*Radiation Report*

# *Single-Event Effects Test Report of the TPS7H2140-SEP Quad-Channel eFuse*

## ABSTRACT

The purpose of this study is to characterize the single-event-effects (SEE) performance due to heavy-ion irradiation of the TPS7H2140-SEP. SEE performance was verified at minimum (4.5 V) and maximum (32 V) operating conditions. Heavy-ions at an $LET_{EFF}$ of 48 MeV × $cm^2$ / mg were used to irradiate three production devices and four pre-production devices. Flux of ≈$10^5$ ions / $cm^2$ × s and fluences of ≈ $10^7$ ions / $cm^2$ per run were used for the characterization. The results demonstrated that the TPS7H2140-SEP is SEL and SEB/SEGR-free up to 48 MeV × $cm^2$ / mg, at T = 125°C and T = 25°C, respectively, and across the full electrical specifications. SET performance for output voltage excursions ≥ |3%| from the nominal voltage, excursions ≥ |4%| from nominal CS, and negative edge transients on the FAULT pin are discussed in Single-Event Transients (SET).

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# 1 Introduction

The TPS7H2140-SEP is a space-enhanced-plastic, 4.5-V to 32-V input, 5.4-A (1.35-A per channel), quad-channel eFuse. The TPS7H2140-SEP is fully protected with four integrated 160-mΩ (typical) NMOS power FETs. Full diagnostics and high-accuracy current sense enables intelligent control of the loads. An external adjustable current limit improves the reliability of whole system by limiting the inrush overload current.

The device is offered in a 28-pin HTSSOP plastic package. Table 1-1 lists general device information and test conditions. For more detailed technical specifications, user guides, and application notes, see the TPS7H2140-SEP product page.

**Table 1-1. Overview Information**

| Description(1) | Device Information |
|---|---|
| TI part number | TPS7H2140-SEP |
| Orderable number | TPS7H2140MPWPTSEP |
| Device function | Quad-channel eFuse |
| Technology | LBC8 |
| Exposure facility | Radiation effects facility, Cyclotron Institute, Texas A&M University (15 MeV / nucleon) |
| Heavy ion fluence per run | $9.85 \times 10^6$ – $1 \times 10^7$ ions/cm$^2$ |
| Irradiation temperature | 25°C (for SEB/SEGR testing & SET testing), and 125°C (for SEL testing) |

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## 2 Single-Event Effects (SEE)

The primary concern for the TPS7H2140-SEP is the robustness against the destructive single-event effects (DSEE), single-event latch-up (SEL), single-event burnout (SEB), and single-event gate rupture (SEGR). In mixed technologies such as the BiCMOS process used on the TPS7H2140-SEP, 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, which is formed between the p-sub and n-well and n+ and p+ contacts. (For more information, see [1 and 2]). 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, the device is reset, or until the high-current state destroys the device. The TPS7H2140-SEP was tested for SEL at the maximum recommended voltage of 32 V and maximum load current of 5.4 A (1.35 A per channel). The device was set up with $OUT_1$ operating in a single configuration. $OUT_2$, $OUT_3$, and $OUT_4$ were operated in a parallel configuration. See Figure 6-1 for more details. The device did not exhibit SEL when heavy-ions with $LET_{EFF}$ = 48 MeV × $cm^2$ / mg at flux ≈$10^5$ ions / $cm^2$× s, fluences of ≈$10^7$ ions / $cm^2$, and a die temperature of 125°C.

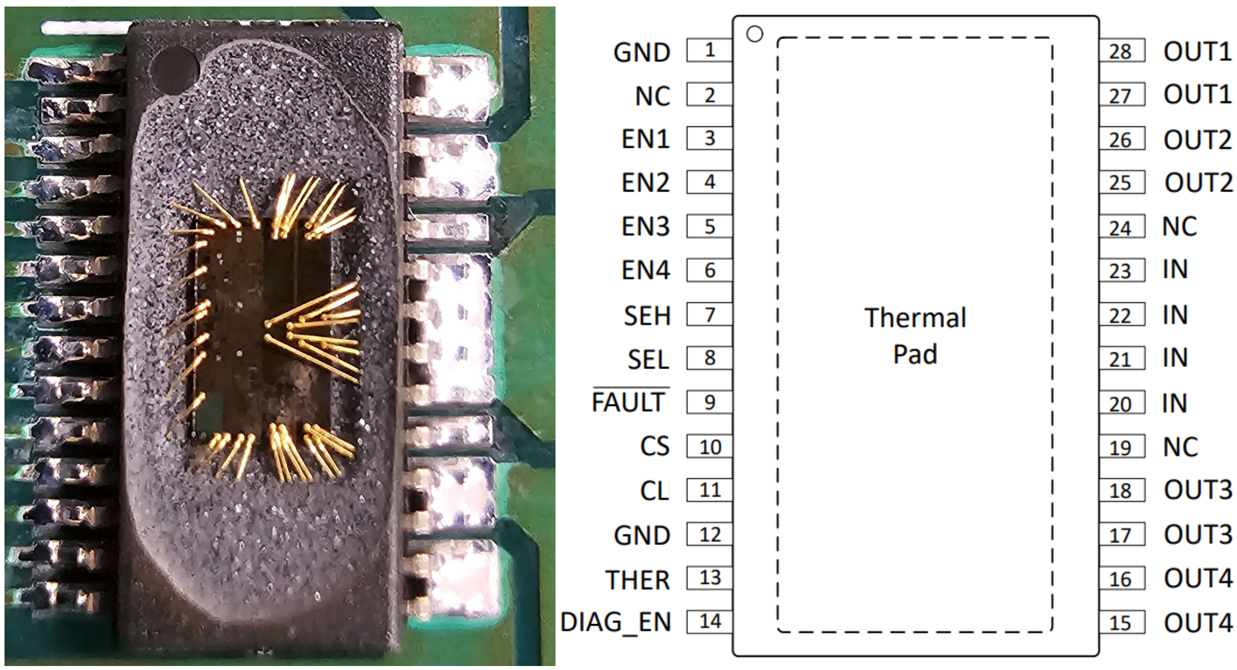
Since this device is designed to conduct large currents up to 5.4 A (1.35 A per channel) and can withstand up to 32 V during the off-state, the power LDMOS introduces a potential susceptibility for SEB and SEGR (2). The TPS7H2140-SEP was evaluated for SEB and SEGR at full load conditions of 5.4 A (1.35 A per channel), and a maximum voltage of 32 V in both the enabled and disabled modes. During SEB and SEGR testing, a single current event was not observed, demonstrating that the TPS7H2140-SEP is SEB and SEGR-free up to $LET_{EFF}$ = 48 MeV·$cm^2$/ mg at a flux of ≈$10^5$ ions / $cm^2$ × s, fluences of ≈$10^7$ ions / $cm^2$, and a die temperature of ≈25°C.

The TPS7H2140-SEP was characterized for SET at a flux of ≈$10^5$ ions / $cm^2$·s, fluences of ≈$10^7$ ions / $cm^2$, and at room temperature. The device was characterized at IN = 4.5 V at a load of 2 A (0.5-A per channel) load. Under these conditions, the device showed three different single-event transients (SET) signatures under heavy-ion irradiation. All observed types of SETs were self-recoverable without requiring external intervention. The observed transients can be classified as:

1. A brief transient of the output voltage (referred here as $OUT_{X,SET}$). For the purpose of this report the transients were characterize for deviations –3% ≤ $OUT_X$ ≤ 3% from the nominal output voltage. For more details, see Section 8.
2. A brief transient on the Current Sense (CS) pin. For the purpose of this report the transients were characterized for deviations –4% ≤ CS ≤ 4% from the nominal output voltage. This type of SET is referred to here as $CS_{SET}$.
3. A $\overline{FAULT}$ upset ≥ 1 V from nominal on a negative-edge trigger.

# 3 Device and Test Board Information

The TPS7H2140-SEP is packaged in a 28-pin HTSSOP plastic package as shown in Figure 3-1. An evaluation board designed for radiation testing was used to evaluate the performance and characteristics of the TPS7H2140-SEP under heavy-ions. Figure 3-2 shows the top view of the evaluation board used for the radiation testing. Figure 3-3 shows the EVM board schematics used for the heavy-ion testing campaign.




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

**Figure 3-1. Photograph of Delidded TPS7H2140-SEP [Left] and Pinout Diagram [Right]**

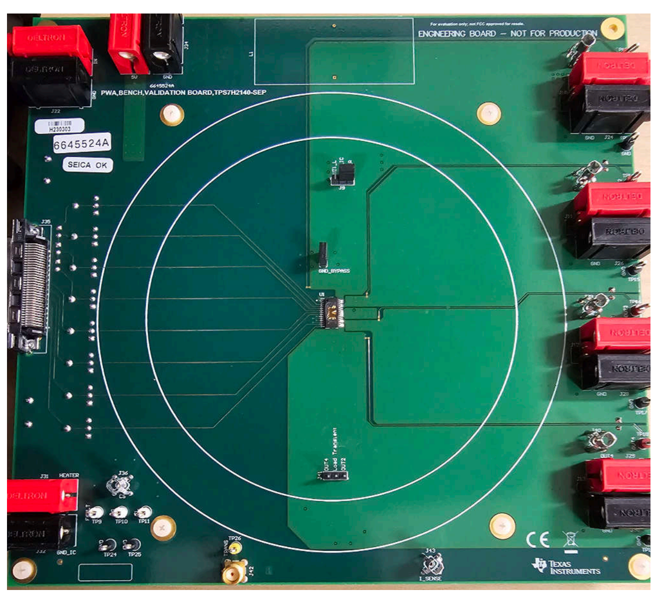



**Figure 3-2. TPS7H2140-SEP Board Top View**

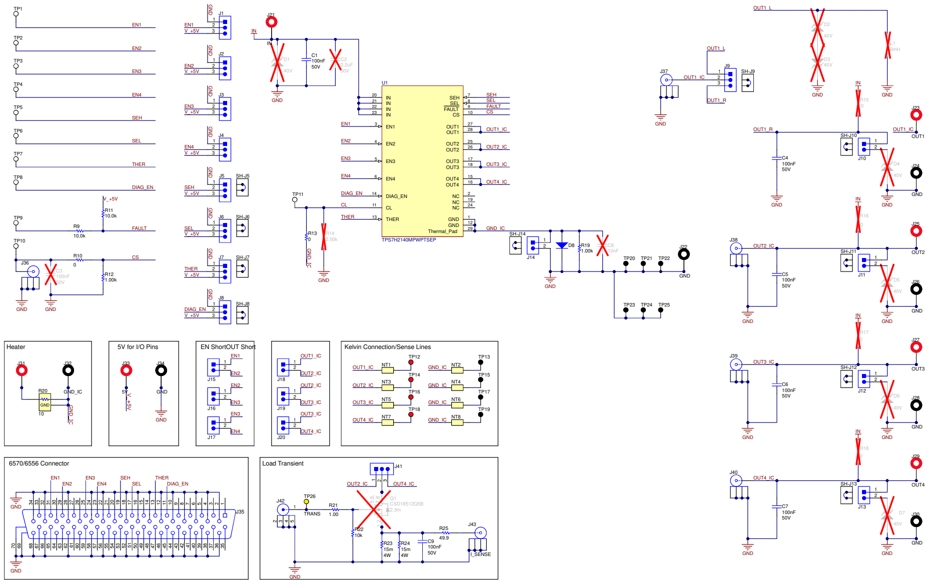


**Figure 3-3. TPS7H2140-SEP SEE Validation EVM Schematic**

# 4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by the Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, the 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 majority of these studies, ion flux of $10^5$ ions / $cm^2$ × s were used to provide heavy-ion fluences of approximately $10^7$ ions / $cm^2$.

For the experiments conducted in this report, the following ions and corresponding angles were used to provide a range of $LET_{EFF}$ of 48 MeV × cm2 / mg.

- Silver ($^{109}Ag$) at 0° for an $LET_{EFF}$ = 48 MeV
  - $Range_{EFF}$ = 91.2 μm
  - Total Kinetic Energy = 1.634 GeV (15 MeV / nucleon)

Ion uniformity for these experiments was between 93 and 96%.

Figure 4-1 shows the TPS7H2140-SEP 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. The in-air gap between the device and the ion beam port window was maintained at 40 millimeters for all runs.

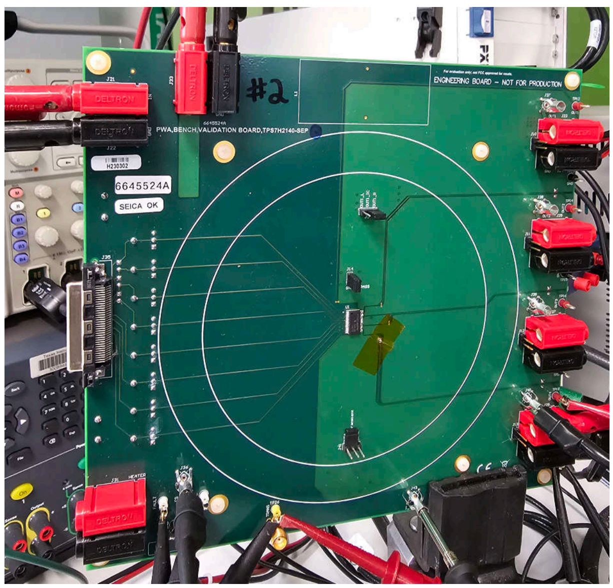



**Figure 4-1. Photograph of the TPS7H2140-SEP Evaluation Board Mounted in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron Radiation Effects Facility**

## 5 Depth, Range, and $LET_{EFF}$ Calculation

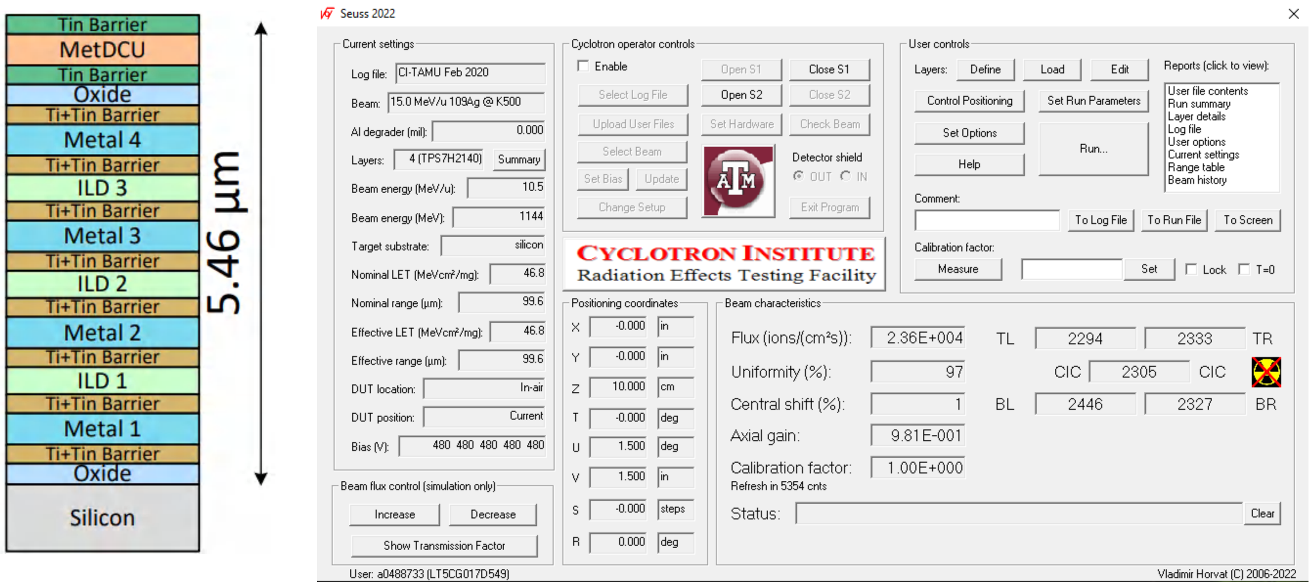



**Figure 5-1. Generalized Cross-Section of the LBC8 Technology BEOL Stack on the TPS7H2140-SEP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right]**

The TPS7H2140-SEP is fabricated in the TI Linear BiCMOS 250-nm process with a back-end-of-line (BEOL) stack consisting of five levels of standard thickness aluminum metal on a 0.6-µm pitch. The total stack height from the surface of the passivation to the silicon surface is 5.46 µm based on nominal layer thickness as shown in Figure 5-1. Accounting for energy loss through the 1-mil thick Aramica beam port window, the 40-mm air gap, and the BEOL stack over the TPS7H2140-SEP, the effective LET ($LET_{EFF}$) at the surface of the silicon substrate, the depth, and the ion range was determined with the SEUSS 2020 Software (provided by the Texas A&M Cyclotron Institute and based on the latest SRIM-2013 [7] models). Table 5-1 lists the results.

**Table 5-1. Krypton Ion $LET_{EFF}$, Depth, and Range in Silicon**

| Ion Type | Angle of Incidence | Degrader Steps (Number) | Degrader Angle | Range in Silicon | $LET_{EFF}$ (MeV·cm$^2$/mg) |
|---|---|---|---|---|---|
| $^{109}$Ag | 0 | 0 | 0 | 99.2 | 48 |

# 6 Test Setup and Procedures

SEE testing was performed on a TPS7H2140-SEP device mounted on a TPS7H2140-SEP SEE validation board. $V_{IN}$, ranging from 4.5 V for SET to 32 V for SEL and SEB/SEGR, was provided to the device using the J21 (IN) and (GND) inputs with the N6766A PS Module mounted on a N6705 precision power supply in a 4-wire configuration. An external source for the I/O pins, ranging from 4.5 V for SET to 5 V for SEL and SEB/SEGR, was provided using the J33 (5 V) and (GND) inputs through channel 1 of an E36311A power supply. A second E36311A power supply, using channel 1 and channel 2, was used on TP1 ($EN_1$) and TP2 ($EN_2$) for $EN_x$, which ranged from 0 V for SEB Off to 4.5 V for SET testing and 5 V for all DSEE testing.

During SEL testing, the device was heated to 125°C by using a TDH35P10R0JE discrete power resistor soldered under the thermal vias on the bottom layer of the validation card. Using a PXIe-4139 SMU, a current of 1 A was forced into the power resistor elevating the die temperature to 125°C. The temperature of the die was verified using a FLIR thermal camera.

The instrument used to load the TPS7H2140-SEP was a Chroma E36300 E-Load that was used in Constant Resistance (CR) mode. The value of CR was adjusted depending on the type of test. For SEL and SEB/SEGR testing, the CR value was set to achieve a total load of 1.35 A per channel. For SET testing, the CR value was set to achieve a total load of 0.5 A per channel.

During all SEE testing, $OUT_1$ was operated independently while $OUT_2$, $OUT_3$, and $OUT_4$ were operated in parallel. Based on Figure 3-3, J16 and J17 were used to place $EN_2$, $EN_3$, and $EN_4$ in parallel operation while J19 and J20 were used to place $OUT_2$, $OUT_3$, and $OUT_4$ in parallel operation.

The signals monitored included $OUT_1$, $OUT_2$, CS, and $\overline{FAULT}$. $OUT_1$ was monitored using a MSO58B which was set to trigger on a 3% window based on the nominal value of $OUT_1$. $OUT_2$ was monitored using a NI PXIe-5172 scope card which was set to trigger on a 3% window based on the nominal value of $OUT_2$. CS was monitored using a second NI PXIe-5172 scope card which was set to trigger on a 4% window based on the nominal value of CS. $\overline{FAULT}$ was monitored using a NI PXIe-5160 scope card which was set to trigger on a negative edge trigger of 1 V less than the nominal value of $\overline{FAULT}$.

All equipment other than the MSO58B 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. The MSO58B was used using the manufacturer interface. The MSO was set to fast-frame for all SET data collection.

Table 6-1 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 TPS7H2140-SEP.

**Table 6-1. Equipment Set and Parameters used for SEE Testing the TPS7H2140-SEP**

| Pin Name | Equipment Used | Equipment Channel Used | Capability | Compliance | Range of Values Used | Trigger |
|---|---|---|---|---|---|---|
| IN | Agilent N6766A | Channel 3 | 60 V, 17 A | 10-A | 4.5 to 32-V | — |
| $EN_1$ | Keysight E36311A (1) | Channel 1 | 6 V, 5 A | 0.1 A | 0 to 5 V | — |
| $EN_2$ | Keysight E36311A (1) | Channel 2 | 25 V, 1 A | 0.1 A | 0 to 5 V | — |
| External 5-V source | Keysight E36311A (2) | Channel 1 | 6 V, 5 A | 0.1 A | 4.5 to 5 V | — |
| Heater | NI PXIe-4139 | Channel 1 | 60 V, 3 A | 15 V | 1 A | — |
| $OUT_1$ | MSO58B | — | 6.25 GS / s | — | 100 MS / s | Window at ±3% |
| $OUT_2$ | NI PXIe-5172 (1) | — | 100 MS / s | — | 10 MS / s | Window at ±3% |
| CS | NI PXIe-5172 (2) | — | 100 MS / s | — | 10 MS / s | Window at ±4% |
| $\overline{FAULT}$ | NI PXIe-5160 | — | 100 MS/s | — | 10 MS / s | Negative edge at nominal 1 V |

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to make sure that the test system was stable under all bias and load conditions prior to being taken to the TAMU facility. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H2140-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 MSO and NI scope cards continuously monitored the signals. When $OUT_X$ exceeded the predefined 3% window triggers, CS exceeded the predefined 4% window triggers, or when the $\overline{FAULT}$ signal changed from high to low (using a negative edge trigger), a data capture was initiated. In addition to monitoring the voltage levels from the scopes, VIN current and 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 and indicated that SEL or SEB/SEGR events did not occur during any of the tests.

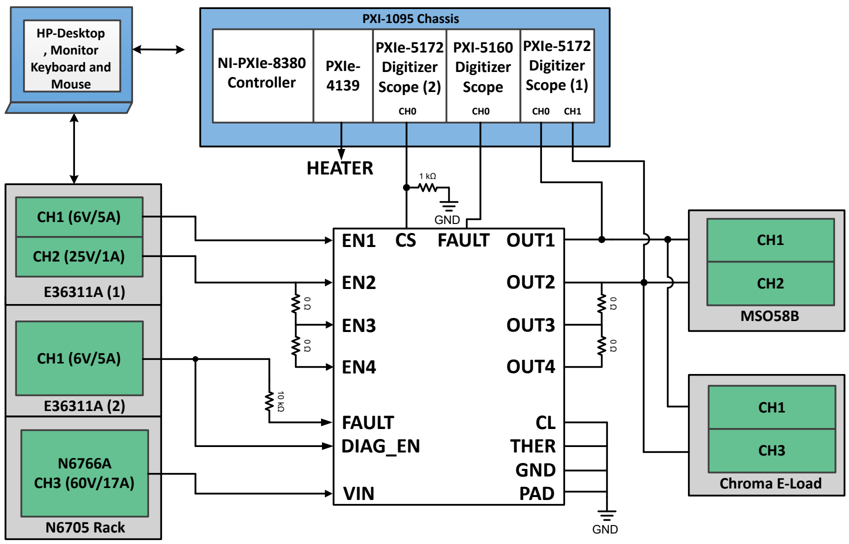



**Figure 6-1. Block Diagram of SEE Test Setup with the TPS7H2140-SEP**

# 7 Destructive Single-Event Effects (DSEE)

## 7.1 Single-Event Latch-up (SEL) Results

During SEL characterization, the device was heated using a TDH35P10R0JE discrete power resistor soldered right under the thermal vias on the bottom layer of the board, maintaining the DUT temperature at 125°C. Prior to radiation, the die to thermocouple temperature was verified using a FLIR IR-camera.

The species used for the SEL testing was a silver ($^{109}$Ag) ion with an angle-of-incidence of 0° for an $LET_{EFF}$ = 48 MeV × cm$^2$ / mg. For more details, see Section 5). The kinetic energy in the vacuum for this ion is 1.634 GeV (15-MeV /amu line). Flux of approximately $10^5$ ions / cm$^2$ × s and a fluence of approximately $10^7$ ions / cm$^2$ were used for the six runs. Run duration to achieve this fluence was approximately two minutes. The six devices were powered up and exposed to the heavy-ions using the maximum recommended voltage of 32 V and maximum load of 5.4 A (1.35 A per channel). The device was set up with $OUT_1$ operating in a single configuration and $OUT_2$, $OUT_3$, $OUT_4$ were operated in a parallel configuration. See Figure 6-1 for more details. $OUT_1$ was loaded to 1.35 A, while $OUT_2$, $OUT_3$, and $OUT_4$ were in parallel loaded to 4.05 A (1.35 A per channel). No SEL events were observed during all six runs, which indicates that the TPS7H2140-SEP is SEL-free. Table 7-1 lists the SEL test conditions and results. Figure 7-1 shows a typical plot of $I_{IN}$ versus time for run 1.

**Table 7-1. Summary of TPS7H2140-SEP SEL Test Condition and Results**

Pre-Production units refers to P-type symbolized units. Productions units refers to units that went through the entire -SEP flow.

| Run Number | Type of Unit | Unit Number | Ion | $LET_{EFF}$ (MeV × cm$^2$ / mg) | FLUX (ions × cm$^2$ / mg) | Fluence (Number ions) |
|---|---|---|---|---|---|---|
| 1 | Preproduction | 2 | $^{109}$Ag | 48 | 1.20 × $10^5$ | 9.95 × $10^6$ |
| 2 | Preproduction | 3 | $^{109}$Ag | 48 | 8.20 × $10^4$ | 9.98 × $10^6$ |
| 3 | Preproduction | 4 | $^{109}$Ag | 48 | 1.04 × $10^5$ | 1.00 × $10^7$ |
| 4 | Production | 5 | $^{109}$Ag | 48 | 2.70 × $10^5$ | 9.85 × $10^6$ |
| 5 | Production | 6 | $^{109}$Ag | 48 | 1.02 × $10^5$ | 1.00 × $10^7$ |
| 6 | Production | 7 | $^{109}$Ag | 48 | 1.00 × $10^5$ | 1.00 × $10^7$ |

Using the MFTF method shown in *Single-Event Effects (SEE) Confidence Interval Calculations* and combining (or summing) the fluences of the six runs at 125°C (5.78 × $10^7$), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{SEL} \leq 6.38 \times 10^{-8}\ \text{cm}^2\ /\ \text{device for}\ LET_{EFF} = 48\ \text{MeV} \times \text{cm}^2/\text{mg and}\ T_J = 125°\text{C}.$$

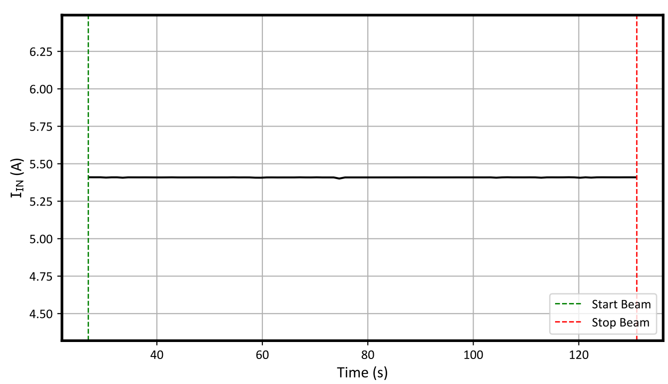



**Figure 7-1. $I_{IN}$ versus Time for Run 1 of the TPS7H2140-SEP at $T_J$ = 125°C**

## 7.2 Single-Event Burnout (SEB) and Single-Event Gate Rupture (SEGR) Results

The species used for the SEL testing was a silver ($^{109}Ag$) ion with an angle-of-incidence of 0° for an $LET_{EFF}$ = 48 MeV × cm$^2$ / mg. For more details, see Section 5). The kinetic energy in the vacuum for this ion is 1.634 GeV (15-MeV / amu line). Flux of approximately $10^5$ ions / cm$^2$ × s and a fluence of approximately $10^7$ ions / cm$^2$ were used for the twelve runs. Run duration to achieve this fluence was approximately two minutes. The six devices were powered up using the recommended maximum voltage of 32 V and the maximum load of 5.4 A (1.35 A per channel). The device was set up with $OUT_1$ operating in a single configuration. $OUT_2$, $OUT_3$, $OUT_4$ were operated in a parallel configuration. See Figure 6-1 for more details. $OUT_1$ was loaded to 1.35-A, while $OUT_2$, $OUT_3$, and $OUT_4$ were in parallel loaded to 4.05 A(1.35 A per channel). The TPS7H2140-SEP was tested under enabled and disabled modes. The device was disabled by using an external power supply on the $EN_X$ test points. During SEB/SEGR testing with the device disabled, no $OUT_X$ transient or input current events were observed. No SEB/SEGR events were observed during all twelve runs, which indicates that the TPS7H2140-SEP is SEB/SEGR-free up to $LET_{EFF}$ = 48 MeV × cm$^2$ / mg and across the full electrical specifications. Table 7-2 lists the SEB test conditions and results. Figure 7-2 and Figure 7-3 show a plot of the current versus time for run 7 (enabled) and run 8 (disabled).

**Table 7-2. Summary of TPS7H2140-SEP SEB Test Condition and Results**

Pre-Production units refers to P-type symbolized units. Productions units refers to units that went through the entire -SEP flow.

| Run Number | Type of Unit | Unit Number | Ion | $LET_{EFF}$ (MeV × cm$^2$ / mg) | Flux (ions × cm$^2$/ mg) | Fluence (Number ions) | Enabled Status |
|---|---|---|---|---|---|---|---|
| 7 | Preproduction | 2 | $^{109}Ag$ | 48 | 1.14 × $10^5$ | 9.97 × $10^6$ | Enabled |
| 8 | Preproduction | 2 | $^{109}Ag$ | 48 | 1.18 × $10^5$ | 1.00 × $10^7$ | Disabled |
| 9 | Preproduction | 3 | $^{109}Ag$ | 48 | 1.01 × $10^5$ | 1.00 × $10^7$ | Enabled |
| 10 | Preproduction | 3 | $^{109}Ag$ | 48 | 8.45 × $10^4$ | 1.00 × $10^7$ | Disabled |
| 11 | Preproduction | 4 | $^{109}Ag$ | 48 | 1.03 × $10^5$ | 1.00 × $10^7$ | Enabled |
| 12 | Preproduction | 4 | $^{109}Ag$ | 48 | 1.04 × $10^5$ | 1.00 × $10^7$ | Disabled |
| 13 | Production | 5 | $^{109}Ag$ | 48 | 1.11 × $10^5$ | 1.00 × $10^7$ | Enabled |
| 14 | Production | 5 | $^{109}Ag$ | 48 | 9.96 × $10^4$ | 1.00 × $10^7$ | Disabled |
| 15 | Production | 6 | $^{109}Ag$ | 48 | 1.00 × $10^5$ | 9.96 × $10^6$ | Enabled |
| 16 | Production | 6 | $^{109}Ag$ | 48 | 1.00 × $10^5$ | 1.00 × $10^7$ | Disabled |
| 17 | Production | 7 | $^{109}Ag$ | 48 | 1.00 × $10^5$ | 1.00 × $10^7$ | Enabled |
| 18 | Production | 7 | $^{109}Ag$ | 48 | 1.00 × $10^5$ | 1.00 × $10^7$ | Disabled |

Using the MFTF method shown in *Single-Event Effects (SEE) Confidence Interval Calculations* and combining (or summing) the fluences of the twelve runs at 25°C (11.93 × $10^7$), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{SEB} \leq 3.09 \times 10^{-8}\ \mathrm{cm}^2\ /\ \text{device for } \mathrm{LET_{EFF}} = 48\ \mathrm{MeV} \times \mathrm{cm}^2/\mathrm{mg} \text{ and } T_J = 25°\mathrm{C}$$

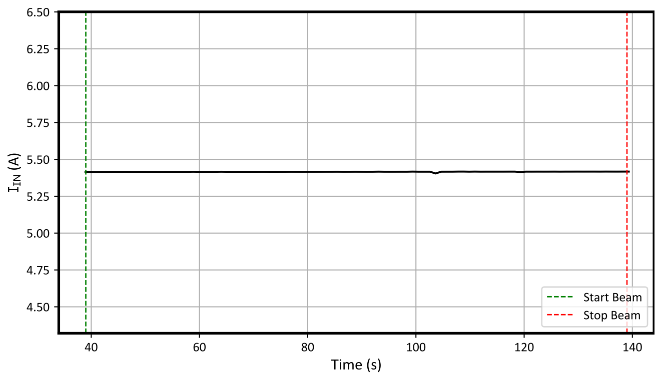



**Figure 7-2. $I_{IN}$ versus Time for Run 7 (Enabled) for the TPS7H2140-SEP**

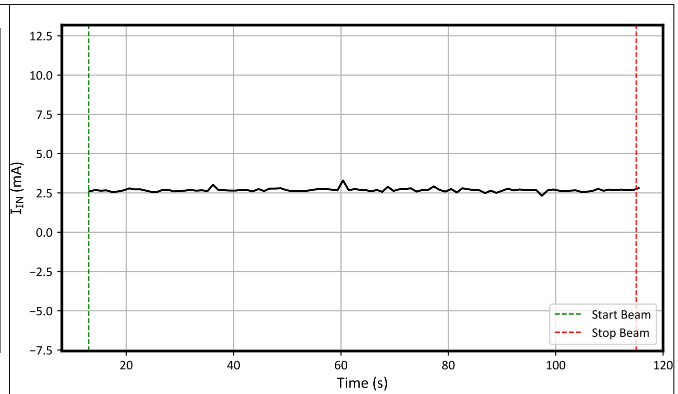



**Figure 7-3. $I_{IN}$ versus Time for Run 8 (Disabled) for the TPS7H2140-SEP**

# 8 Single-Event Transients (SET)

SETs are defined as heavy-ion-induced transients upsets on the $OUT_X$, the CS pin, and the $\overline{FAULT}$ pin of the TPS7H2140-SEP. SET testing was performed at room temperature (no external temperature control applied). The species used for the SET testing was $^{109}Ag$ for a $LET_{EFF}$ = 48 MeV × $cm^2$ / mg. For more details, see Section 5. 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.

One unit was tested across multiple input and output conditions to determine the worst case setup for SETs. This unit was tested with a $V_{IN}$ of 4.5, 12, and 28 V with loads of 2 A (0.5 A per channel) and 5.4 A (1.35 A per channel.) The worst case condition was found to be minimum $V_{IN}$ (4.5 V) and a low load, 2 A (0.5 A per channel), was shown to be the worst case in transients for $OUT_X$, which is considered to be the most important signal. All five other units were only characterized at the worst case SET scenario.

$OUT_X$ SETs were characterized using a window trigger of ±3% around the nominal output voltage. To capture the SETs, a MSO58B, two NI PXI-5172 scope cards, and one NI PXI-5160 scope card was used to continuously monitor $OUT_X$, CS, and $\overline{FAULT}$. Each scope was operated independently from each other. The output voltage was monitored by using the TP12 and the TP14 test points on the board, while the CS was monitored using the TP10 test point, and $\overline{FAULT}$ from the TP9 test point.

The NI scopes were programmed to a sample rate of 10 M samples per second (S / s) and recorded 50 k samples, with a 20% pretrigger reference, in case of an event (trigger).

Under heavy-ions, the TPS7H2140-SEP exhibits three transient upsets that were fully recoverable without requiring external intervention.

1. A brief transient of the output voltage (referred here as $V_{OUT,SET}$). For the purpose of this report the transients were characterized for deviations –3% ≤ $V_{OUT}$ ≤ 3% from the nominal output voltage.
2. A brief transient on the Current Sense (CS) pin. For the purpose of this report, the transients were characterized for deviations –4% ≤ $V_{CS}$ ≤ 4% from the nominal output voltage. This type of SET is referred to here as $V_{CS,SET}$.
3. A $V_{\overline{FAULT}}$ upset ≤ nominal - 1 V on a negative-edge trigger.

Test conditions and results are listed in Table 8-1. Figure 8-2 shows typical time domain plots for all the different types of the observed SETs. Note that $V_{OUT}$ was not monitored on the scope that $V_{CS}$ was triggered from, and as a result, any $V_{CS}$ drops due to a $V_{OUT,SET}$ occurring cannot be classified.

**Table 8-1. Summary of TPS7H2140-SEP SET Test Condition and Results**

Preproduction units refer to P-type symbolized units. Production units refers to units that completed the entire -SEP flow.

| Run Number | Unit Type | Unit Number | Ion | $LET_{EFF}$ (MeV × $cm^2$/mg) | FLUX (ions × $cm^2$/ mg) | Fluence (Number ions) | $OUT_{1,SET}$ (Number) ≥ \|3%\| | $OUT_{2,SET}$ (Number) ≥ \|3%\| | $CS_{SET}$ ≥ \|4%\| | $FAULT_{SET}$ ≥ 1-V |
|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Preproduction | 1 | $^{109}Ag$ | 48 | $9.98 \times 10^4$ | $1.00 \times 10^7$ | 849 | 849 | 1673 | 25 |
| 20 | Preproduction | 1 | $^{109}Ag$ | 48 | $9.80 \times 10^4$ | $9.99 \times 10^6$ | 314 | 353 | 1351 | 34 |
| 21 | Preproduction | 1 | $^{109}Ag$ | 48 | $9.96 \times 10^4$ | $1.00 \times 10^7$ | 702 | 688 | 1773 | 17 |
| 22 | Preproduction | 1 | $^{109}Ag$ | 48 | $9.55 \times 10^4$ | $9.98\times 10^6$ | 208 | 204 | 2226 | 15 |
| 23 | Preproduction | 1 | $^{109}Ag$ | 48 | $9.02 \times 10^4$ | $9.96 \times 10^6$ | 208 | 204 | 1519 | 22 |
| 24 | Preproduction | 1 | $^{109}Ag$ | 48 | $1.10 \times 10^5$ | $9.97 \times 10^6$ | 175 | 175 | 2341 | 25 |
| 25 | Preproduction | 2 | $^{109}Ag$ | 48 | $1.16 \times 10^5$ | $9.96 \times 10^6$ | 751 | 759 | 1381 | 21 |
| 26 | Preproduction | 3 | $^{109}Ag$ | 48 | $1.07 \times 10^5$ | $1.00 \times 10^7$ | 548 | 849 | 1417 | 13 |
| 27 | Preproduction | 4 | $^{109}Ag$ | 48 | $1.09 \times 10^5$ | $1.00 \times 10^7$ | 788 | 775 | 1530 | 20 |
| 28 | Production | 5 | $^{109}Ag$ | 48 | $1.19 \times 10^5$ | $1.00 \times 10^7$ | 830 | 830 | 4879 | 25 |
| 29 | Production | 6 | $^{109}Ag$ | 48 | $9.48 \times 10^4$ | $9.97 \times 10^6$ | 852 | 852 | 4910 | 28 |

Using the MFTF method shown in *Single-Event Effects (SEE) Confidence Interval Calculations*, the upper-bound cross-section (using a 95% confidence level) is calculated for the different SETs as shown in Table 8-2.

**Table 8-2. Upper Bound Cross Section for SETs at 95% Confidence Interval and Room Temperature**

| SET Type | Total Fluence (Number of Ions) | Total Number of Upsets | Upper Bound Cross Section ($cm^2$ / device) |
|---|---|---|---|
| $OUT_{1,SET}$ ≥ \|3%\| | $10.83 \times 10^7$ | 6225 | $5.89 \times 10^{-5}$ |
| $OUT_{2,SET}$ ≥ \|3%\| | | 6538 | $6.19 \times 10^{-5}$ |
| $CS_{SET}$ ≥ \|4%\| | | 25000 | $2.34 \times 10^{-4}$ |
| $\overline{FAULT}_{SET}$ ≤ Nominal -1 V | | 245 | $2.56 \times 10^{-6}$ |

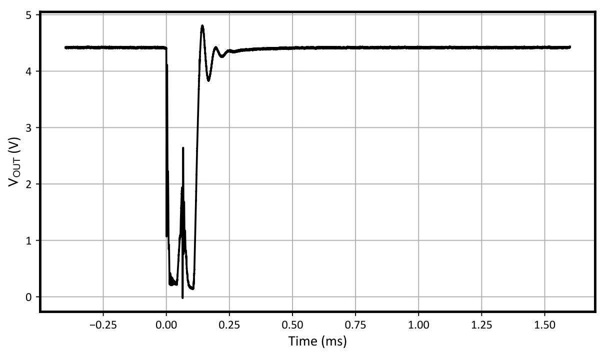



**Figure 8-1. Typical $V_{OUT,SET}$**

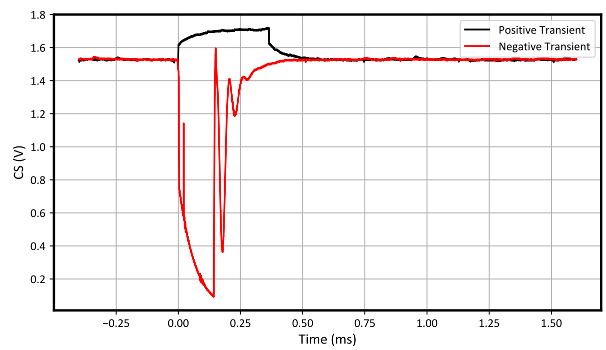



**Figure 8-2. Typical $CS_{SET}$**

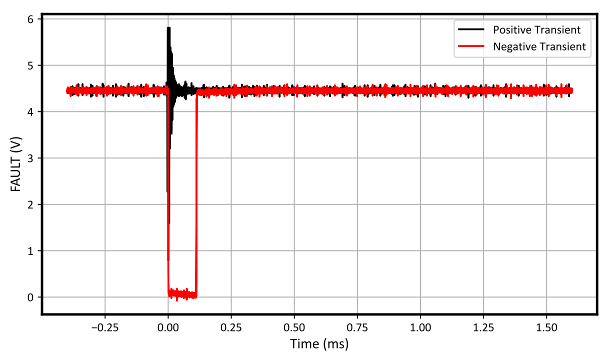



**Figure 8-3. Typical $\overline{FAULT}_{SET}$**

# 9 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 100 mils (2.54 mm) 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 SEB/SEGR, the event rate calculation for the SEL and the SEB/SEGR is listed in Table 9-1 and Table 9-2, respectively. Note that this number is for reference since no SEL or SEB/SEGR events were observed.

**Table 9-1. 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) | 48 | $4.50 \times 10^{-4}$ | $6.38 \times 10^{-8}$ | $2.87 \times 10^{-11}$ | $1.20 \times 10^{-3}$ | $9.54 \times 10^{7}$ |
| GEO | | $1.48 \times 10^{-3}$ | | $9.42 \times 10^{-11}$ | $3.93 \times 10^{-3}$ | $2.91 \times 10^{7}$ |

**Table 9-2. SEB/SEGR 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) | 48 | $4.50 \times 10^{-4}$ | $3.09 \times 10^{-8}$ | $1.39 \times 10^{-11}$ | $5.80 \times 10^{-4}$ | $1.97 \times 10^{8}$ |
| GEO | | $1.48 \times 10^{-3}$ | | $4.56 \times 10^{-11}$ | $1.90 \times 10^{-3}$ | $6.00 \times 10^{7}$ |

## 10 Summary

The purpose of this study was to characterize the effect of heavy-ion irradiation on the single-event effect (SEE) performance of the TPS7H2140-SEP quad-channel eFuse. Heavy-ions with $LET_{EFF}$ = 48 MeV × $cm^2$/mg were used for the SEE characterization campaign. Flux of $10^5$ ions / $cm^2$ × s and fluences to 1 × $10^7$ ions / $cm^2$ per run were used for the characterization. The SEE results demonstrated that the TPS7H2140-SEP eFuse is free of destructive SEB events and SEL-free up to $LET_{EFF}$ = 48 MeV × $cm^2$ / mg and across the full electrical specifications. Transients at $LET_{EFF}$ = 48 MeV × $cm^2$ / mg are discussed. CREME96-based worst-week event-rate calculations for LEO (ISS) and GEO orbits for the DSEE are shown for reference.

## 11 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.
2. G. Bruguier and J. M. Palau, "Single particle-induced latchup", *IEEE Trans. Nucl. Sci., Vol. 43(2)*, Mar. 1996, pp. 522-532.
3. G. H. Johnson, J. H. Hohl, R. D. Schrimpf and K. F. Galloway, "Simulating single-event burnout of n-channel power MOSFET's," in IEEE Transactions on Electron Devices, vol. 40, no. 5, pp. 1001-1008, May 1993.
4. J. R. Brews, M. Allenspach, R. D. Schrimpf, K. F. Galloway,J. L. Titus and C. F. Wheatley, "A conceptual model of a single-event gate-rupture in power MOSFETs," in IEEE Transactions on Nuclear Science, vol. 40, no. 6, pp. 1959-1966, Dec. 1993.
5. G. H. Johnson, R. D. Schrimpf, K. F. Galloway, and R. Koga,“Temperature dependence of single event burnout in n-channel power MOSFETs [for space application],” IEEE Trans. Nucl. Sci., 39(6), Dec. 1992, pp.1605-1612.
6. Cyclotron Institute, Texas A&M University, *Texas A&M University Cyclotron Institute Radiation Effects Facility*, webpage.
7. James F. Ziegler, *"The Stopping and Range of Ions in Matter"*, webpage.
8. D. Kececioglu, “Reliability and Life Testing Handbook”, Vol. 1, PTR Prentice Hall, New Jersey,1993, pp. 186-193.
9. Vanderbilt University, *CREME-MC*, webpage.
10. A. J. Tylka, J. H. Adams, P. R. Boberg, et al.,"CREME96: A Revision of the Cosmic Ray Effects on Micro-Electronics Code", *IEEE Trans. on Nucl. Sci., Vol. 44(6)*, Dec. 1997, pp. 2150-2160.
11. 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.