Radiation Report

AFE7950-SP Single Event Effects Report

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the AFE7950-SP. Heavy-ions with LET_{EFF} (Effective Linear Energy Transfer) of up to 70 MeV·cm^2/mg were used to irradiate the device. Tests were run across a range of flux and fluences for the characterization. Flux was between 10^2 and 10^5 ions/(cm^2·s) and fluence up to 10^7 ions/cm^2 per run. The results demonstrated that the AFE7950-SP is single event latch-up free at a device junction temperature of 125°C. Single event upsets and functional interrupts are characterized at ambient room temperature, no external heat applied, up to 58 MeV·cm^2/mg. See Section 7 for more details.

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Trademarks

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1 Introduction

The AFE7950-SP is a high performance, wide bandwidth multi-channel transceiver, integrating four RF sampling transmitter chains, four RF sampling receiver, chains and two RF sampling feedback chains (six RF sampling ADCs total). With operation up to 12GHz, this device enables direct RF sampling in the L, S, C, and X-band frequency ranges without the need for additional frequency conversions stages. This improvement in density and flexibility enables high-channel-count, multi-mission systems.

The TX signal paths support interpolation and digital up conversion options that deliver up to 1200MHz of signal bandwidth for four TX or 2400MHz for two TX. The output of the DUCs drives a 12GSPS DAC (digital to analog converter) with a mixed mode output option to enhance 2nd Nyquist operation. The DAC output includes a variable gain amplifier (TX DSA) with 40dB range and 1dB analog and 0.125dB digital steps.

Each receiver chain includes a 25dB range DSA (Digital Step Attenuator), followed by a 3GSPS ADC (analog-to-digital converter). Each receiver channel has an analog peak power detector and various digital power detectors to assist an external or internal autonomous automatic gain controller, and RF overload detectors for device reliability protection. Flexible decimation options provide optimization of data bandwidth up to 1200MHz for four RX without FB paths or 600MHz with two FB paths (1200MHz BW each).

Table 1-1. Overview Information

Description	Device Information
Generic part number	AFE7950-SP
Orderable part number	AFE7950ALKSHP
Device Function	4T6R RF Sampling AFE with 12GSPS DACs and 3GSPS ADCs
Device Package	400-pin ALK FCBGA (17x17mm)

Table 1-1. Overview Information (continued)

Description	Device Information
Technology	TSMC C28 28nm Bulk CMOS
Exposure facility	Radiation Effects Facility Cyclotron Institute, Texas A&M University (15MeV/Nucleon)
Heavy Ion Fluence per run	Up to 1 x 10^7 ions/cm^2
Irradiation Junction Temperature	125°C

2 Single-Event Effects

The primary concern of interest for the AFE7950-SP is the robustness against Single-Event Latch-up (SEL) and Single -Event Functional Interrupt (SEFI)

In CMOS technologies, such as the TSMC's 28nm CMOS (C28) process used on the AFE7950-SP, the CMOS circuitry introduces a potential for 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-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). This current between power and ground persists or is latched until power is removed, the device is reset, or until the device is destroyed by the high-current state. The AFE7950-SP was tested for SEL using the AFE7950EVM which operates the device at recommended power supply voltages. The device exhibits no SEL with heavy-ions up to LET_{EFF} = 70 MeV·cm^2/mg at a flux ≈ 10^5 ions/cm^2·s, fluence of ≈ 10^7 ions/cm^2, and a die temperature of 125°C, using Pr.

The AFE7950-SP was characterized for SEUs at fluxes between 10^2 ions/cm^2·s and 10^3 ions/cm^2·s and with a fluence up to 10^6 ions/cm^2 at ambient room temperature. More details regarding single event upsets and functional interupts can be found in Section 7.

3 Device and Test Board Information

The AFE7950-SP is packaged in a 400-pin FCBGA (TI package code ALK) organic substrate flip-chip package. AFE7950EVM evaluation boards were re-worked with AFE7950-SP devices to evaluate the performance and characteristics of the AFE7950-SP under heavy-ions.

Figure 3-2 shows the top view of the evaluation board used for the radiation testing. AFE7950EVM User's Guide provides more detail on the EVM which was used for testing.

Devices are prepared by de-lidding and then thinning down the backside of silicon substrate down to target thickness of approximately 50um. Example thickness profile is shown in Figure 3-1.

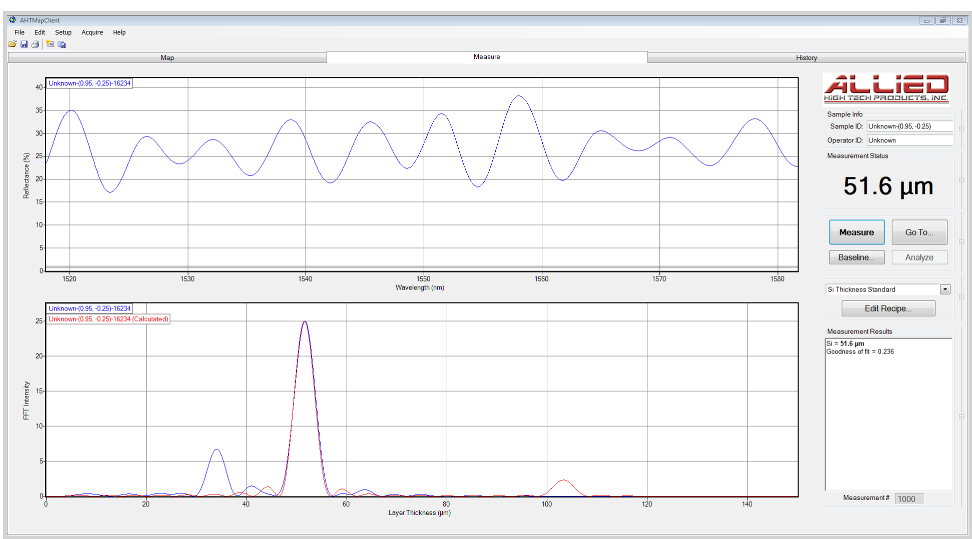

Figure 3-1. Silicon Thickness Profile

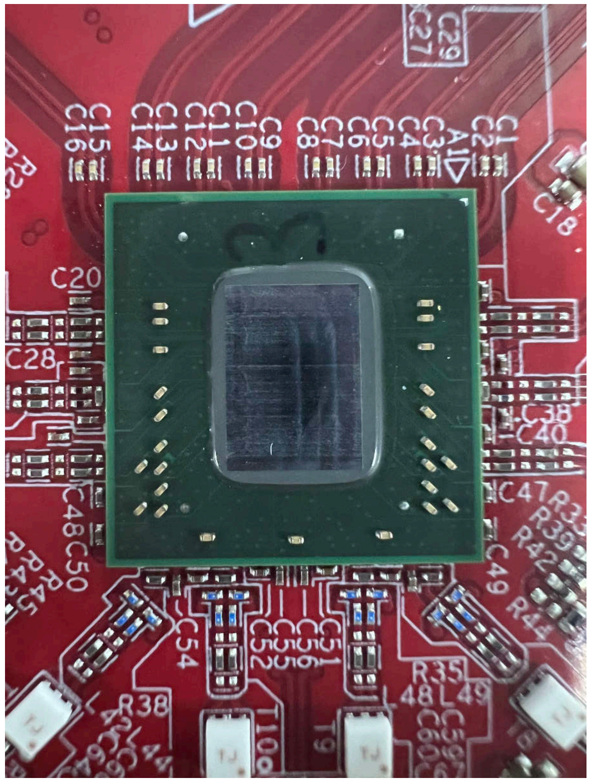

Figure 3-2. Photograph of Delidded AFE7950-SP

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by the TAMU Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced Electron Cyclotron Resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 1in diameter circular cross-sectional area for the in-air station. Uniformity is achieved by magnetic de-focusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For this characterization, ion flux of 10^2 to 10^3 ions/cm^2·s were used to provide heavy-ion fluences of up to 10^7 ions/cm^2 for our runs. Ion uniformity for these experiments were between 94 and 98%. See Section 7 for more details on the ions used and results of the runs.

Figure 4-1 shows the test board used for the experiments at the TAMU facility. Although not visible in this photo, the beam port has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the accelerator with only minor ion energy loss. A 40-mm in-air gap between the device and the ion beam port window was maintained at these distances for all runs respective to the ion that was tested.

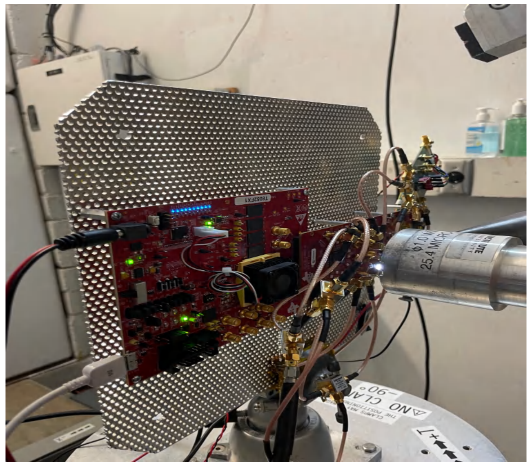

Figure 4-1. AFE7950-SP Mounted and Positioned for Heavy-Ion Exposure

5 Test Setup and Procedures

SEE testing was performed on AFE7950-SP devices soldered down to AFE7950EVMs. The units were de-lidded and were then thinned from the backside down to 50um to enable heavy ion penetration through the Si .The test setup also includes a TSW14J56EVM to aid in FFT captures of all 6 RX Channels and a spectrum analyzer to capture the 4 TX Channel DAC outputs. All RX inputs are connected to a R&S SGS100A signal generator using a splitter and the TX outputs are connected to the Aligent E4445A Spectrum Analyzer through a RF switch.

The device configuration used for testing is as follows:

1. Device/EVM was powered up to Vnom using an external 5.5V, 5A max power supply.
   a. The 5.5V is broken out to 0.925V, 1.2V, and 1.8V by on-board LDOs
2. Internal PLL is used. Reference clock is 491.52MHz, sent from the on-board LMK04828.
3. F_{in} on the ADCs was set to 9520MHz, F_{out} on the DACs was 9520MHz. The NCO was set to 9500MHz for both the RX and TX Channels.
4. RX and TX channels were tested independently. TX channel was not looped back to RX.
5. LMFS Config was set to the following:
   a. ADC LMFS: 6-12-4-1-0
   b. DAC LMFS: 8-8-2-1-0

Before the start of every run, a software reset and reprogramming of the device was done and then frequency spectrum plots were recorded for all the RX and TX channels. RX channels were captured in the HSDC Pro software using the TSW14J56EVM. TX channels were captured directly from the spectrum analyzer. The beam was then started and subsequently stopped when we observed SNR degradation. However, while we observed and captured all of the RX and TX channels individually, we did not monitor all the channels at the same time. This means that for our testing, only RX channel FB1 was taken into account when determining when to stop the run. More details on how this affects our calculations can be found in section Single Event Upsets. After the beam was stopped, frequency spectrum captures were taken of all the RX and TX channels. Software resets were then performed to make sure failing channels were able to be recovered.

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 MXIExpress cable and a NI PXIe-8381 remote control module. During SEL and SET testing the device junction temperature was maintained at 125°C by using a Closed-Loop PID controlled heat gun (MISTRAL 6 System (120-V, 2400-W)) that was set to only cool air. Die temperature was verified built-in die temp sensor.

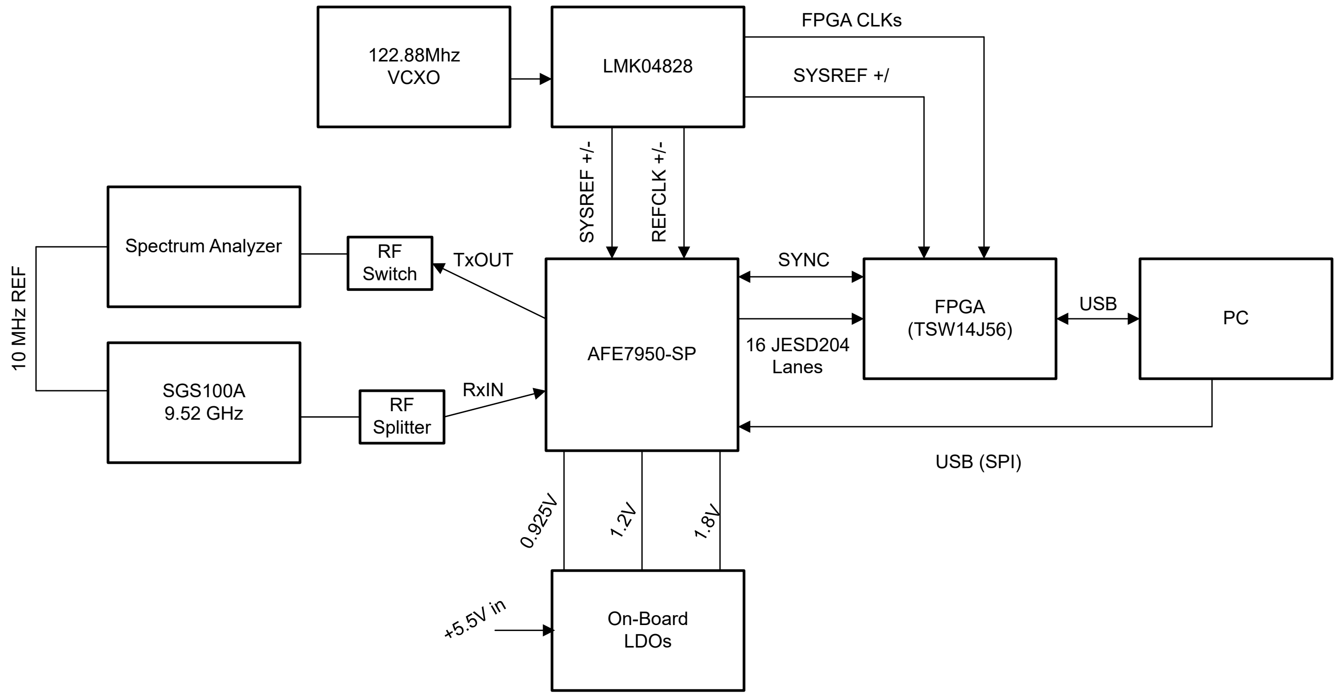

Figure 5-1. AFE7950 Block Diagram

6 Destructive Single-Event Effects (DSEE)

During SEL characterization, the device junction temperature was maintained at 125°C. The die temperature was monitored using on chip thermistors.

The species used for the SEL testing was Silver (^{109}Ag) and (Praseodymium (^{141}Pr) ion for an LET_{EFF} of 57.73 and 70.12 MeV·cm^2/mg respectively. Flux of 10^5 ions/cm^2·s and a fluence of 10^7 ions/cm^2. Run duration to achieve this fluence was less than 2 minutes. No destructive SEL events were observed during all six runs, indicating that the AFE7950-SP is SEL-free. During SEL runs, the device exhibited SEFI that degraded device performance. A soft-reset and re-programming did not return the device to the pre-beam-exposure nominal-performance state. Power-cycling and re-programming was required to return the device to the pre-beam-exposure nominal-performance state. Table 6-1 shows the SEL test conditions.

Table 6-1. SEL Run Conditions

Run Number	Temp	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions·cm^2/s)	Fluence (ions·cm^2)	PS to EVM Board (V)
1	125°C	Ag	57.73	1.00×10^5	1.00×10^7	5.5
2	125°C	Ag	57.73	1.00×10^5	1.00×10^7	5.5
3	125°C	Ag	57.73	1.00×10^5	1.00×10^7	5.5
4	125°C	Pr	70.66	1.00×10^5	1.00×10^7	5.5
5	125°C	Pr	70.66	1.00×10^5	1.00×10^7	5.5
6	125°C	Pr	70.66	1.00×10^5	1.00×10^7	5.5

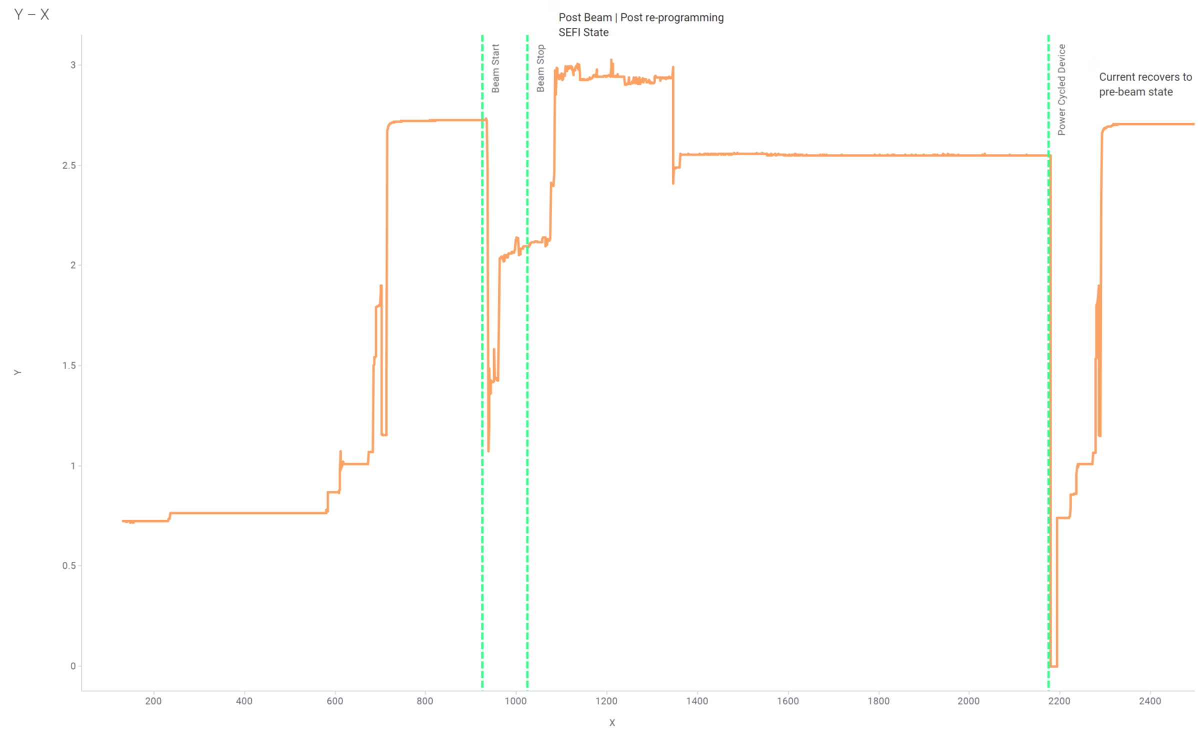

Figure 6-1. AFE7950-SP Current During SEL Run #1

7 Single-Event Effects (SEE)

Single Event Upsets

Deviations in AC performance of the RX channel were used as a figure of merit for SEU. SNR degradation was treated as the main indicator of an upset to the AFE7950-SP. Prior to an SEU beam run, the AFE7950-SP was power-cycled, programmed, and baseline FFTs were stored for all RX and TX channels. When the SNR noisefloor degraded from the baseline of 100dB, the beam stops and device is re-programmed (no power cycle involved) and have the fluence recorded. To determine the correlation between channels, a snapshot of the status of all the channels was recorded when RX channel 1 recorded an SEU event.Figure 7-1 shows the summary of what other channels failed at end of run.

Run	Fluence	ADC1	ADC2	ADC3	ADC4	FB1	FB2	DAC1	DAC2	DAC3	DAC4	ION	Comments
2	3.89E3	Failed	Good	Good	Failed	Failed	Failed	Good	Failed	Failed	Failed	Ag ION 48MeV	
3	1.67E+04	Failed	Good	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed		
4	**3.79E+04**	Good	Good	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed		We monitored FB2 for fails during run
5	1.97E+04	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed	Failed		
7	1.47E+04	Failed	Failed	Failed	Good	Good	Failed	Failed	Failed	Failed	Failed		
8	1.02E+04	Failed	Good	Good	Good	Failed	Good	Good	Good	Good	Good		
9	1.13E+04												
10	6.67E+03												ADC JESD SYNC Lost
11	3.98E+03	Failed	Good	Failed	Good	Good	Good	Failed	Good	Good	Good		
12	1.46E+04							Failed	Failed	Failed	Failed		ADC JESD SYNC Lost
Run	Fluence	ADC1	ADC2	ADC3	ADC4	FB1	FB2	DAC1	DAC2	DAC3	DAC4	ION	Comments
1	6.17E+04	Failed	Good	Good	Failed	Failed	Failed	Failed	Good	Good	Good	Ar ION 9.75MeV	
2	2.52E+04	Failed	Good	Good	Good	Good	Good	Good	Good	Good	Good		
3	4.89E+04	Failed	Good	Good	Good	Failed	Good	Failed	Failed	Failed	Failed		We monitored FB2 for fails during run
4	9.44E+04	Failed	Failed	Good	Failed	Failed	Failed	Failed	Failed	Failed	Failed		
5	1.82E+04	Failed	Failed	Failed	Good	Good	Failed	Failed	Failed	Failed	Failed		ADC JESD SYNC Lost
6	1.34E+04							Good	Good	Good	Good		ADC JESD SYNC Lost

Figure 7-1. State of Channels Post Beam

Table 7-1. SEU Runs

Run #		LETEFF (MeV·cm²/mg)	Fluence (ions/ cm^2)	Flux (ions/ [cm^2·s])	Uniformity	Run Time
1	Ag	57.73	3.89×10^3	9.71×10^2		40.06
2		57.73	1.67×10^4	9.58×10^2		174.00
3		57.73	3.79×10^4	9.047×10^2	97.00	418.88
4		57.73	1.97×10^4	8.83×10^2	98.00	223.35
5		57.73	1.47×10^4	9.83×10^2	98.00	149.28
6		57.73	1.02×10^4	8.75×10^2	98.00	117.00
7		57.73	1.13×10^4	1.17×10^2	95.00	96.25
8		57.73	6.67×10^3	1.22×10^2	95.00	54.37
9		57.73	3.98×10^3	1.21×10^2	96.00	32.83
10		57.73	1.46×10^4	1.23×10^2	97.00	118.66
1	Cu	24.54	1.71×10^4	1.25×10^2	92	137.08
2		24.54	2.14×10^4	1.14×10^2	94	167.9
3		24.54	2.75×10^3	1.08×10^2	95	25.31
4		24.54	9.65×10^4	1.10×10^2	91	877.87
5		24.54	1.31×10^4	1.05×10^2	90	124.68
6		24.54	2.60×10^4	1.06×10^2	94	244.22
7		24.54	3.46×10^4	1.35×10^2	100	255.88
8		24.54	9.20×10^3	1.37×10^2	95	67.25
9		24.54	1.37×10^4	1.34×10^2	93	102.37
10		24.54	1.94×10^4	1.57×10^2	97	123.42
11		24.54	3.34×10^4	1.55×10^2	97	215.81
1	Ar	9.75	6.17×10^4	1.20×10^2	94.00	557.00
2		9.75	2.52×10^4	1.17×10^3	95.00	22.00
3		9.75	4.89×10^4	1.16×10^3	95.00	42.08
4		9.75	9.44×10^4	1.25×10^3	94.00	75.40
5		9.75	1.82×10^4	1.18×10^3	95.00	15.50
6		9.75	1.34×10^4	1.24×10^3	95.00	10.78

Single-Event Functional Interrupts

The single events that needed power-cycling and reprogramming were classified as a SEFI event. Our procedure for recording SEFIs was to run the beam for a predetermined amount of time based on the flux level. The typical time period was 5 minutes for a flux of 1E2. At the end of the interval, the beam was paused and the device was re-programmed to the original state. If the RX channel 1 SNR came back to a SNR noisefloor of a 100dB then the beam continues for the next period of time. If the noise floor did not recover, reconfiguration of the device is done after power cycling the device. The fluence that accumulated so far is used to calculate the cross section of SEFI for the particular LET.

Table 7-2. SEFI Runs

Flux (ions·cm^2/s)	Ion	LET (MeV·cm²/mg)	Time	Fluence	SEFI?
1.00×10^4	Ar	9.75	25 sec	2.45×10^5	No
1.00×10^4			50 sec	4.88×10^5	No
1.00×10^4			75 sec	7.15×10^5	No
1.00×10^4			100 sec	9.53×10^5	Yes
1.00×10^2	Cu	24.54	5 min	4.43×10^4	No
1.00×10^2			10 min	8.79×10^4	No
1.00×10^2			15 min	1.28×10^5	No
1.00×10^2			20 min	1.71×10^5	No
1.00×10^2			25 min	2.16×10^5	No
1.00×10^2			30 min	2.56×10^5	No
1.00×10^2			35 min	3.00×10^5	Yes
1.00×10^2	Ag	57.73	5 min	3.92×10^4	No
1.00×10^2			20 min	1.60×10^5	No
1.00×10^2			25 min	2.00×10^5	No
1.00×10^2			30 min	2.39×10^5	Yes

8 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations and simplified SEE cross-sections according to methods described in *Heavy Ion Orbital Environment Single-Event Effects Estimations*. A minimum shielding configuration of 100 mils (2.54mm) of aluminum, and worst-week solar activity (this is similar to a 99% upper bound for the environment) is assumed. Using the 95% upper-bounds for the SEL and SET, the event rates for SEU and SEFIs are shown in Table 8-1 andTable 8-2. For SEU event rate calculations, the total fluence of each run was integrated to come up with cross section levels at each LET. Plots for corresponding Weibull curve are found below. For this particular device, even at the lower LETs of 9.75 Mev, both SEFIs and SEUs are occurring. For the MTBF calculations, an onset of one was used to be conservative.

Table 8-1. SET Event Rate Calculations of SEUs 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)	1	1.31×10^{-4}	2.57×10^{-4}	1.07×10^4	1.07×10^1
GEO			2.18×10^{-3}	9.09×10^4	1.26

Table 8-2. SET Event Rate Calculations of SEFIs 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)	1	2.33×10^{-5}	9.48×10^{-5}	3.95×10^3	2.89×10^1
GEO			8.29×10^{-4}	3.45×10^3	3.30

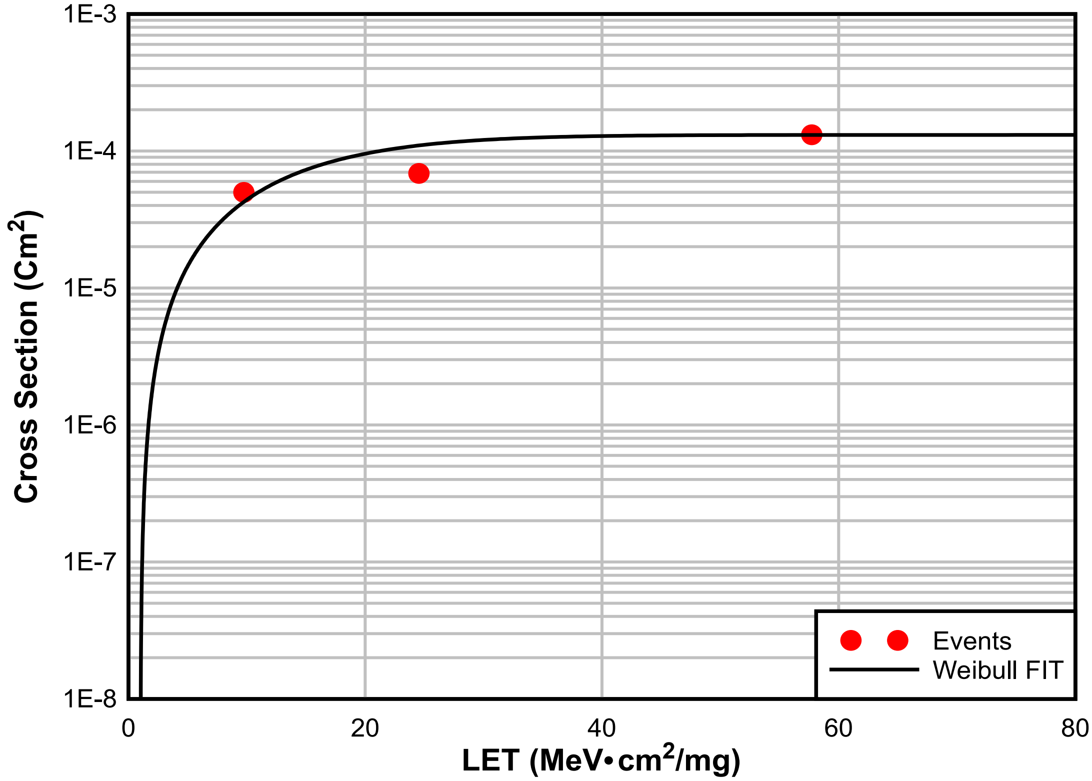

Figure 8-1. Weibull Curve Characterizing SEUs

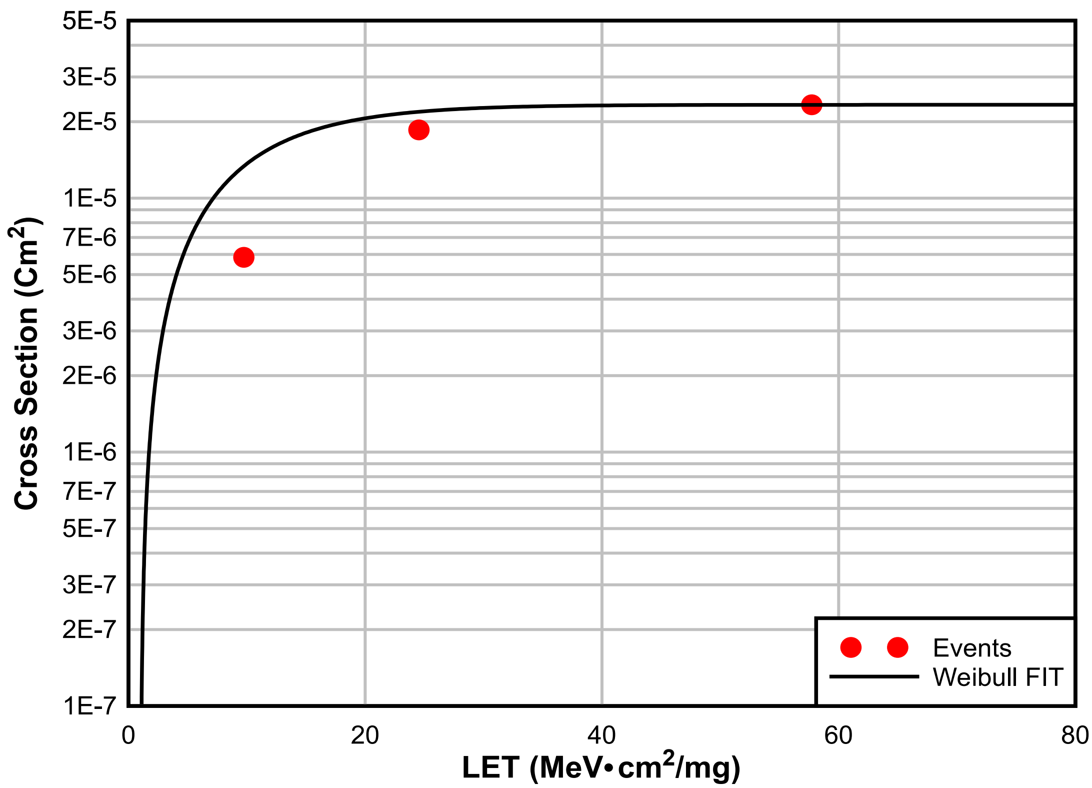

Figure 8-2. Weibull Curve Characterizing SEFIs

9 References

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265