Application Report
SLUA985 – February 2020

Single-Event Effects Test Report of the UC1843B-SP Current Mode PWM Controller

ABSTRACT

The purpose of this study is to characterize the single-event-effect (SEE) performance due to heavy-ion irradiation of the UC1843B-SP. Heavy-ions with LET_{EFF} ranging from 20 to 74 MeV·cm²/mg were used to irradiate production RHA devices in 23 experiments with fluences ranging from 10^6 to 2×10^7 per run. The results demonstrated that the UC1843B-SP is SEL-free up to 75 MeV·cm²/mg at T = 125°C, SEB-free up to 74 MeV·cm²/mg at room temperature, and across the full electrical specifications. The SET cross section for V_{OUT} and the PWM (output) is presented and discussed.

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1 Introduction

The UC1843B-SP control IC is a pin-for-pin compatible, radiation-improved version of the UC1843A-SP. Providing the necessary characteristics to control current-mode power supplies, this device has improved features. Start-up current is specified to be less than 0.5 mA and oscillator discharge current is trimmed to 8.3 mA. The controller can support various DC to DC topologies such as the following:

- Forward
- Flyback
- Buck
- Boost
- Half-Bridge (using external interface I.C.)
- Full-Bridge (using external interface I.C.)
- Push Pull (using external interface I.C.)

The device is offered in a thermally-enhanced 10-pin ceramic, dual in-line flat package. Table 1 lists the general device information and test conditions. Visit the UC1843B-SP product page for more detailed technical specifications, user's guides, and applications notes.

Table 1. Overview Information[1]

DESCRIPTION	DEVICE INFORMATION
TI Part Number	UC1843B-SP
Orderable Name	5962R8670412VYC
Device Function	Current-Mode PWM Controller
Technology	JI
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University
Irradiation Temperature	25°C and 125°C (For SEL Testing)

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2 Single-Event Effects

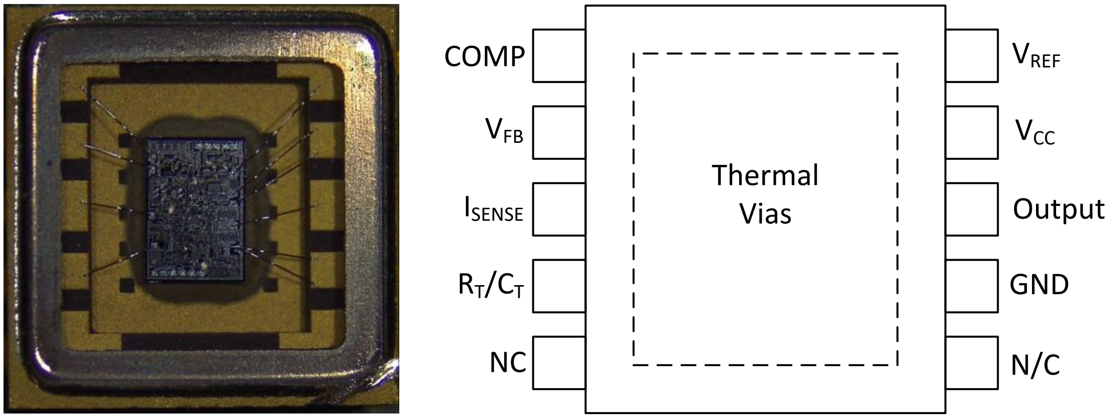
The concerns for the UC1843B-SP is its resilience against the destructive single event effects (DSEE): single-event latch-up (SEL) and single event burnout (SEB). The UC1843B-SP is a bipolar-only process. Because of the bipolar process, the controller is virtually SEL-free. However, the device was checked for SEL. For testing, the device was powered at the absolute maximum voltage at VCC = 30 V and heated to approximately 125°C. No current fluctuation outside of the normal behavior was observed during the exposure with heavy-ions up to 75 MeV·cm^2/mg, fluence of 10^7 ions/cm^2, and a die temperature of approximately 125°C.

Since BJT devices can suffer SEB, the UC1843B-SP was tested at the absolute maximum input voltage for burnout. No current increase was observed, demonstrating that the UC1843B-SP is SEB-free across the full electrical specifications and up to 75 MeV·cm^2/mg, fluence of 10^7 ions/cm^2 at room temperature.

In addition to the destructive behavior, the UC1843B-SP was evaluated for Single-Event-Transients (SET). In any electronic circuit, the passage of heavy ion through the active areas of the silicon can result in transient charge collection. This charge collection ultimately affects circuit behavior by moving internal voltage nodes, affecting overall circuit behavior. In any power supply application, the proper operation of down-steam circuits are sensitive to the robustness and integrity of the rails. Transient events must be bounded and short in duration in order for the system to tolerate them. The UC1843B-SP was characterized for SET on the output when using the controller in a flyback topology. The Pulse-Width-Modulated (PWM) output signal was characterized for changes that exceed ±5% from the nominal value as well as separately characterized for changes that exceed ±25% from the nominal value. These signals were characterized, discussed, and summarized in detail in this report. Furthermore, for each of the different single-event effect, an in-orbit rate for LEO and GEO (ISS) using worst week method is presented for reference.

3 Test Device and Evaluation Board Information

The UC1843B-SP is packaged in a 10-pin, thermally-enhanced, dual-ceramic, flat pack package (HKU) as shown in Figure 1. The UC1843BEVM-CVAL evaluation board was used to evaluate the performance and characteristics of the UC1843B-SP under heavy-ions. Figure 2 shows the top views of the evaluation board used for the radiation testing. Figure 3 and Figure 4 show the board schematics for the EVM as used for the heavy-ion testing. See the UC1843B-SP Evaluation Module for more information about the evaluation board.



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

Figure 1. Photograph of De-lidded UC1843B-SP [Left] and Pinout Diagram [Right]

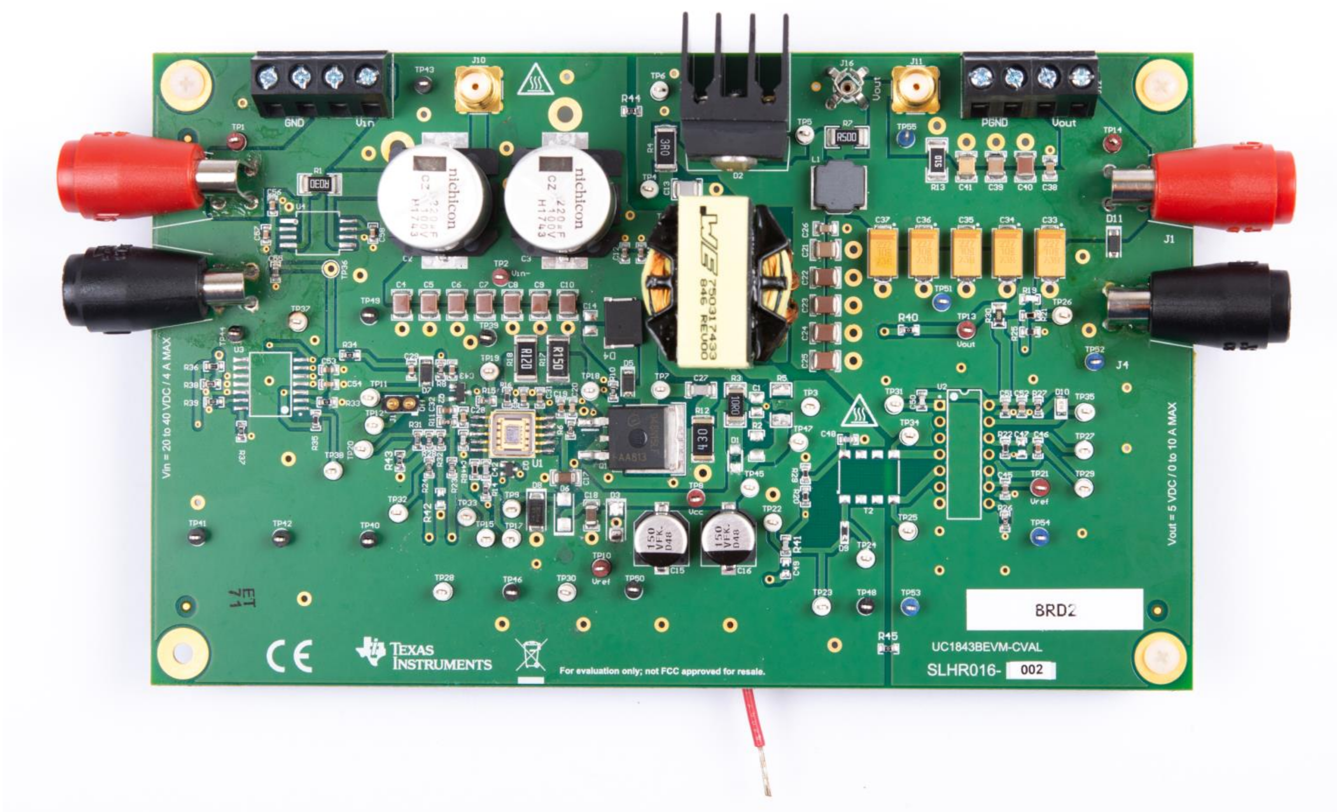


Figure 2. UC1843B-SP EVM Top View

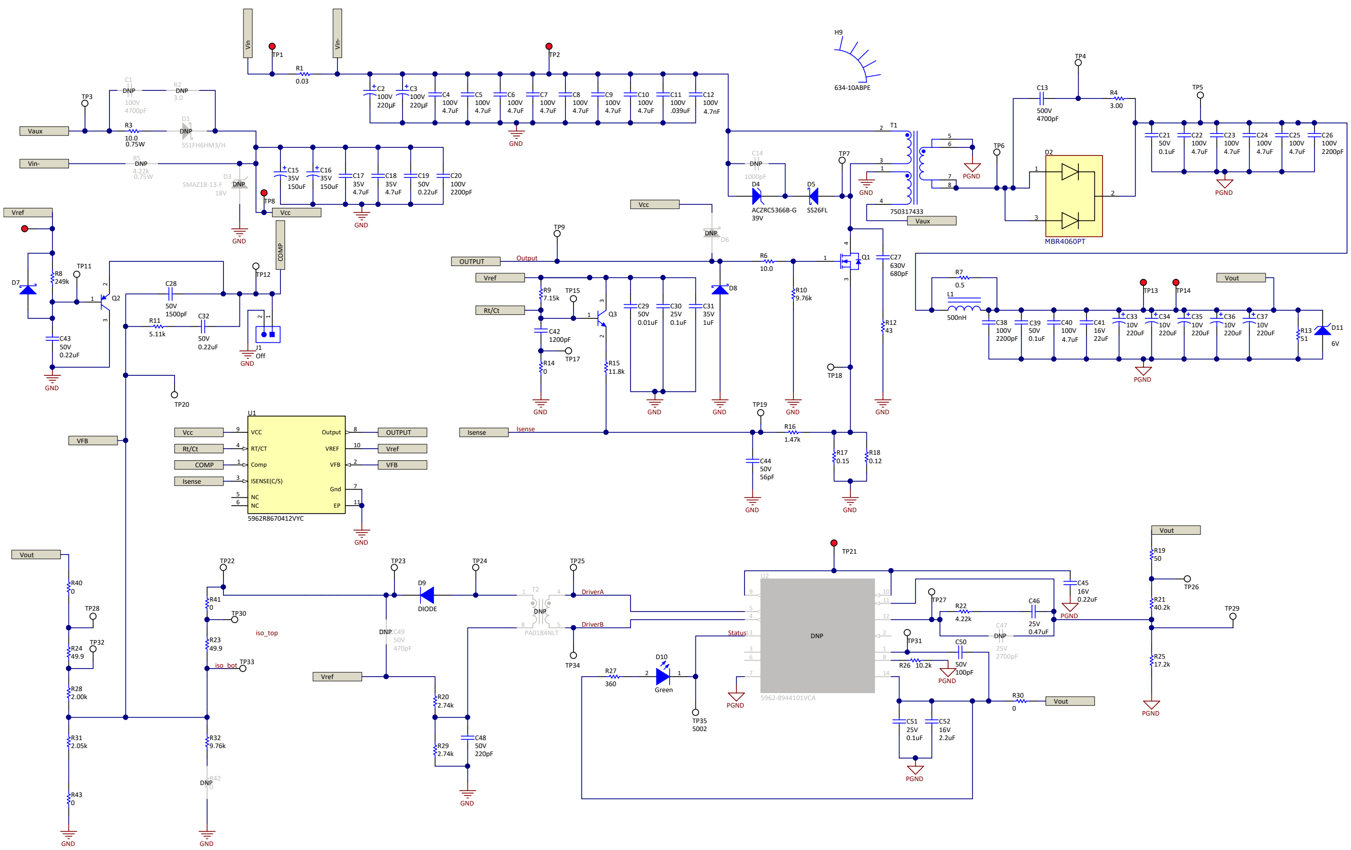


Figure 3. Page 1 of the Schematics of the UC1843BEVM-CVAL EVM as Used for the Heavy-ion Testing Campaign

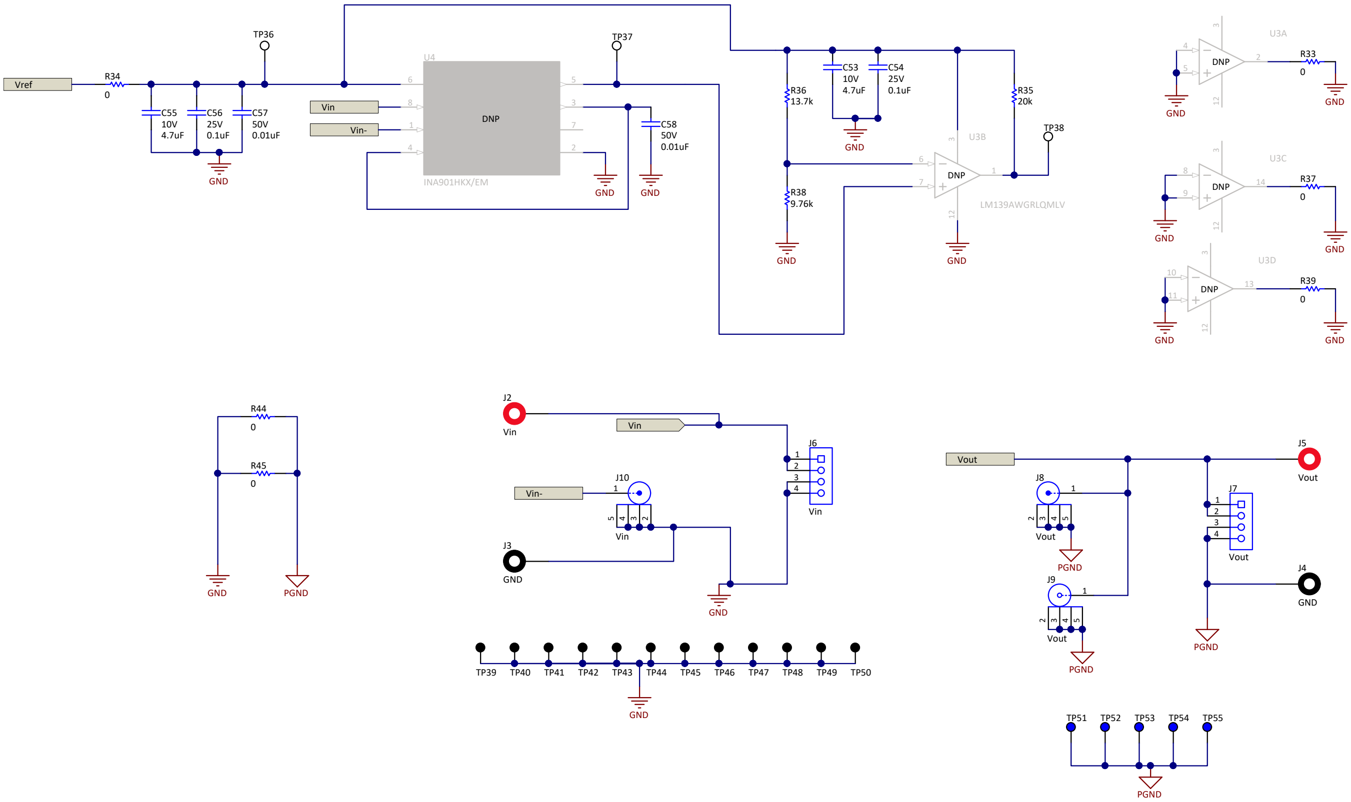


Figure 4. Page 2 of the Schematics of the UC1843BEVM-CVAL EVM as Used for the Heavy-ion Testing Campaign

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 one inch 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 the bulk of these studies, ion flux of 10^4 and 10^5 ions/cm^2·s were used to provide heavy-ion fluences of 10^6 and 10^7 ions/cm^2.

For the experiments conducted on this report, ^{63}Cu ions at angles of 0º and 50º of incidence were used for an LET_{EFF} of 20 and 31.3 MeV·cm^2/mg, respectively. ^{109}Ag ions at angles of 0º and 27º of incidence were used for an LET_{EFF} of 48.6 and 54.7 MeV·cm^2/mg, respectively. Also, ^{141}Pr ions at angles of 0º and 27º of incidence were used for an LET_{EFF} of 65.8 and 74 MeV·cm^2/mg, respectively. The total kinetic energy of ^{63}Cu, ^{109}Ag, and ^{141}Pr in vacuum are 0.944, 1.63, and 2.11 GeV, respectively at 15 MeV/nucleon. Ion uniformity for these experiments was between 79% and 96%.

Figure 5 shows the UC1843B-SP 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. Test points were soldered on the back for easy access of the signals while having enough room to change the angle of incidence and maintaining the distance to the die. The in-air gap between the device and the ion beam port window was maintained at 40 and 50 mm.

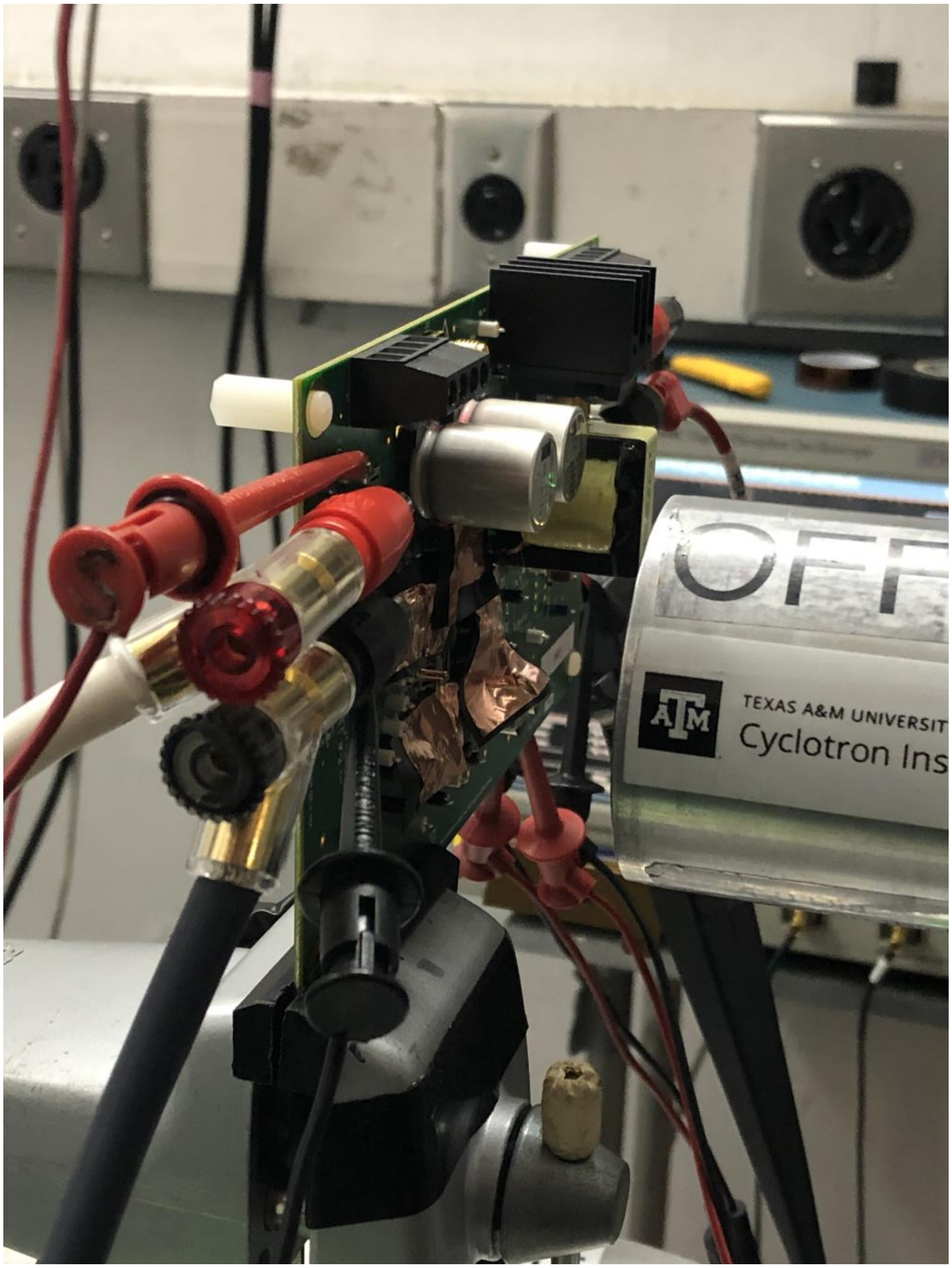


Figure 5. Photograph of the UC1843B-SP Mounted on the UC1843BEVM-CVAL EVM in Front of the Heavy-ion Beam Exit Port at the TAMU Accelerator Facility

5 Depth, Range, and LET_{EFF} Calculation

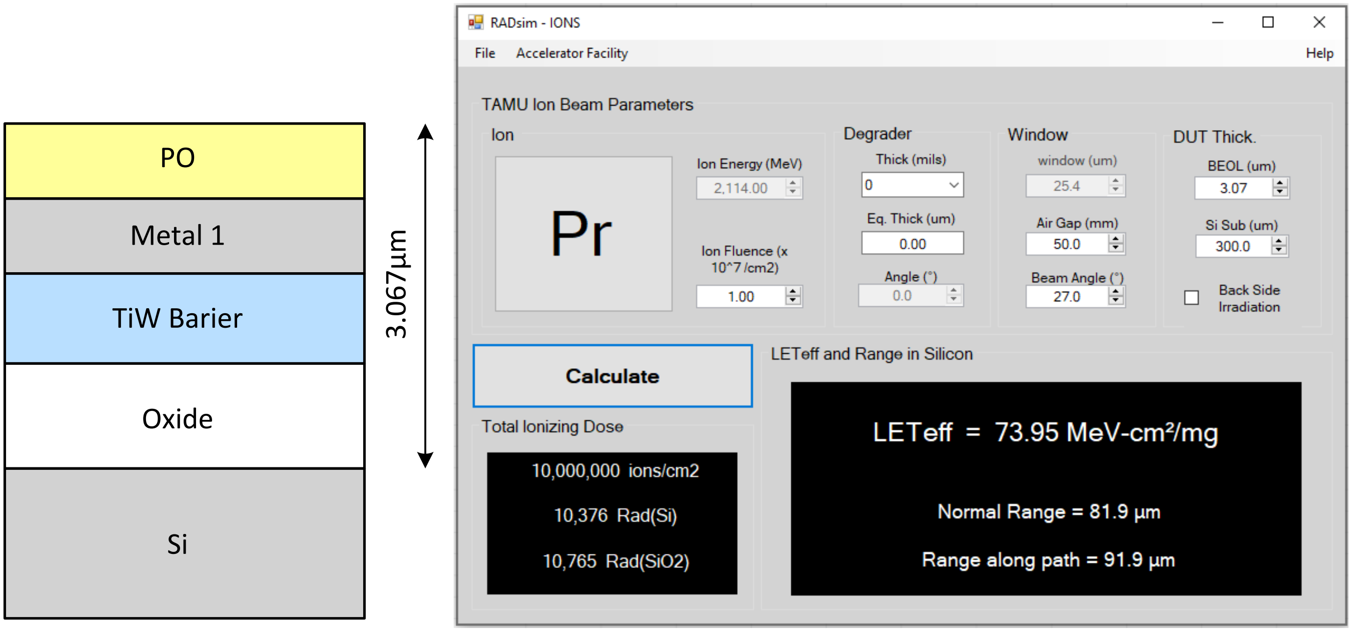


Figure 6. Generalized Cross Section of the JI Technology BEOL Stack on the UC1843B-SP [Left] and GUI of RADsim Application Used to Determine Key Ion Parameter [Right]

The UC1843B-SP is fabricated in the Texas Instruments Linear JI process with a back-end-of-line (BEOL) stack consisting of one level of standard thickness aluminum metal. Since LET for any given ion is largely a function of the material density through which the ion is traveling, and since the density of aluminum (2.70 g/cm^3) and silicon oxide (2.65 g/cm^3) are similar, the stack is modeled as a homogenous layer of silicon dioxide. The thickness from the surface of the passivation to the silicon surface is 3.067 µm (based on nominal thickness layer) as shown in Figure 6.

The left side of Figure 6 shows a generalized JI technology BEOL stack on the UC1843B-SP cross section. The right side of the image shows the GUI of the RADsim-IONS (based on SRIM) applications used to determine key ion parameters such as LET_{EFF}, depth and range for a given ion type, energy, stack, and facility. The application accounts for the 1-mil thick Aramica (DuPont™ KEVLAR®) and the distance from the DUT (in this case 40 and 50 mm). Table 2 shows the results for the ions used for the purpose of UC1843B-SP SEE characterization.

Table 2. LET_{EFF} Depth and Range for the Ions Used for SEE Characterization of the UC1843B-SP

ION TYPE	ANGLE OF INCIDENCE (°)	AIR DISTANCE (mm)	DEPTH IN SILICON (µm)	RANGE IN SILICON (µm)	LET_{EFF} (MeV·cm^2/mg)
^{63}Cu	0	40	120.4	120.4	20
^{63}Cu	50	40	76.6	118.7	31.3
^{109}Ag	0	50	87	87	48.6
^{109}Ag	27	50	77.2	86.6	54.7
^{141}Pr	0	50	92.2	92.2	65.8
^{141}Pr	27	50	81.9	91.9	74

6 Test Setup and Procedures

SEE testing was performed on a UC1843B-SP device mounted on a UC1843BEVM-CVAL board. The power stage (V_{IN}) was powered by using the J2 (V_{IN}) and J3 (GND) banana inputs. The UC1843B-SP (V_{CC}) power was provided by using the TP8 test point and TP39 for GND. In the EVM configuration, V_{CC} is powered using an auxiliary winding on the isolation transformer. However, for all the data collected on this report, V_{CC} and V_{IN} were provided using channel #3 and #4 of an N6702 precision power supply, respectively. The model of PS channels used are:

- Channel #3 model: N6776A
- Channel #4 model: N6775A

Since the 1'' beam port aramica exposes other active circuitry in the vicinity of UC1843B-SP, copper tape was used to cover them. For all data collected and discussed in this report, the output voltage (V_{OUT}) was regulated to 5 V. At this voltage, a 1-Ω and 375 m-Ω power resistor were used to load the UC1843BEVM-CVAL to 5 and 10 Amps, respectively. The losses in the wires of the load account for the non-linear change in the resistance when compared to the current. For the SEL and SEB, the UC1843B-SP (V_{CC}) was powered up to the maximum absolute operating voltage of 30 V and the load of the UC1843BEVM-CVAL was set to 5 A. During the SET data collection, the device (V_{CC}) was powered up to the minimum recommended operating voltage of 12 V and the UC1843BEVM-CVAL was loaded with a 10 A load.

The SET events were monitored using a National Instruments™ (NI) PXie-5105 (60 MS/s and 60 MHz of bandwidth) digitizer module and one Tektronix DPO7104C Digital Phosphor Oscilloscope (DPO) with four channels of 40 GS/s and 2.5 GHz of bandwidth. The DPO was used to monitor the PWM (Output) and V_{OUT} signals, and was triggered from the PWM using a pulse width window at ±5% from the nominal value. The NI-PXIe Scope card was used to monitor and trigger from V_{OUT} at using a window trigger set to ±5.2% from the nominal value.

Figure 7 shows a block diagram of the setup used for SEE testing on the UC1843B-SP. Table 3 shows the connections, limits, and compliance values that were used during the characterization. In general, the UC1843B-SP was tested at room temperature (no external heating applied). A die temperature of 125°C was used for SEL testing and was achieved with a convection heat gun aimed at the die. The die temperature was monitored during the testing using a K-Type thermocouple attached to the heat slug of the EVM with thermal compound. Correlation was achieved using a thermal camera before the SEE characterization.

All boards used for SEE testing were fully checked for functionality and dry runs performed to ensure that the test system was stable under all bias and load conditions prior to being taken to the TAMU facility. All equipment other than the DPO was controlled and monitored using a custom-developed LabVIEW™ program (PXI-RadTest) running on a NI PXIe-8135 Controller. During the heavy-ion testing, the LabView control program powered up the UC1843B-SP and UC1843BEVM-CVAL, and set the monitoring functions of the external equipment. After functionality and stability had been 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 PXIe-5101 scope cards continuously monitored V_{OUT}. When the output voltage exceeds the pre-defined 5.2% window trigger, data capture was initiated on the scope cards. 10 k samples were recorded with a pre-defined 20% reference (percent of the data vector before the trigger happens).

The NI scope cards captured events lasting up to 5 ms (10 k samples at 2 MS/s). In parallel, the DPO monitored the PWM (output) and V_{OUT} triggering from a pre-define 5% window trigger around the nominal pulse width and a 5.2% around the nominal output voltage of the UC1843BEVM-CVAL. The sample rate was set to 5 MS/s with a total capture time of 20 µs total (2 µs/div) and recording 20% or 4 µs before the event. The DPO was set to fast frame during and the counter cleared before each run started. Under this configuration, the scope has a 3.2-µs update rate, indicating that it can re-arm and be ready for next trigger within 3.2 µs. In addition to monitoring the voltage levels of scope and DPO, the V_{IN} and V_{CC} current as well as the +5 V signal from TAMU were monitored at all times. **No sudden increases in current were observed (outside of normal fluctuations) on any of the test runs indicating that no SEL events occurred during any of the tests.**

Table 3. Equipment Set and Parameters Used for the SEE Testing the UC1843B-SP

PARAMETER	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{IN}	Agilent N6700 PS Channel # 4	5 A	5 A	20 and 40 V
V_{CC}	Agilent N6700 PS Channel # 3	3 A	0.5 and 0.1 A	12 and 30 V
Oscilloscope Card	NI PXie-5105	60 MS/s	-	2 MS/s
Digital Phosphor Oscilloscope	Tektronix DPO7104C	40 GS/s	-	5 MS/s
Digital I/O	NI PXie-6556	200 MHz	-	50 MHz

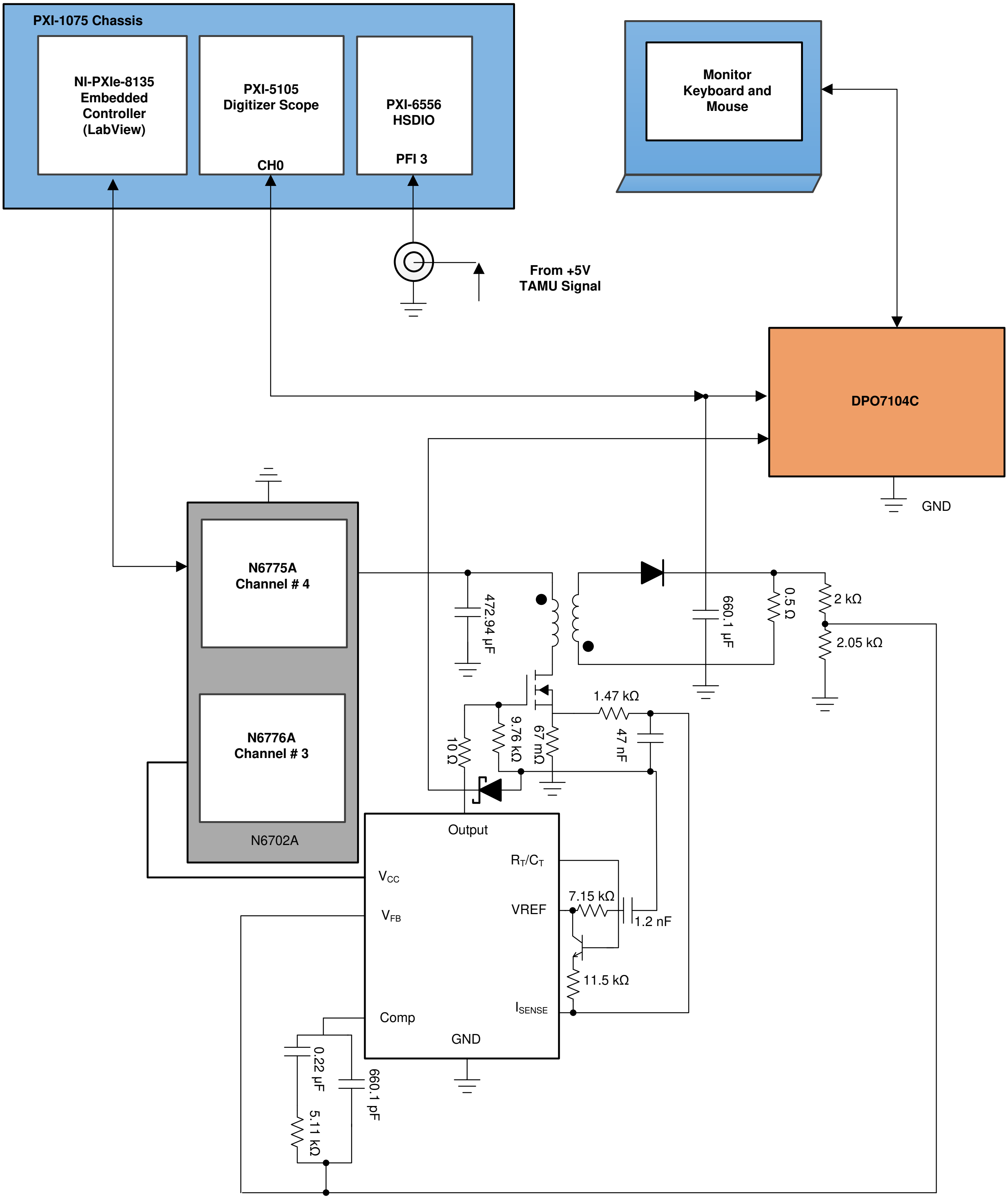


Figure 7. Block Diagram of the Test Setup Used for UC1843B-SP SEE Characterization

7 Destructive Single Event Effects (DSEE)

7.1 Single-Event-Latchup (SEL)

SEL characterizations was performed with a die temperature of 125°C. The device was heated by using a convection heat gun aimed at the die. The die temperature was monitored during the testing using a K-Type thermocouple attached to the heat slug of the a EVM with thermal compound. Prior to the SEE testing session, thermocouple and die temperature were correlated by using a thermal infrared (IR) camera. The device was exposed to a Praseodymium (Pr) heavy-ion beam incident on the die surface at 0° and 38.8° for an LET_{EFF} of 65.7 and 74 MeV·cm^2/mg, respectively. A flux of approximately 10^5 ions/cm^2·s and fluence ≥ 10^7 ions/cm^2 was used. The run duration to achieve 10^7 ions/cm^2 fluence at 10^5 ions/cm^2·s flux was approximately two minutes. V_{CC} was set to the maximum absolute voltage of 30 V while the output voltage of the UC1843BEVM-CVAL was set to 5 V at a 5-A load on the power stage.

Table 4 summarizes the SEL test conditions and results. Figure 8 shows a typical current plot. **No SEL events were observed under the test runs, indicating that the UC1843B-SP is SEL-immune at T = 125°C and LET_{EFF} = 74 MeV·cm^2/mg.**

The SEL cross section was calculated based on zero events observed using a 95% confidence interval (see Appendix A for discussion of the cross section calculation method).

σ_{SEL} ≤ 1.87 × 10^{-7} cm^2/device at LET_{EFF} = 74 MeV·cm^2/mg, T = 125 °C, and 95% confidence.

Table 4. Summary of UC1843B-SP SEL Test Conditions and Results with T = 125°C

RUN #	UNIT #	TEMPERATURE (°C)	DISTANCE (mm)	ANGLE OF INCIDENCE (°)	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/cm^2·s)	FLUENCE (ions/cm^2)	LOAD ON POWER STAGE (A)	SEL EVENTS
1	1	125	40	0	65.7	9.18 x 10^4	1.02 x 10^7	5	0
2	1	125	50	27	74	9.63 x 10^4	2.2 x 10^7	5	0

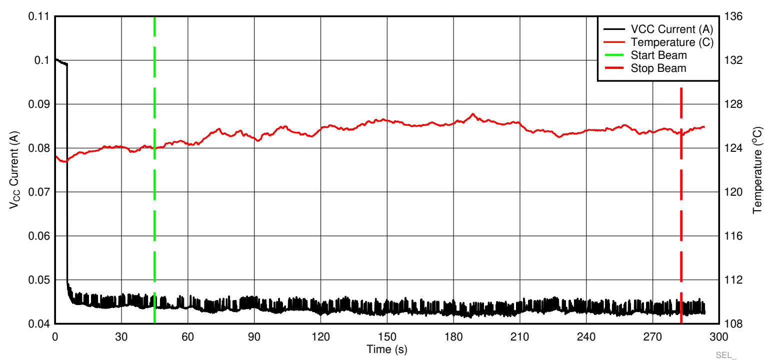


Figure 8. V_{CC} Current (Left Axis) and Temperature (Right Axis) versus Time for SEL Run #2 at T = 125°C and 74 MeV·cm^2/mg

7.2 Single-Event-Burnout (SEB)

SEB was performed at room temperature with ^{141}Pr at an angle of incidence of 27° for an LET_{EFF} of 74 MeV·cm^2/mg. V_{CC} was set to the maximum absolute voltage of 30 V while the output voltage was set to 5 V at a 5-A load on the power stage. Flux of approximately 10^5 ions/cm^2·s and fluence of 2 x 10^7 ions/cm^2 was used. The device was evaluated when the DUT was enabled.

Table 5 summarizes the SEL test conditions and results. Figure 9 shows a typical current plot. **No SEB or current spikes events were observed under the test run, indicating that the UC1843B-SP is SEB-immune at T = 25°C and LET_{EFF} = 74 MeV·cm^2/mg.**

The SEB cross section was calculated based on zero events observed using a 95% confidence interval (see Appendix A for discussion of the cross section calculation method).

σ_{SEB} ≤ 1.88 x 10^{-7} cm^2/device at LET_{EFF} = 74 MeV·cm^2/mg, T = 25°C, and 95% confidence.

Table 5. Summary of UC1843B-SP SEB Test Conditions and Results with T = 25°C and LET_{EFF} = 74 MeV·cm²/mg

RUN #	UNIT #	TEMPERATURE (°C)	DISTANCE (mm)	ANGLE OF INCIDENCE (°)	LET_{EFF} (MeV·cm²/mg)	FLUX (ions/cm²·s)	FLUENCE (ions/cm²)	LOAD ON POWER STAGE (A)	SEB EVENTS
3	1	25	50	27	74	5.99×10^4	2×10^7	5	0

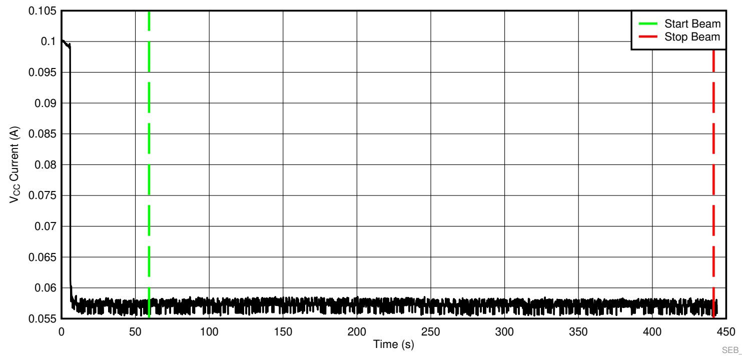


Figure 9. V_{CC} Current versus Time for SEB Run #3 at Room Temperature and 74 MeV·cm²/mg

8 Single Event Transients (SET)

SETs were defined as heavy-ion-induced transient variation on the V_{OUT} (regulated 5 V) or PWM (output) of the UC1843B-SP that were higher than ±5.2% from the nominal value for V_{OUT} and ±5% for PWM (output). Characterization was conducted at output voltages of 5 V and load of 10 A on power stage. Transients characterization was conducted at room temperature with ^{63}Cu ions at 0º and 50º angle of incidence for an LET_{EFF} of 20 and 31.3 MeV·cm²/mg, respectively. ^{109}Ag ions at angles of 0º and 27º of incidence were used for an LET_{EFF} of 48.6 and 54.7 MeV·cm²/mg, respectively. Also, ^{141}Pr ions at angles of 0º and 27º of incidence were used for an LET_{EFF} of 65.8 and 74 MeV·cm²/mg, respectively (see Table 2 for more details on the ions used).

Table 6 summarizes the test conditions and results for the UC1843B-SP SET characterization. Flux of ≈ 10^4 ions/cm²·s and fluences of ≥ 10^6 ions/cm² were used. To capture the transients, window trigger of ±5.2% around the nominal voltage was used for the V_{OUT}. For this condition, all observed upsets were positive in polarity. Figure 10 shows the cross section and the weibull fit for V_{OUT} upsets > ±5.2%. The weibull fit parameters per Equation 1 are shown in Table 7.

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

Figure 11 and Figure 12 show the histogram of all observed upsets > ±5.2% from the nominal output voltage and the transient time for the upsets, respectively. Figure 13 and Figure 14 show the worst case observed voltage excusion and transient time at V_{OUT}, respectively.

For the PWM (output) of the UC1843B-SP, a ±5% window pulse trigger was used. The trigger condition was set capture data any time the pulse width exceed the ±5% window on the DPO. The data was post-process to ±25%, however, for each run, only 500 upsets of the total number of upsets were recorded on memory. Since the whole data set was not available, the ±25% was created by determining the percentage of the 500 recorded waveforms that exceed the limit. This number was linearly scaled with the total number of observed upsets. The number of upsets was calculated as:

$$N_{\geq |25\%|} = \left(\frac{N_{\geq |25\%|}}{N_{\geq |5\%|}}\right) \times N_{\geq |5\%|} \quad (2)$$

Figure 15 shows the PWM cross section and weibull fit for upsets ≥ 5 and 25 %. Table 8 shows the weibull fit parameters. Typical observed time domain plots for the PWM SET are presented in Figure 16 to Figure 18.

The SET upper bound cross section for the V_{OUT} and PWM (Outputs) was calculated using a 95% confidence interval (see Appendix A for discussion of the cross section calculation method).

$\sigma_{SET\text{-}VOUT} \leq 7.71 \times 10^{-5}$ cm²/device at LET_{EFF} = 74 MeV·cm²/mg, T = 25 °C and 95% confidence.

$\sigma_{SET\text{-}PWM@5\%} \leq 9.68 \times 10^{-3}$ cm^2/device at LET_{EFF} = 74 MeV·cm^2/mg, T = 25 °C and 95% confidence.

$\sigma_{SET\text{-}PWM@5\%} \leq 2.11 \times 10^{-3}$ cm^2/device at LET_{EFF} = 74 MeV·cm^2/mg, T = 25 °C and 95% confidence.

Table 6. Summary of UC1843B-SP SET Test Conditions and Results with T = 25°C

RUN #	UNIT #	DISTANCE (mm)	ION	ANGLE OF INCIDENCE (°)	LET_{EFF} (MeV·cm^2/mg)	FLUX (ions/cm^2·s)	FLUENCE (ions/cm^2)	V_{OUT} UPSETS > |5.2%|(#)	PWM UPSETS > |5%|(#)	PWM UPSETS > |25%|(#)
4	2	40	Cu	0	20	1.14×10^4	9.97×10^5	0	5873	435
5	2	40	Cu	0	20	1.13×10^4	1×10^6	0	5846	410
6	2	40	Cu	0	20	1.1×10^4	1×10^6	0	5746	N/A
7	2	40	Cu	50	31.3	1.13×10^4	1×10^6	0	7486	1513
8	2	40	Cu	50	31.3	1.15×10^4	9.99×10^5	0	7829	1050
9	2	40	Cu	50	31.3	1.17×10^4	1×10^6	0	7774	1244
10	2	50	Ag	0	48.6	1.13×10^4	9.98×10^5	21	9257	1778
11	2	50	Ag	0	48.6	1.11×10^4	9.96×10^5	21	9377	1970
12	2	50	Ag	0	48.6	1.10×10^4	1.01×10^6	13	9335	1718
13	2	50	Ag	27	54.7	1.13×10^4	9.99×10^5	18	9671	2089
14	2	50	Ag	27	54.7	1.09×10^4	9.95×10^5	13	9647	2161
15	2	50	Ag	27	57.7	1.08×10^4	9.95×10^5	22	9276	1893
16	1	50	Pr	0	65.8	7.5×10^3	8.41×10^5	52	N/A	N/A
17	1	50	Pr	0	65.8	8.26×10^3	1.0×10^6	59	N/A	N/A
18	1	50	Pr	0	65.8	5.88×10^3	9.99×10^5	69	N/A	1720
19	1	50	Pr	0	65.8	5.73×10^3	1.0×10^6	82	4648	2206
20	1	50	Pr	27	74	8.46×10^3	2.0×10^6	100	N/A	N/A
21	1	50	Pr	27	74	7.51×10^3	1.01×10^6	43	N/A	N/A
22	1	50	Pr	27	74	7.23×10^3	3.03×10^5	14	N/A	N/A
23	1	50	Pr	27	74	6.45×10^3	1.0×10^6	48	N/A	N/A

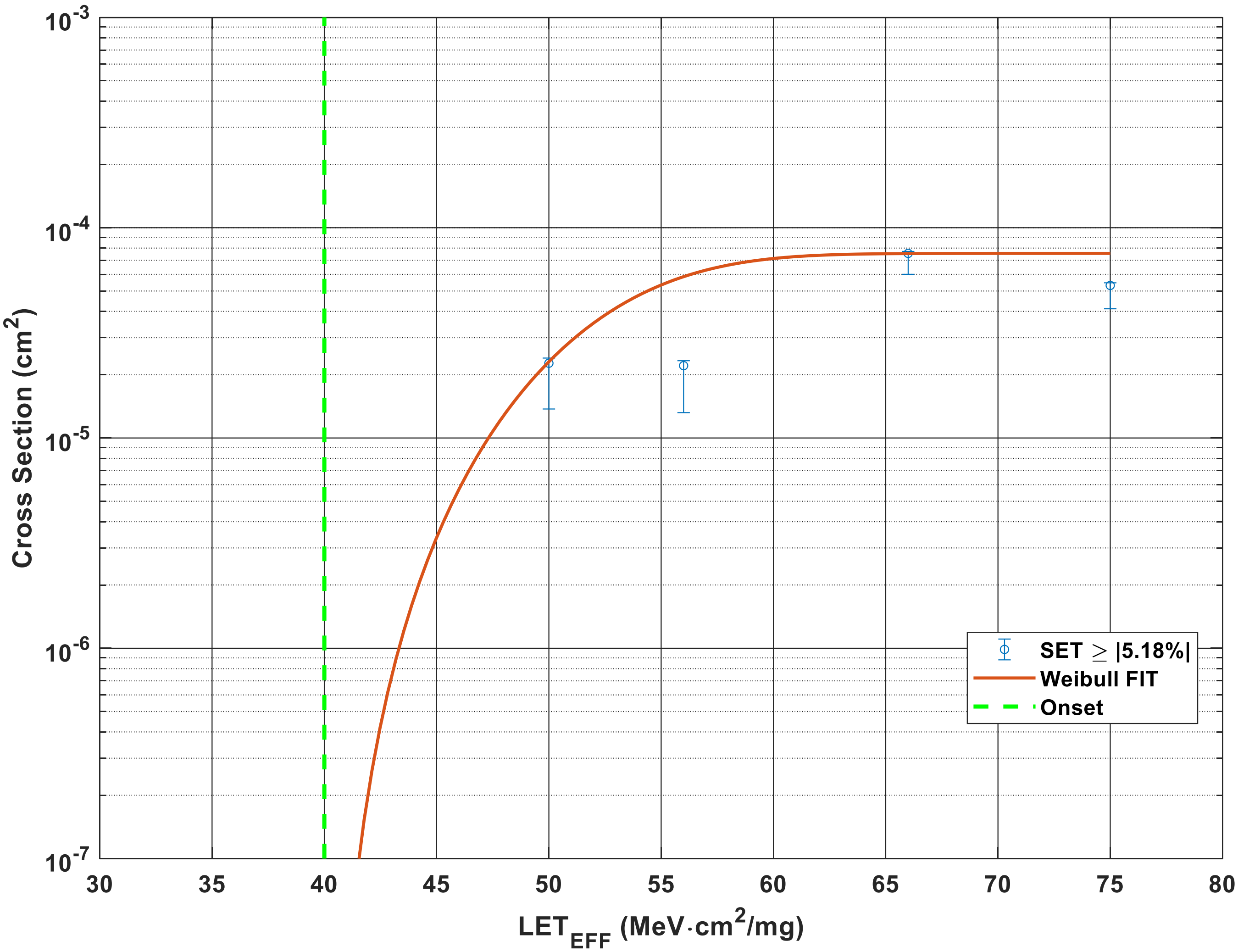


Figure 10. V_{OUT} Cross Section versus LET (V_{IN} = 40 V, V_{CC} = 12 V, V_{OUT} = 5 V, and Load = 10 A) for Upsets > 5.2%

Table 7. Weibull Fit Parameters for the V_{OUT} X-Section (for the Upsets ≥ ±5.2% from the Nominal Voltage)

PARAMETER	VALUE
Onset	40
σ_{SAT}	7.71 x 10^{-5}
W	14
s	3

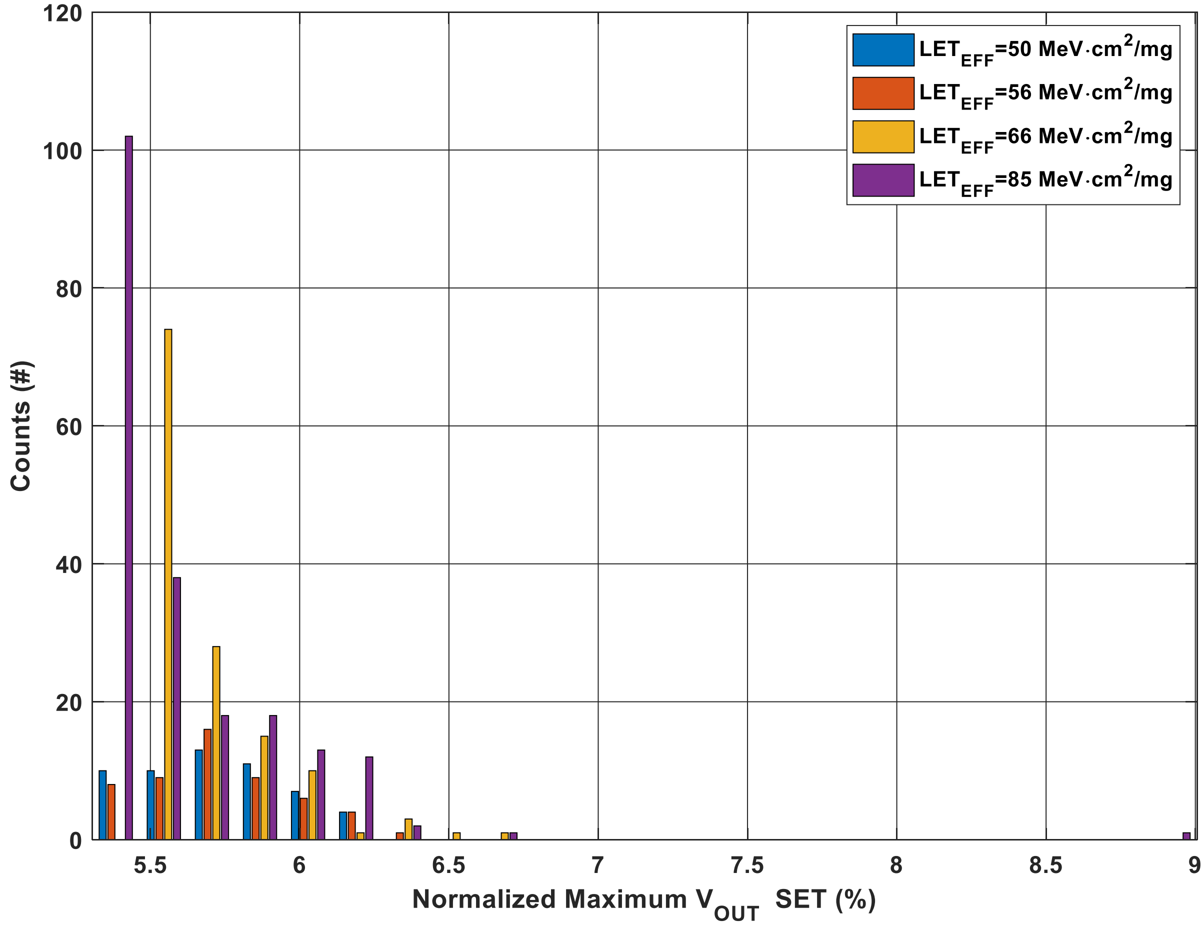


Figure 11. Histogram of the Normalized Magnitude for All Observed Upsets on V_{OUT} > ±5.2% by LET

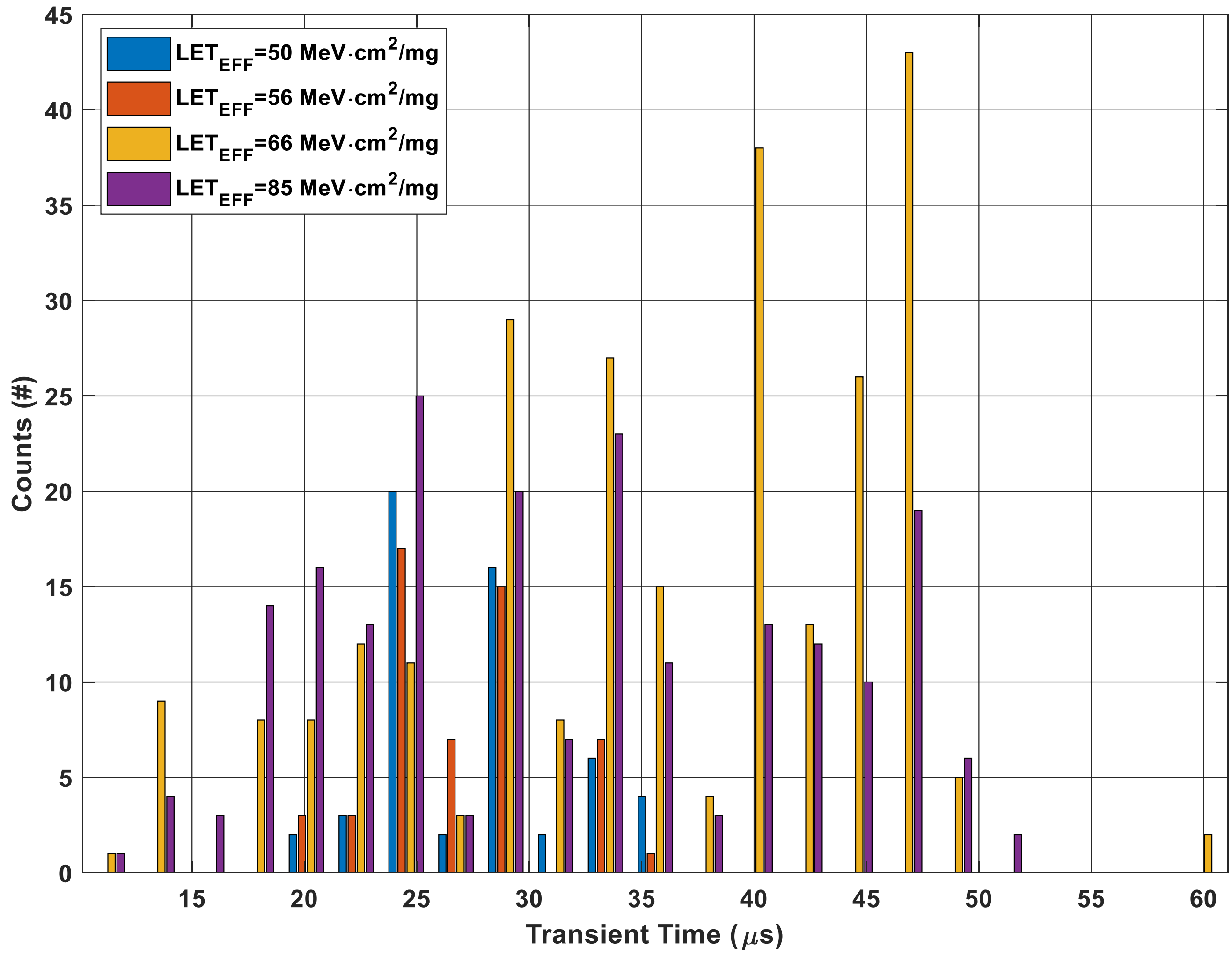


Figure 12. Histogram of the Transient Time in Microseconds for All Observed Upsets on V_{OUT} > ±5.2% by LET

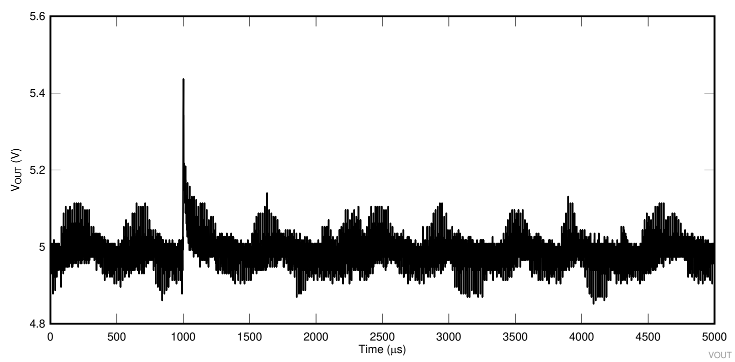


Figure 13. Observed Worst Case V_{OUT} Voltage Excusion (Run #21, Upset #95)

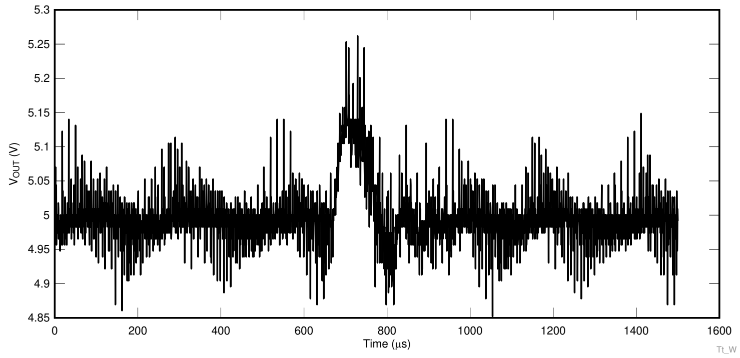


Figure 14. Observed Worst Case V_{OUT} Transient Time (Run #19, Upset #10)

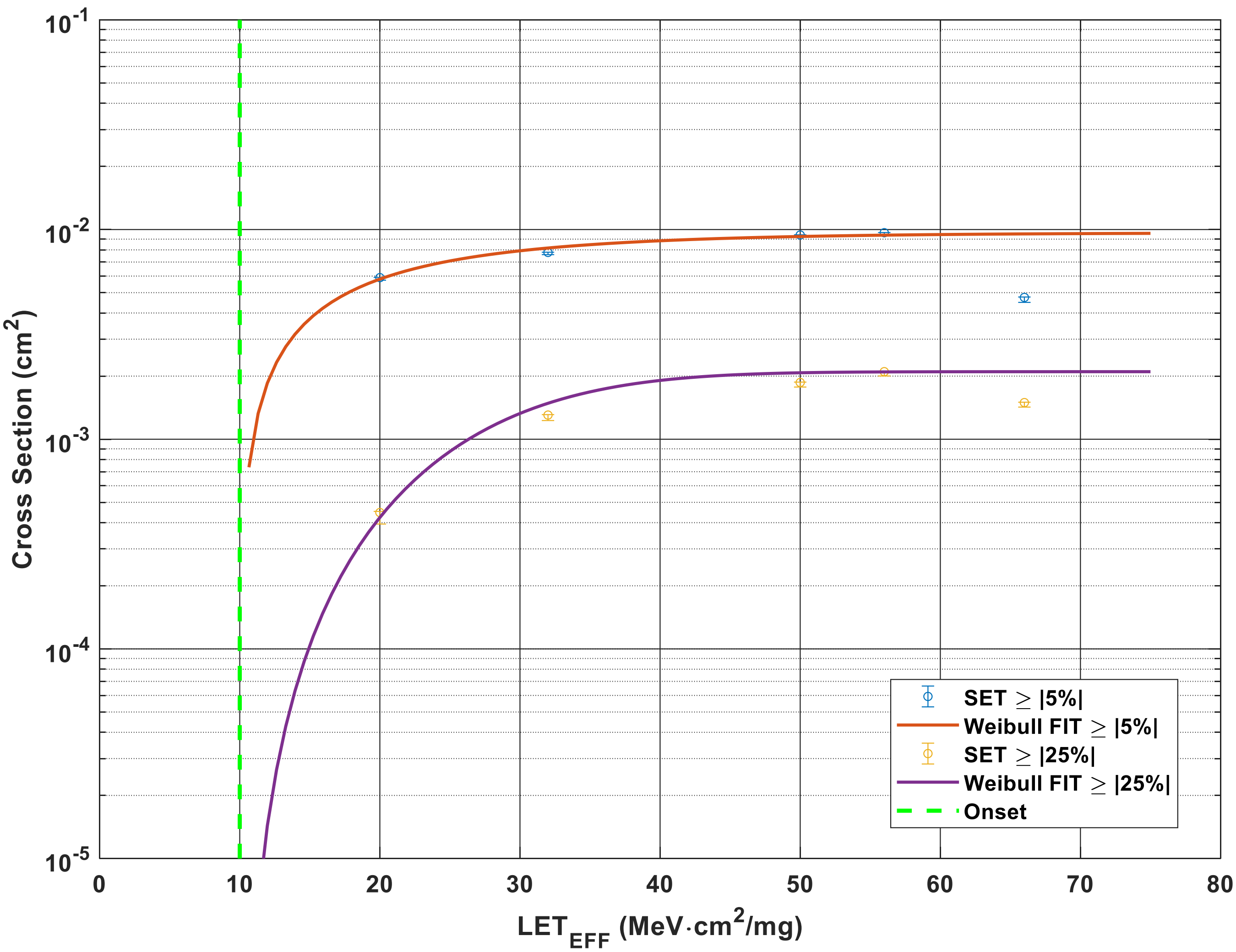


Figure 15. Weibull Fit Parameters for the PWM Cross Section for Upsets ≥ 5% and 25%

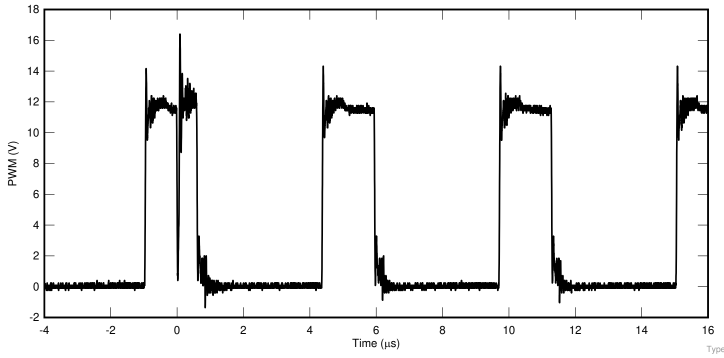


Figure 16. Observed SET at the PWM (Type I)

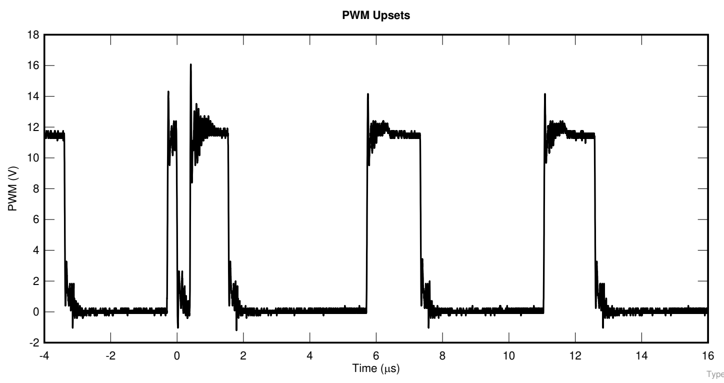


Figure 17. Observed SET at the PWM (Type II)

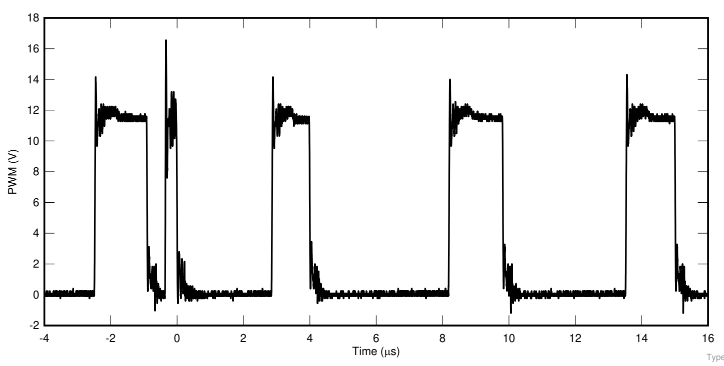


Figure 18. Observed SET at the PWM (Type III)

Table 8. Weibull Fit Parameters for the PWM Cross Section for Upsets ≥ 5% and 25%

PARAMETER	VALUE	CONDITION
Onset	10	5%
σ_{SAT}	9.68 x 10^{-3}	
W	11	
s	0.9	
Onset	10	25%
σ_{SAT}	2.11 x 10^{-3}	
W	20	
s	2.15	

9 Event Rate Calculations

Events rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations. A minimum shielding of 100 mils (2.54 mm) of aluminum and "worst week" solar activity was assumed. "Worst Week" is similar to 99% upper bound for the environment. With zero upsets for SEL and SEB, the error rate was calculated using the upper bound cross section and the integral flux at 74 MeV·cm^2/mg. Otherwise, the respective on-set and the upper bound at 75 MeV·cm^2/mg was used. To be conservative, all rate calculations were done using the upper-bound, even when the upset rate is greater than zero.

Table 9. SEL Event Rate Calculations for Worst-Case LEO and GEO Orbits

ORBIT TYPE	ONSET (MeV·cm^2/mg)	CREME96 INTEGRAL FLUX (/day·cm^2)	SATURATION CROSS SECTION (cm^2)	EVENT RATE (/DAY)	EVENT RATE (FIT)	MTBE (YEARS)
LEO (ISS)	74	6.68 x 10^{-5}	1.87 x 10^{-7}	1.25 x 10^{-11}	5.2 x 10^{-4}	2.19 x 10^{8}
GEO		1.88 x 10^{-4}		3.53 x 10^{-11}	1.5 x 10^{-3}	7.75 x 10^{7}

Table 10. SEB Event Rate Calculations for Worst-Case LEO and GEO Orbits

ORBIT TYPE	ONSET (MeV·cm^2/mg)	CREME96 INTEGRAL FLUX (/day·cm^2)	SATURATION CROSS SECTION (cm^2)	EVENT RATE (/DAY)	EVENT RATE (FIT)	MTBE (YEARS)
LEO (ISS)	74	6.68 x 10^{-5}	1.88 x 10^{-7}	1.25 x 10^{-11}	5.23 x 10^{-4}	2.18 x 10^{8}
GEO		1.88 x 10^{-4}		3.55 x 10^{-11}	1.51 x 10^{-3}	7.71 x 10^{7}

Table 11. V_{OUT} ≥ 5.2% SET Event Rate Calculations for Worst-Case LEO and GEO Orbits

ORBIT TYPE	ONSET (MeV·cm^2/mg)	CREME96 INTEGRAL FLUX (/day·cm^2)	SATURATION CROSS SECTION (cm^2)	EVENT RATE (/DAY)	EVENT RATE (FIT)	MTBE (YEARS)
LEO (ISS)	40	8.4 x 10^{-4}	7.71 x 10^{-5}	6.48 x 10^{-8}	2.71	4.23 x 10^{4}
GEO		3 x 10^{-3}		2.31 x 10^{-7}	9.63	1.19 x 10^{4}

Table 12. PWM ≥ 5% SET Event Rate Calculations for Worst-Case LEO and GEO Orbits

ORBIT TYPE	ONSET (MeV·cm^2/mg)	CREME96 INTEGRAL FLUX (/day·cm^2)	SATURATION CROSS SECTION (cm^2)	EVENT RATE (/DAY)	EVENT RATE (FIT)	MTBE (YEARS)
LEO (ISS)	10	33.59	9.68 x 10^{-3}	0.325	1.35 x 10^{7}	8.4 x 10^{-3}
GEO		277.83		2.689	1.12 x 10^{8}	0.001

Table 13. PWM ≥ 25% SET Event Rate Calculations for Worst-Case LEO and GEO Orbits

ORBIT TYPE	ONSET (MeV·cm^2/mg)	CREME96 INTEGRAL FLUX (/day·cm^2)	SATURATION CROSS SECTION (cm^2)	EVENT RATE (/DAY)	EVENT RATE (FIT)	MTBE (YEARS)
LEO (ISS)	10	33.59	2.11 x 10^{-3}	0.071	2.95 x 10^{6}	0.039
GEO		277.83		0.586	2.44 x 10^{7}	0.005

10 Summary

The purpose of this report is to summarize the UC1843B-SP SEE performance under heavy-ion irradiation. The data shows the device is SEL (T = 125°C) and SEB (T = 25°C)-free up to 74 MeV·cm^2/mg and across the full electrical specifications. The SET cross section for V_{OUT} with a flyback configuration had upsets ≥ |5.2%| and above the nominal voltage at 5-V is presented and discussed. The SET cross section for the PWM output upsets ≥ |5% and 25%| above the nominal pulse width is also presented and discussed. For the purpose of reference, the orbit rate calculation for the LEO (ISS) and GEO for the SEL, SEB and SET was discussed.

Total Ionizing Dose From SEE Experiments

The production TPS60501A-SP POL is rated to a total ionizing dose (TID) of 100 krad(Si). In the course of the SEE testing, the heavy-ion exposures delivered ≈ 10 krad(Si) per 10^7 ions/cm^2 run. The cumulative TID exposure for each device respectively, over all runs they underwent, was determined to be below the 100 krad(Si). All qualified production devices used in the studies described in this report stayed within specification and were fully-functional after the heavy-ion SEE testing was completed.

Confidence Interval Calculations

For conventional products where hundreds of failures are seen during a single exposure, one can determine the average failure rate of parts being tested in a heavy-ion beam as a function of fluence with high degree of certainty and reasonably tight standard deviation, and thus have a good deal of confidence that the calculated cross section is accurate.

With radiation hardened parts however, determining the cross section becomes more difficult since often few, or even, no failures are observed during an entire exposure. Determining the cross section using an average failure rate with standard deviation is no longer a viable option, and the common practice of assuming a single error occurred at the conclusion of a null-result can end up in a greatly underestimated cross section.

In cases where observed failures are rare or non-existent, the use of confidence intervals and the chi-squared distribution is indicated. The Chi-Squared distribution is particularly well-suited for the determination of a reliability level when the failures occur at a constant rate. In the case of SEE testing, where the ion events are random in time and position within the irradiation area, one expects a failure rate that is independent of time (presuming that parametric shifts induced by the total ionizing dose do not affect the failure rate), and thus the use of chi-squared statistical techniques is valid (since events are rare an exponential or Poisson distribution is usually used).

In a typical SEE experiment, the device-under-test (DUT) is exposed to a known, fixed fluence (ions/cm^2) while the DUT is monitored for failures. This is analogous to fixed-time reliability testing and, more specifically, time-terminated testing, where the reliability test is terminated after a fixed amount of time whether or not a failure has occurred (in the case of SEE tests fluence is substituted for time and hence it is a fixed fluence test) [14]. Calculating a confidence interval specifically provides a range of values which is likely to contain the parameter of interest (the actual number of failures/fluence). Confidence intervals are constructed at a specific confidence level. For example, a 95% confidence level implies that if a given number of units were sampled numerous times and a confidence interval estimated for each test, the resulting set of confidence intervals would bracket the true population parameter in about 95% of the cases.

In order to estimate the cross section from a null-result (no fails observed for a given fluence) with a confidence interval, start with the standard reliability determination of lower-bound (minimum) mean-time-to-failure for fixed-time testing (an exponential distribution is assumed):

$$\mathrm{MTTF} = \frac{2nT}{\chi^2_{2(d+1);100\left(1-\frac{\alpha}{2}\right)}}$$

where

- *MTTF* is the minimum (lower-bound) mean-time-to-failure
- *n* is the number of units tested (presuming each unit is tested under identical conditions)
- *T*, is the test time
- x^2 is the chi-square distribution evaluated at 100(1 – α / 2) confidence level
- d is the degrees-of-freedom (the number of failures observed) (3)

With slight modification for this purpose, invert the inequality and substitute *F* (fluence) in the place of *T*:

$$MFTF = \frac{2nF}{\chi^2_{2(d+1);100\left(1-\frac{\alpha}{2}\right)}}$$

where
- *MFTF* is mean-fluence-to-failure
- *F* is the test fluence
- x^2 is the chi-square distribution evaluated at 100(1 – α / 2) confidence
- *d* is the degrees-of-freedom (the number of failures observed) (4)

The inverse relation between MTTF and failure rate is mirrored with the MFTF. Thus the upper-bound cross section is obtained by inverting the MFTF:

$$\sigma = \frac{\chi^2_{2(d+1);100\left(1-\frac{\alpha}{2}\right)}}{2nF} \quad (5)$$

Assume that all tests are terminated at a total fluence of 10^6 ions/cm^2. Also assume that we have a number of devices with very different performances that are tested under identical conditions. Assume a 95% confidence level (σ = 0.05). Note that as *d* increases from 0 events to 100 events, the actual confidence interval becomes smaller, indicating that the range of values of the true value of the population parameter (in this case the cross section) is approaching the mean value + 1 standard deviation. This makes sense when one considers that as more events are observed the statistics are improved such that uncertainty in the actual device performance is reduced.

Table 14. Experimental Example Calculation of Mean-Fluence-to-Failure (MFTF) and σ Using a 95% Confidence Interval[(1)]

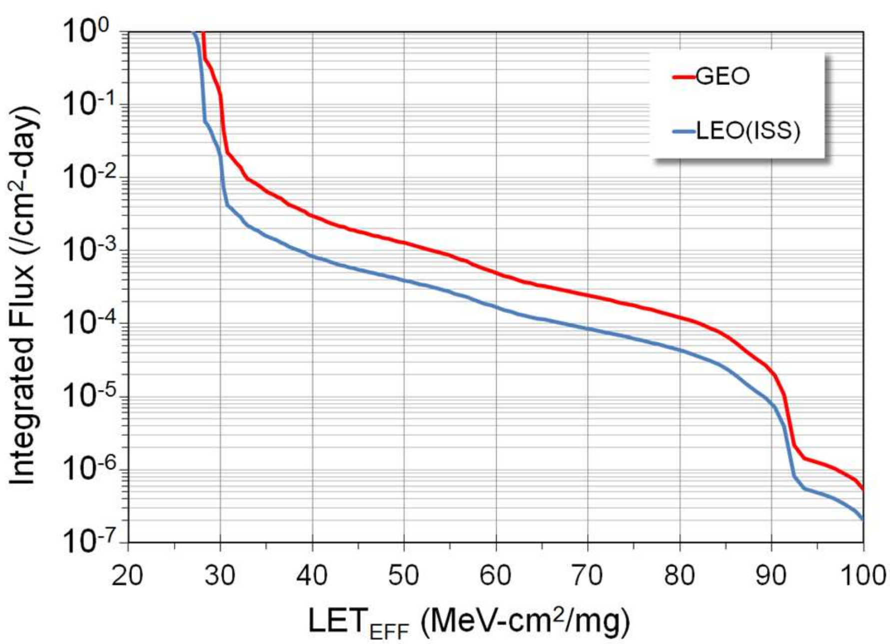
DEGREES-OF-FREEDOM (d)	2(d + 1)	χ^2 AT 95%	CALCULATED CROSS SECTION (cm^2)		
			UPPER-BOUND AT 95% CONFIDENCE	MEAN	AVERAGE + STANDARD DEVIATION
0	2	7.38	3.69E–06	0.00E+00	0.00E+00
1	4	11.14	5.57E–06	1.00E–06	2.00E–06
2	6	14.45	7.22E–06	2.00E–06	3.41E–06
3	8	17.53	8.77E–06	3.00E–06	4.73E–06
4	10	20.48	1.02E–05	4.00E–06	6.00E–06
5	12	23.34	1.17E–05	5.00E–06	7.24E–06
10	22	36.78	1.84E–05	1.00E–05	1.32E–05
50	102	131.84	6.59E–05	5.00E–05	5.71E–05
100	202	243.25	1.22E–04	1.00E–04	1.10E–04

(1) Using a 95% confidence for several different observed results (d = 0, 1, 2...100 observed events during fixed-fluence tests) assuming 10^6 ion/cm^2 for each test.

Orbital Environment Estimations

To calculate on-orbit SEE event rates, one needs both the device SEE cross section and the flux of particles encountered in a particular orbit. Device SEE cross sections are usually determined experimentally while flux of particles in orbit is calculated using various codes. For the purpose of generating some event rates, a Low-Earth Orbit (LEO) and a Geostationary-Earth Orbit (GEO) were calculated using CREME96. CREME96 code, short for Cosmic Ray Effects on Micro-Electronics is a suite of programs [15][16] that enable estimation of the radiation environment in near-Earth orbits. CREME96 is one of several tools available in the aerospace industry to provide accurate space environment calculations. Over the years since its introduction, the CREME models have been compared with on-orbit data and demonstrated their accuracy. In particular, CREME96 incorporates realistic “worst-case” solar particle event models, where fluxes can increase by several orders-of-magnitude over short periods of time.

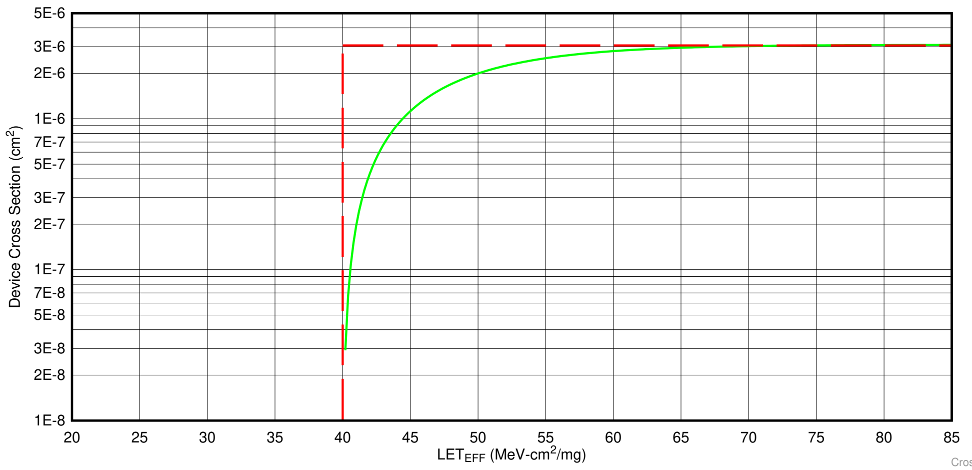
For the purposes of generating conservative event rates, the worst-week model (based on the biggest solar event lasting a week in the last 45 years) was selected, which has been equated to a 99%-confidence level worst-case event [17][18]. The integrated flux includes protons to heavy ions from solar and galactic sources. A minimal shielding configuration is assumed at 100 mils (2.54 mm) of aluminum. Two orbital environments were estimated, that of the International Space Station (ISS), which is LEO, and the GEO environment. Figure 19 shows the integrated flux (from high LET to low) for these two environments.



(1) LEO(ISS) (blue) and a GEO (red) environment as calculated by CREME96, assuming worst-week and 100 mils (2.54 mm) of aluminum shielding.

Figure 19. Integral Particle Flux versus LET_{EFF}

Using this data, you can extract integral particle fluxes for any arbitrary LET of interest. To simplify the calculation of event rates, assume that all cross section curves are square – meaning that below the onset LET the cross section is identically zero while above the onset LET the cross section is uniformly equal to the saturation cross section. Figure 20 illustrates the approximation, with the green curve being the actual Weibull fit to the data with the "square" approximation shown as the red-dashed line. This allows you to calculate event rates with a single multiplication, the event rate becoming simply the product of the integral flux at the onset LET, and the saturation cross section. Obviously this leads to an overestimation of the event rate since the area under the square approximation is larger than the actual cross section curve – but for the purposes of calculating upper-bound event rate estimates, this modification avoids the need to do the integral over the flux and cross section curves.



(1) Weibull Fit (green) is "simplified" with the use of a square approximation (red dashed line).

Figure 20. Device Cross Section versus LET_{EFF}

To demonstrate how the event rates in this report were calculated, assume that you wish to calculate an event rate for a GEO orbit for the device whose cross section is shown in Figure 20. Using the red curve in Figure 19 and the onset LET value obtained from Figure 20 (approximately 40 MeV-cm^2/mg), you find the GEO integral flux to be approximately 2.97 × 10^{-3} ions/cm^2-day. The event rate is the product of the integral flux and the saturation cross section in Figure 20 (approximately 3.09 × 10^{-6} cm^2):

$$GEO\ Event\ Rate = \left(2.97 \times 10^{-3} \frac{ions}{cm^2 \times day}\right) \times (3.09 \times 10^{-6}\ cm^2) = 9.17 \times 10^{-9}\ \frac{events}{day} \quad (6)$$

$$GEO\ Event\ Rate = 3.82 \times 10^{-10} \frac{events}{hr} = 0.382\ FIT \quad (7)$$

$$MTBF = 298901\ Years\ ! \quad (8)$$

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