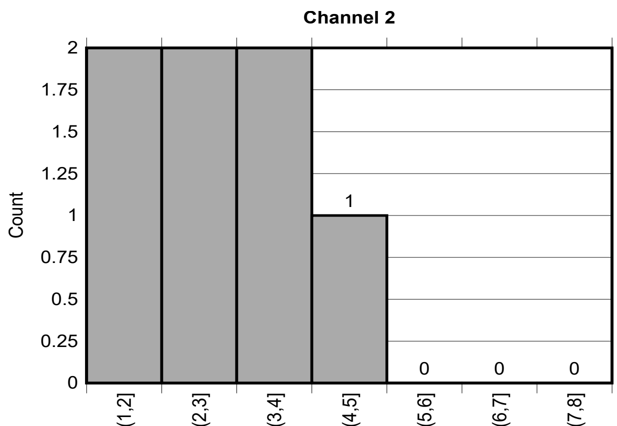

Figure 3-4. Channel 2

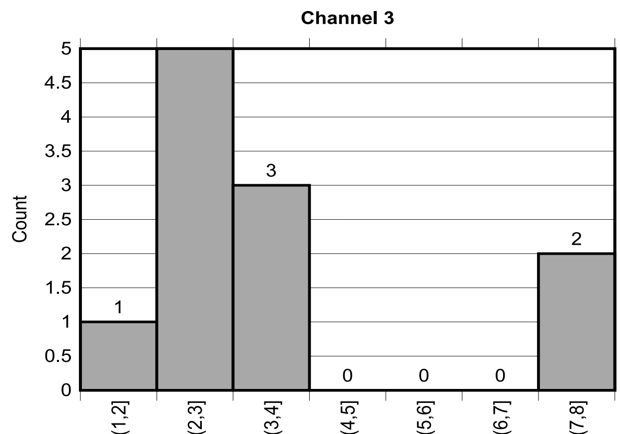

Figure 3-5. Channel 3

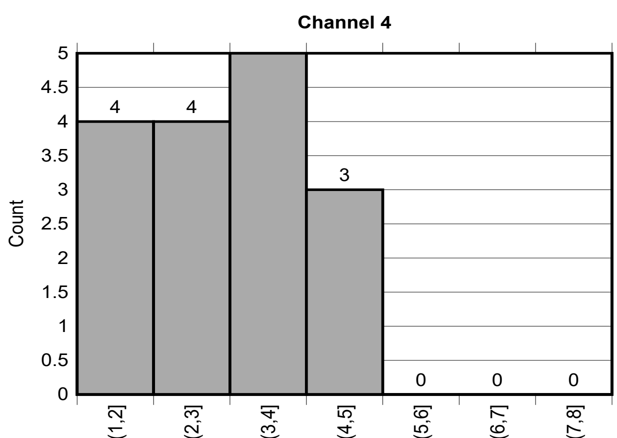

Figure 3-6. Channel 4

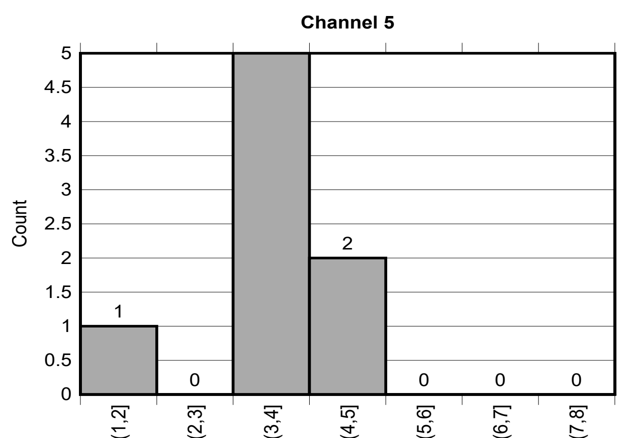

Figure 3-7. Channel 5

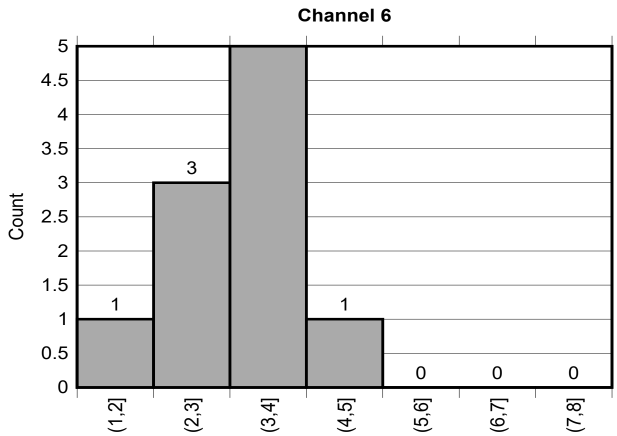

Figure 3-8. Channel 6

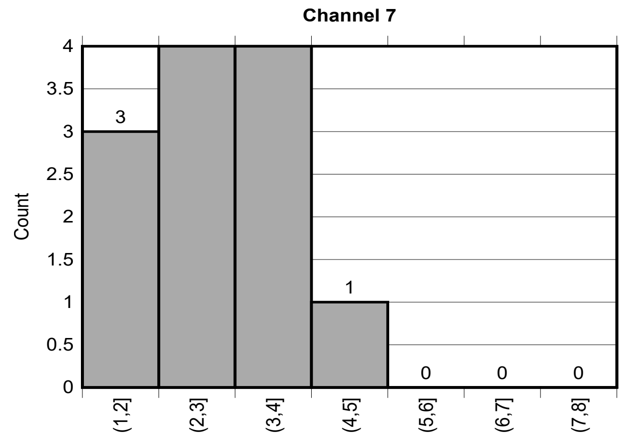

Figure 3-9. Channel 7

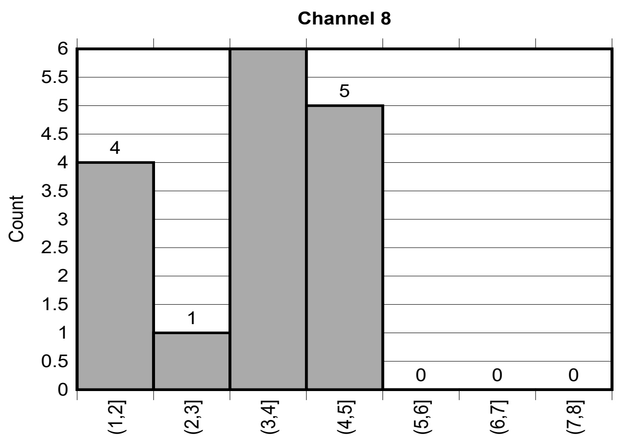

Figure 3-10. Channel 8

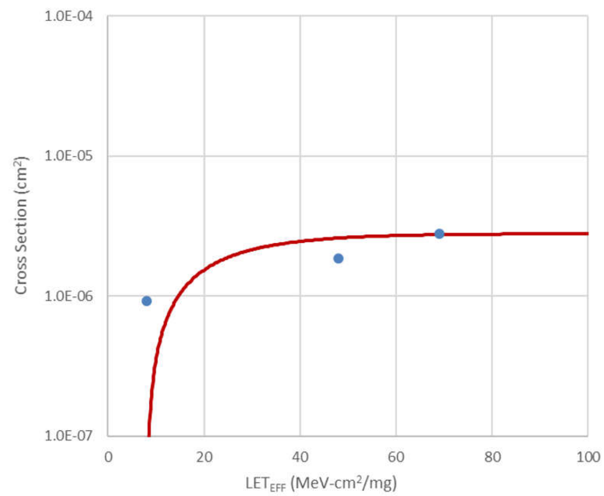

Figure 3-11. Weibull Plot: V+ 1.7 V - Local Channel

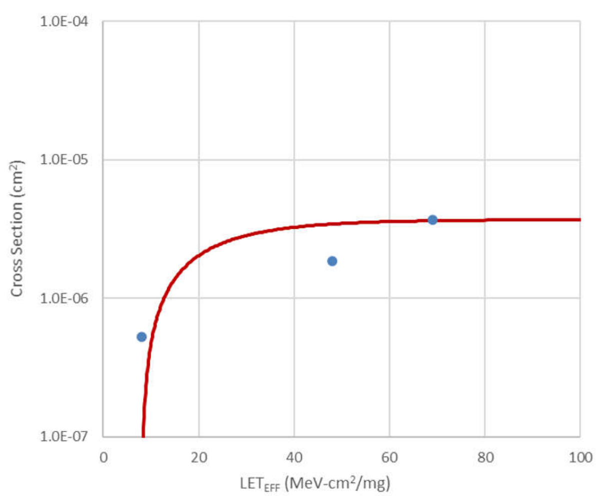

Figure 3-12. Weibull Plot: V+ 2.0 V - Local Channel

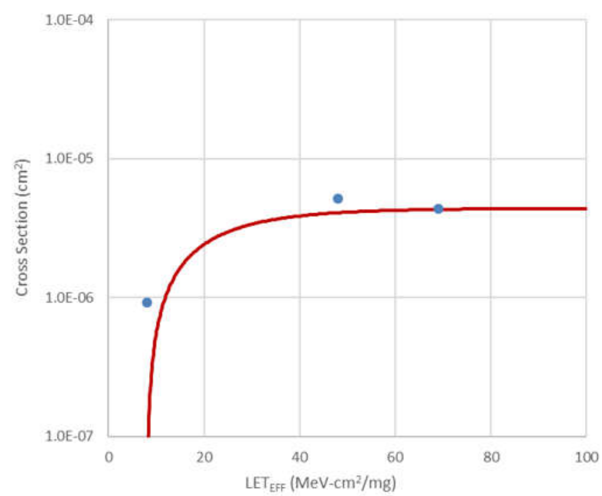

Figure 3-13. Weibull Plot: V+ 1.7 V - Channel 1

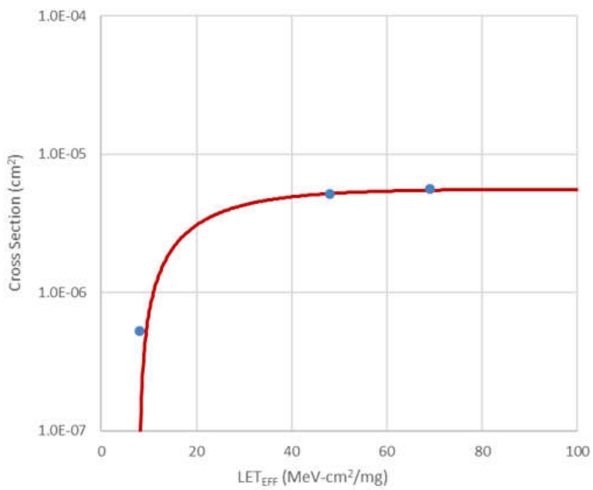

Figure 3-14. Weibull Plot: V+ 2.0 V - Channel 1

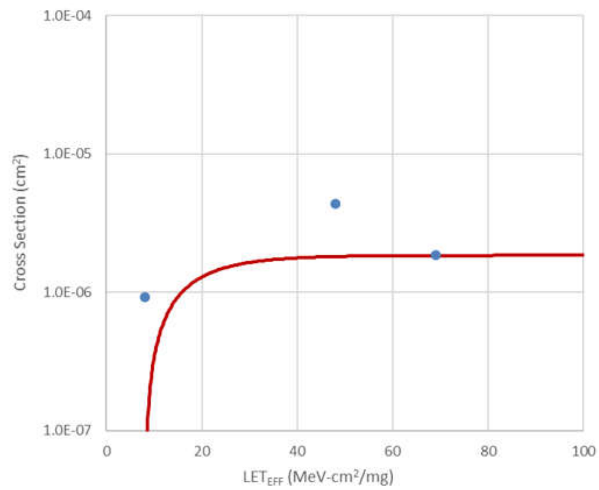

Figure 3-15. Weibull Plot: V+ 1.7 V - Channel 2

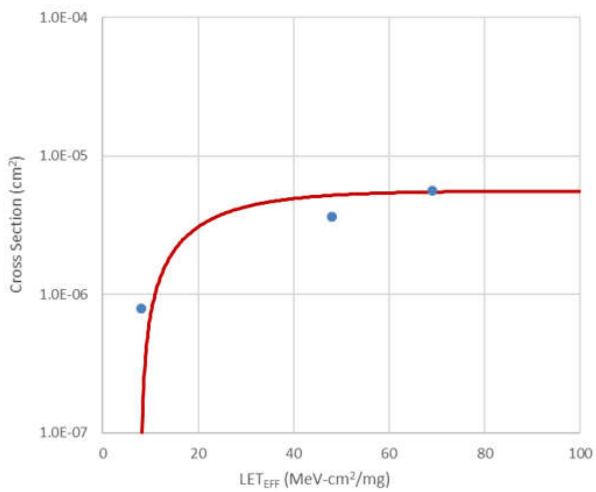

Figure 3-16. Weibull Plot: V+ 2.0 V - Channel 2

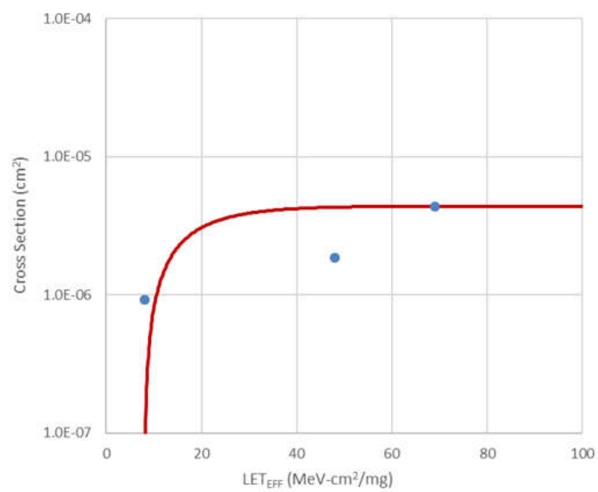

Figure 3-17. Weibull Plot: V+ 1.7 V - Channel 3

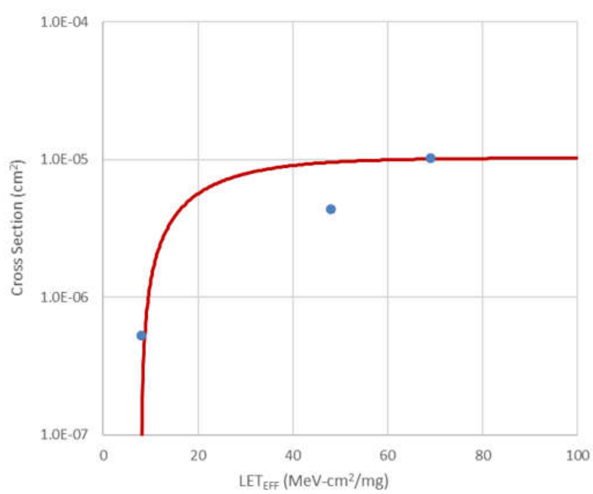

Figure 3-18. Weibull Plot: V+ 2.0 V - Channel 3

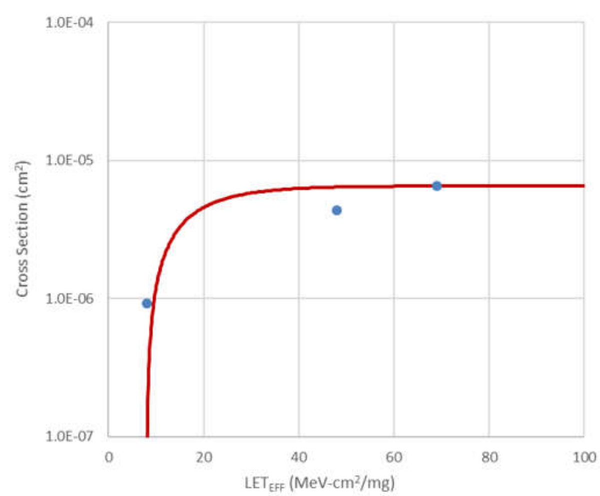

Figure 3-19. Weibull Plot: V+ 1.7 V - Channel 4

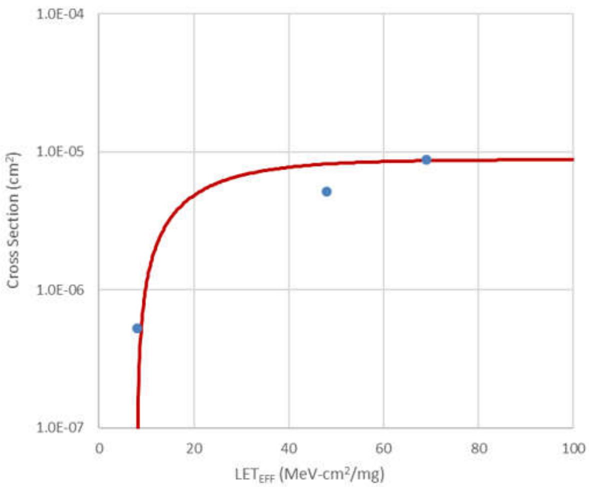

Figure 3-20. Weibull Plot: V+ 2.0 V - Channel 4

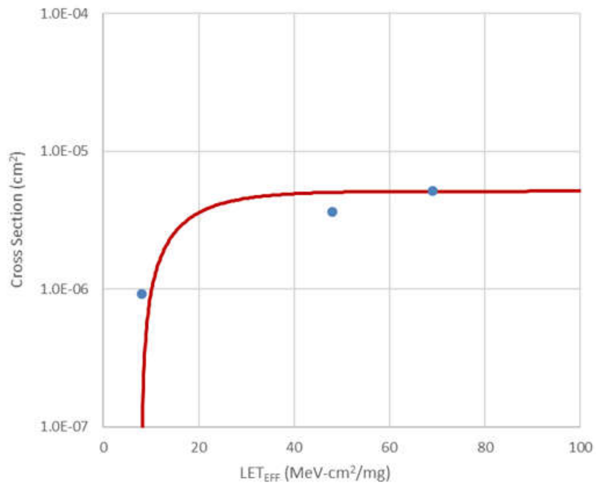

Figure 3-21. Weibull Plot: V+ 1.7 V - Channel 5

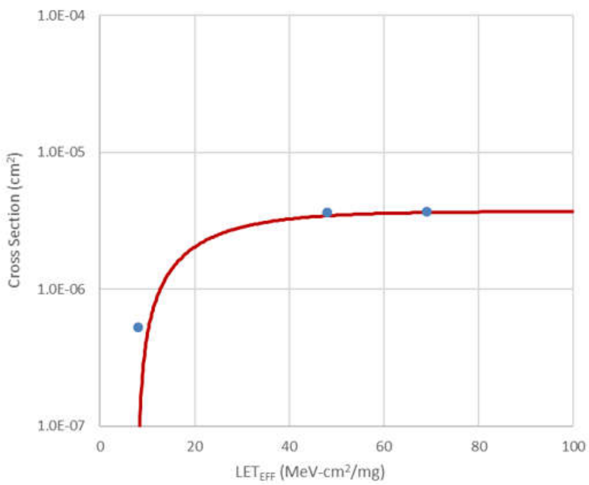

Figure 3-22. Weibull Plot: V+ 2.0 V - Channel 5

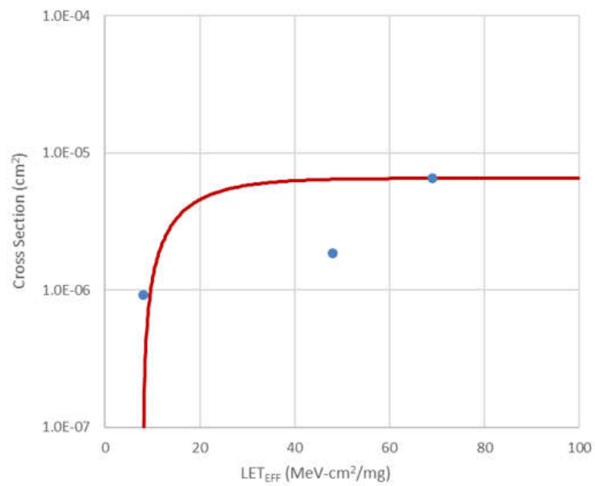

Figure 3-23. Weibull Plot: V+ 1.7 V - Channel 6

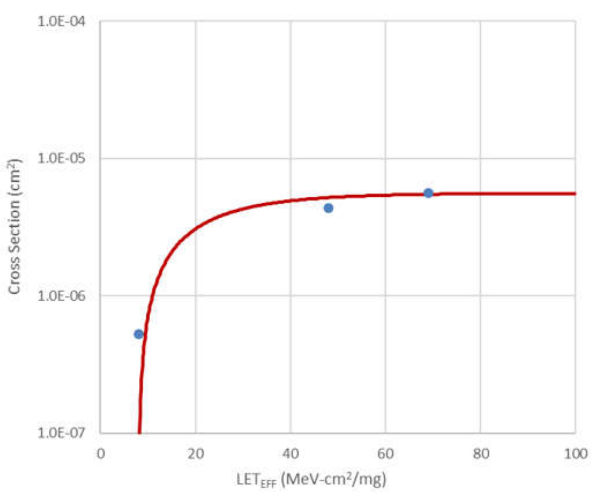

Figure 3-24. Weibull Plot: V+ 2.0 V - Channel 6

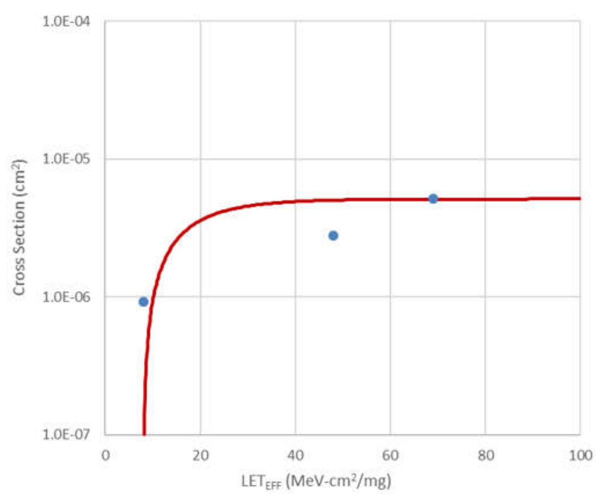

Figure 3-25. Weibull Plot: V+ 1.7 V - Channel 7

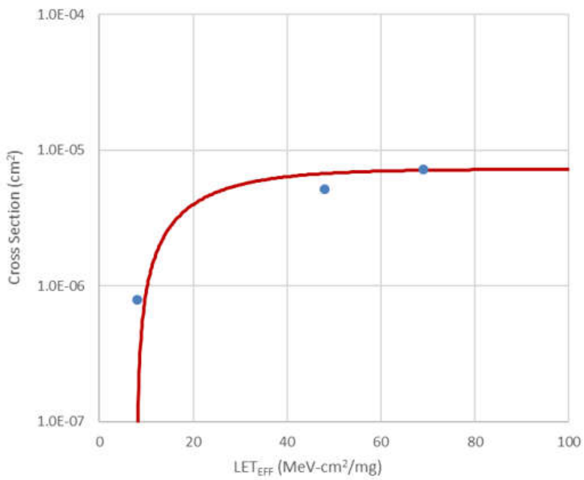

Figure 3-26. Weibull Plot: V+ 2.0 V - Channel 7

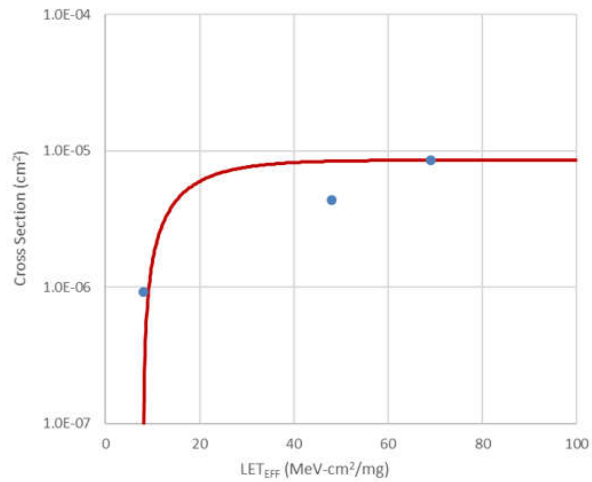

Figure 3-27. Weibull Plot: V+ 1.7 V - Channel 8

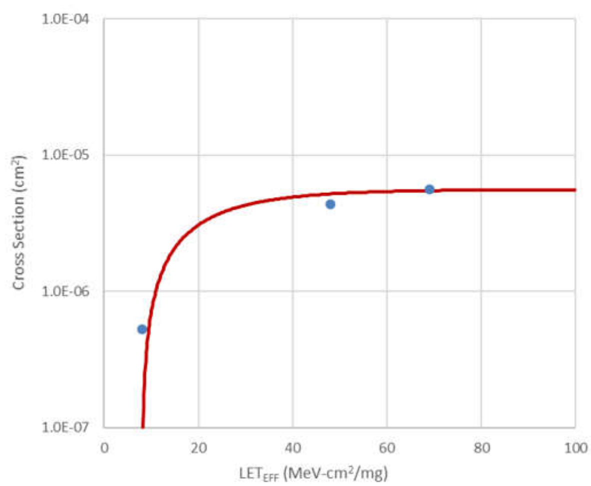

Figure 3-28. Weibull Plot: V+ 2.0 V - Channel 8

3.3 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations. The error rate was calculated using the upper bound cross section.

Table 3-5. 1.7-V SET Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	8.0000	2.49×10^{-5}	6.39×10^{-6}	2.66×10^{2}	4.29×10^{2}
GEO			5.05×10^{-5}	2.11×10^{3}	5.42×10^{1}

Table 3-6. 2.0-V SET Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	8.0000	2.97×10^{-5}	7.60×10^{-6}	3.17×10^{2}	3.60×10^{2}
GEO			6.02×10^{-5}	2.51×10^{3}	4.55×10^{1}

4 Summary

This report summarizes all data collected on the TMP9R00-SP. The data shows the TMP9R00-SP is latch-up immune up to 75 MeV. A SET study was done by monitoring the temperature readout of all 9 channels and recording events greater than ±1.5°C from the initial recorded temperatures.

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