Radiation Report

Single-Event-Effects Test Report of the TPS7H2211-SP Load Switch

ABSTRACT

The purpose of this study is to characterize the Single-Event-Effects (SEE) performance due to heavy-ion irradiation of the TPS7H2211-SP. Heavy-ions with LET_{EFF} (Effective Linear Energy Transfer) of 75 MeV·cm^2/mg were used to irradiate 18 RHA devices. A flux of approximately 10^5 ions/(cm^2 × s) and fluence of approximately 10^7 ions / cm^2 per run were used for the characterization. The results demonstrated that the TPS7H2211-SP is Single Event Latch-Up, Single-Event-Burnout and Single-Event-Gate-Rupture (EN = High)-free at T = 125°C and 25°C, respectively, using ^{141}Pr and ^{165}Ho across the full electrical specifications. The device is Single-Event-Burnout/Single-Event-Gate-Rupture (EN = Low)-free up to V_{IN} = 12.8 V. Not a single transient was observed when V_{IN} > 8 V or $LEF_{EFF} \leq 65$ MeV × cm^2 / mg. See the Single Event Transients section for more details. This report uses the QMLV TPS7H2211-SP device in a ceramic package. This report is also applicable for the QMLP TPS7H2211-SP device in a plastic package which uses the same die as the QMLV device.

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1 Introduction

The TPS7H2211-SP is a space-grade, 4.5-V to 14-V input, 3.5-A, load switch. The device provides reverse current protection, overvoltage protection, and a configurable rise time. The device contains a P-channel MOSFET which operates over the full input range and supports the maximum 3.5 A of continuous current. The switch is controlled through the active-high Enable (EN) input pin, which is capable of interfacing directly with low-voltage control signals.

Other protection features include thermal shutdown, internal current limiting (fast trip), and an overvoltage detection pin.

The device is offered in a 16-pin ceramic package (CFP). Table 1-1 lists general device information and test conditions. For more detailed technical specifications, user guides, and application notes, see the TPS7H2211-SP product page.

Table 1-1. Overview Information

Description(1)	Device Information
TI part number	TPS7H2211-SP
Orderable number	5962R1822001VXC
Device function	Integrated single channel load switch
Technology	250-nm linear BiCMOS 7
Exposure facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV / nucleon)
Heavy ion fluence per run	$\geq 1 \times 10^7$ ions/cm^2
Irradiation temperature	25°C (for SEB testing), 25°C (for SET testing), and 125°C (for SEL testing)

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2 Single-Event Effects

The primary concern of interest for the TPS7H2211-SP is the robustness against the Destructive Single-Event Effects (DSEE) named as:

- Single-Event Latch-up (SEL)
- Single-Event Burn-out (SEB)
- Single-Event Gate Rupture (SEGR)

In mixed technologies, such as the Linear BiCMOS 7 process used on the TPS7H2211-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) [1, 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). 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 TPS7H2211-SP was tested for SEL at the maximum recommended voltage of 14 V and maximum load current of 3.5 A. The device exhibits no-SEL with heavy-ions of LET_{EFF} = 75 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, using ^{141}Pr and ^{165}Ho.

DMOS are susceptible to SEB/SEGR while in the off state. However, the device was also evaluated on all possible cases (enable and disable). SEB is similar to the SEL and occurs when the parasitic BJT of the DMOSFET is turned on by the heavy ion strike. When a heavy ion with sufficient energy hits the p body, an excess charge is created, which induces a voltage drop. This voltage drop forward biases the emitter-base junction of the parasitic NPN (formed by the N+ source, the P base region, and the N-drift region). If this happens when the DMOSFET is under a high drain bias, a secondary breakdown of the parasitic npn BJT can occur, creating permanent damage of the DMOS.

When the heavy-ion hits the neck region of the DMOS (under the gate), electron hole-pairs are created on the oxide and silicon. Drift separates the excess electrons and holes due to the positive bias field on the drain to source of the DMOS. Holes are driven upward to the dioxide while the electrons are transported toward the drain. The collected holes on the dioxide create an equal image of electrons on the opposite side of the gate dioxide. Since the charge injection and collection after an event is faster than the transport and recombination of the e-h pairs, a voltage transient can be developed across the gate oxide. If this build-up voltage is higher than the oxide breakdown, permanent damage can be induced on the oxide, creating a destructive gate rupture. The TPS7H2211-SP was evaluated for SEB/SEGR at full load conditions (3.5 A), enabled/disabled modes and LET_{EFF} of 75 MeV·cm^2 / mg using ^{141}Pr (at angle of incidence of 30°) and ^{165}Ho (at angle of incidence of 0°). A flux of approximately 10^5 ions / cm^2 × s, fluence of approximately 10^7 ions / cm^2, and a die temperature of approximately 25°C per run was used during the SEB/SEGR characterization. The device is SEB/SEGR-free up to 14 V when using ^{141} Pr (under enabled/disabled mode), and ^{165}Ho (under enabled mode). When using ^{165}Ho and disabled mode, the device is SEB/SEGR-free up to 12.8 V.

The TPS7H2211-SP was characterized for SET at flux of approximately 10^5 ions / cm^2 × s, fluences of approximately 10^{7}ions / cm^2, and room temperature. The device was characterized at input voltages ranging from 4.5 V (minimum recommended voltage) to 14 V (maximum recommended voltage), at I_{LOAD} of 3.5 A and under no-load conditions. The TPS7H2211-SP is SET-free at V_{IN} > 8 V. For more details, see Section 8.

3 Device and Test Board Information

The TPS7H2211-SP is packaged in a 16-pin (CFP) ceramic package as shown in Figure 3-1. A modified TPS7H2211EVM-CVAL evaluation board was used to evaluate the performance and characteristics of the TPS7H2211-SP under heavy-ions. The only difference between the board used for the heavy-ion test campaign and the official TPS7H2211EVM-CVAL board is the separation of the output voltage (V_{OUT}) plane.

This change was made to accelerate the testing by minimizing board change during the test campaign. Figure 3-2 shows the top view of the evaluation board used for the radiation testing. Figure 3-3 shows the EVM board schematics for dual site testing. For more information about the evaluation board, see the *TPS7H2211-SP Evaluation Module User's Guide*.

The package was de-lidded to reveal the die face for all heavy-ion testing

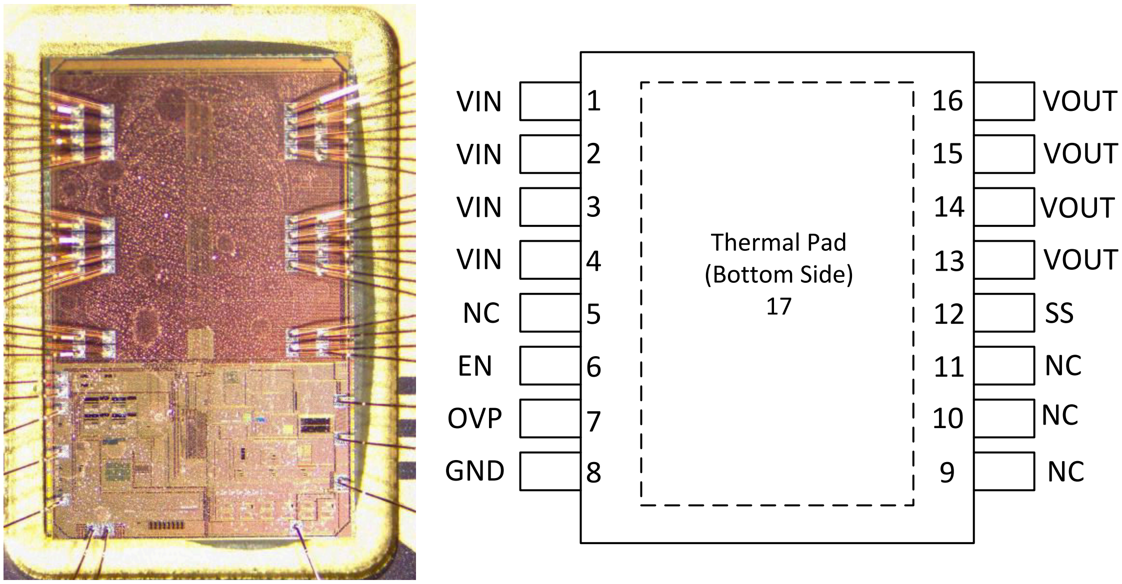


Figure 3-1. Photograph of Delidded TPS7H2211-SP (Left) and Pin Out Diagram (Right)

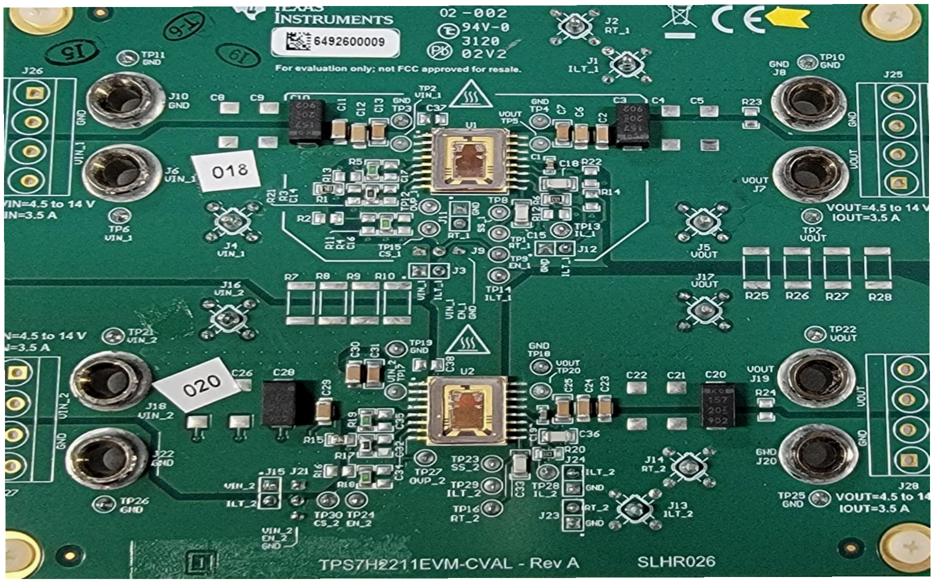


Figure 3-2. TPS7H2211-SP Board Top View

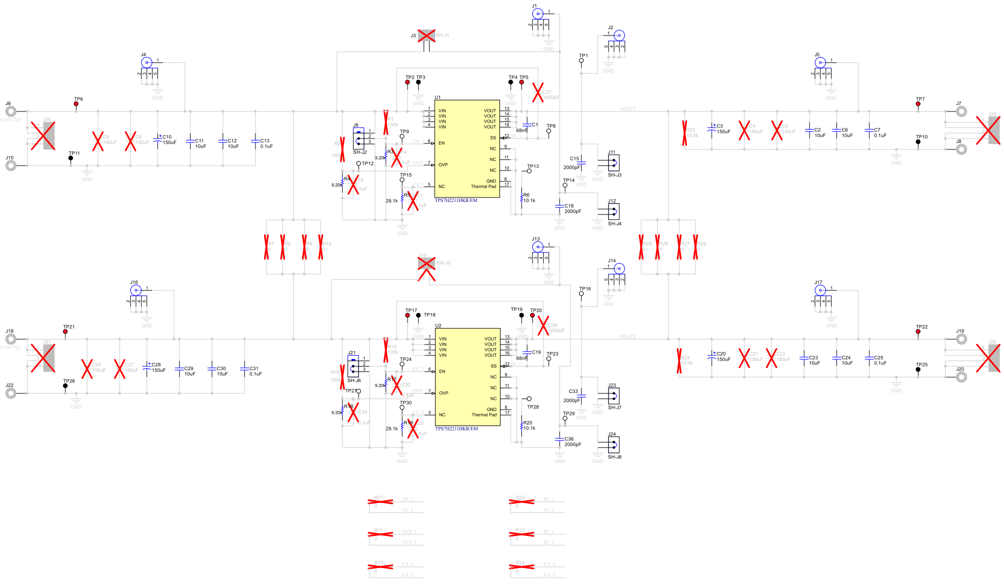


Figure 3-3. TPS7H2211-SP EVM Schematic for Dual Site EVM

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 1-in 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 the bulk of these studies, ion flux of approximately 10^5 ions / cm^2× s were used to provide heavy-ion fluences of approximately 10^7 ions / cm^2 per run.

For the experiments conducted on this report, Pr and Ho ions were used to achieve LET_{EFF} of 65 and 75 MeV·cm^2 / mg. The specific conditions for each ion were:

- Pr at an angle of incedence of 0° for 65 MeV × cm^2 / mg
- Pr at an angle of incedence of 30° for 75 MeV × cm^2 / mg
  - Total kinetic energy of ^{141}Pr 2.11 GeV (15-MeV / amu line)
- Ho at an angle of incedence of 0° for 75 MeV·cm^2 / mg
  - Total kinetic energy of ^{165}Ho 2.47 GeV (15-MeV / amu line)

Ion uniformity for these experiments was between 87 and 99%.

Figure 4-1 shows the TPS7H2211-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. All through-hole test points were soldered backwards for easy access of the signals while having enough room to change the angle of incidence and maintaining the 30-mm (^{165}Ho) or 40-mm (^{141}Pr) distance to the die. The in-air gap between the device and the ion beam port window was maintained at these distances for all runs respective to the ion we were testing with.

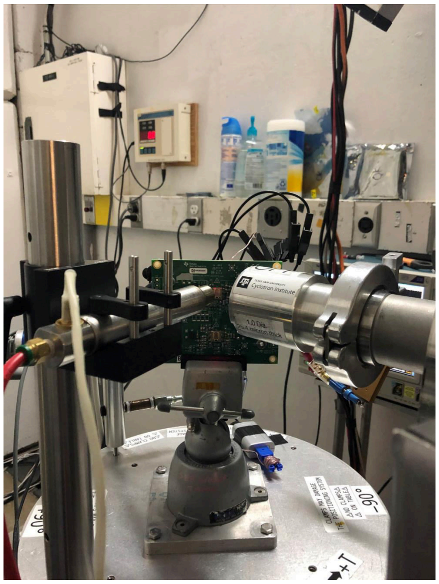
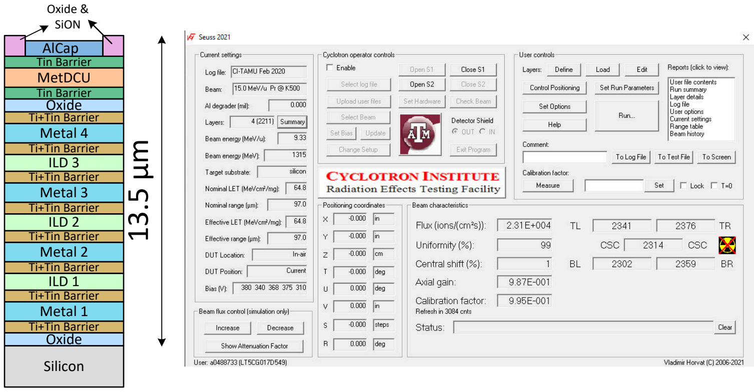


Figure 4-1. Photograph of the TPS7H2211-SP Evaluation Board Mounted in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 Depth, Range, and LET$_{EFF}$ Calculation



Current settings

Log file: CI-TAMU Feb 2020
Beam: 15.0 MeV/u Pr @ K500
Al degrader (mil): 0.000
Layers: 4 (2211) Summary
Beam energy (MeV/u): 9.33
Beam energy (MeV): 1315
Target substrate: silicon
Nominal LET (MeVcm²/mg): 64.8
Nominal range (µm): 97.0
Effective LET (MeVcm²/mg): 64.8
Effective range (µm): 97.0
DUT Location: In-air
DUT Position: Current
Bias (V): 380 340 368 375 310

Positioning coordinates

X	-0.000	in
Y	-0.000	in
Z	-0.000	cm
T	-0.000	deg
U	0.000	deg
V	0.000	in
S	-0.000	steps
R	0.000	deg

Beam characteristics

Flux (ions/(cm²s)): 2.31E+004
Uniformity (%): 99
Central shift (%): 1
Axial gain: 9.87E-001
Calibration factor: 9.95E-001
Refresh in 3084 cnts
Status:

TL	2341	2376	TR
CSC	2314		CSC
BL	2302	2359	BR

User: a0488733 (LT5CG017D549)

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Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H2211-SP (Left) and SEUSS 2020 Application Used to Determine Key Ion Parameters (Right)

The TPS7H2211-SP is fabricated in the TI Linear BiCMOS 7 (LBC7, 250-nm process with a Back-End-Of-Line (BEOL) stack consisting of four levels of standard thickness aluminum metal. The total stack height from the surface of the passivation to the silicon surface is 13.5 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 TPS7H2211-SP, 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. The LET$_{EFF}$ vs range for the ^{141}Pr and ^{165}Ho heavy-ion is shown on Figure 5-2. The stack was modeled as a homogeneous layer of silicon dioxide (valid since SiO_2 and aluminum density are similar).

Table 5-1. Praseodymium and Homium Ion LET$_{EFF}$ Depth and Range in Silicon

Ion Type	Angle of Incidence (°)	Range$_{EFF}$ in Silicon (µm)	LET$_{EFF}$ (MeV × cm^2 / mg)
^{141}Pr	0	97	65
^{141}Pr	30	84.1	75
^{165}Ho	0	93.6	75

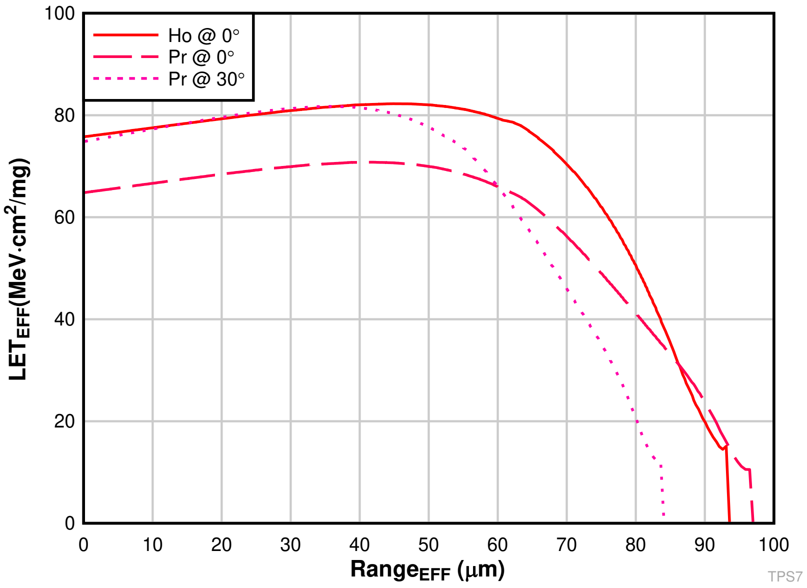


Figure 5-2. LET$_{EFF}$ vs Range for the Conditions Used for the SEE Test Campaign

6 Test Setup and Procedures

SEE testing was performed on a TPS7H2211-SP device mounted on a modified TPS7H2211EVM-CVAL. The device power was provided by using the J6 (VIN-1) and J10 (GND) inputs for the top and the J18 (VIN-2) and J22 (GND) inputs for the bottom with the N6765A precision power supply in a 4-wire configuration mounted on a N6705 rack. A Chroma E-Load (Electronic Load) on the Constant-Current (CC) and Constant-Resistance (CR) modes were used to load the device to 3.5 A for the SEE testing campaign.

For the SEL and SEB/SEGR, the device was powered up to the maximum recommended operating voltage of 14 V and loaded with the maximum load of 3.5 A. For the SEB/SEGR characterization, the device was tested under enabled and disabled modes. The device was disabled by using the TP 9 for the top and TP24 for the bottom, connecting EN to GND. The E-Load was connected even when the device was disabled to help differentiate if an SET momentarily activated the device under the heavy-ion irradiation. During the SEB/SEGR testing with the device enabled, not a single input current event was observed when testing with ^{141}Pr and ^{165}Ho up to V_{IN} = 14 V. Under the disabled mode, the device passed up to 14 V when using ^{141}Pr and up to 12.8 V when using ^{165}Ho.

For the SET characterization, the TPS7H2211-SP was evaluated at input voltages ranging from 4.5 V (minimum recommended voltage) to 14 V (maximum recommended voltage), at I_{LOAD} of 3.5 A and under no-load conditions. The SET events were monitored using one National Instruments™ (NI) PXIe-5162 scope card and oneNational Instruments™ (NI) PXIe-5172 scope card. The 5172 scope was used to monitored and trigger from V_{OUT} using a window trigger around ±3% from the nominal output voltage. The 5162 scope was used to monitor and trigger from the Soft-Start (SS) at VIN-0.3 V, using a edge/positive trigger. Both scopes were mounted on a NI PXIe-1095 chassis. During SET testing, no V_{OUT} or SS transients or SS SETs were observed at V_{IN} > 8 V.

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 via an MXI-Express cable and a NI PXIe-8381 remote control module. Figure 6-1 shows a block diagram of the setup used for SEE testing of the TPS7H2211-SP. Table 6-1 shows the connections, limits, and compliance values used during the testing. A die temperature of 125°C was used for SEL and was achieved with the use of a convection heat gun aimed at the die. For the SEB/SEGR testing, the device was tested at room temperature ≈ 25°C. For SET testing, the device was tested at room temperature (no cooling or heating was applied to the DUT). The die temperature was monitored during all the testing using a T-Type thermocouple attached to the thermal pad vias (on the bottom side of the EVM) with thermal paste. The thermocouple was held in place by using high temperature tape (kapton-tape). Die to thermocouple temperature was verified using a IR-camera prior to the SEE test campaign.

Table 6-1. Equipment Set and Parameters Used for SEE Testing the TPS7H2211-SP

Pin Name	Equipment Used	Capability	Compliance	Range of Values Used
VIN	Agilent N6766A PS (Channel 1)	15 A	10 A	4.5 and 14 V
Oscilloscope Card on SS	NI-PXIe 5162	5 GS/s	—	5 MS / s
Oscilloscope Card on V_{OUT}	NI-PXIe 5172	100 MS/s	—	5 MS / s

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 TPS7H2211-SP device and set the external sourcing and 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 NI scope cards continuously monitored the signals. When the output voltage exceeds the pre-defined ±3% window trigger, or when the PG signal changed from High to Low (using a negative edge trigger), a data capture was initiated. In addition to monitoring the voltage levels of the two scopes, VIN current and the 5-V (Beam On/Off) 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 no SEL events occurred during any of the tests.

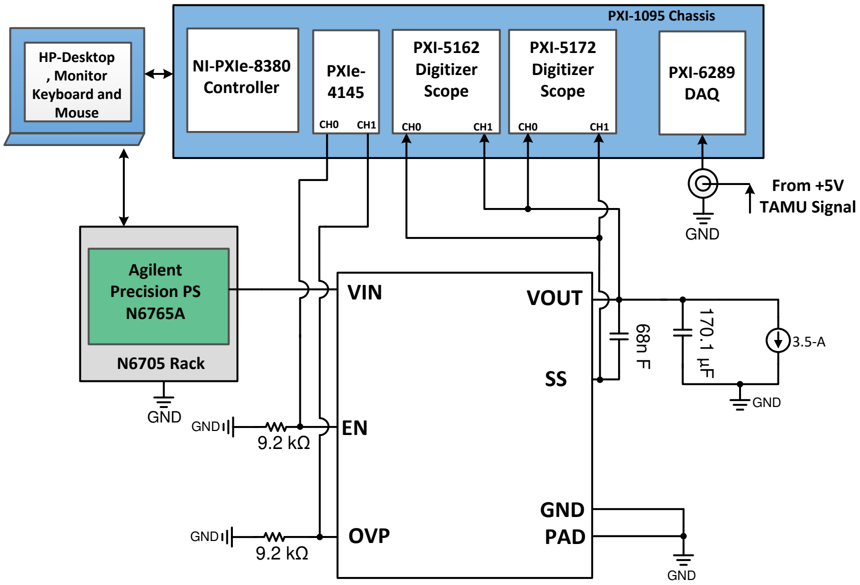


Figure 6-1. Block Diagram of SEE Test Setup With the TPS7H2211-SP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-Up (SEL) Results

During SEL characterization, the device was heated using forced hot air, maintaining the DUT temperature at 125°C. The die temperature was monitored during the testing using a T-Type thermocouple attached to the thermal pad vias (on the bottom side of the EVM) with thermal paste. The thermocouple was held in-place by using high temperature tape (kapton®-tape). Die to thermocouple temperature was verified using a IR-camera.

The species used for the SEL testing was a Praseodymium (^{141}Pr) ion with an angle-of-incidence of 30° for an LET_{EFF} = 75 MeV × cm^2/mg and a Homium (^{165}Ho) ion with an angle-of-incidence of 0° for an LET_{EFF} = 75 MeV × cm^2/mg (for more details, see *Depth, Range, and LET EFF Calculation*). The kinetic energy in the vacuum for this Pr is 2.11 GeV (15-MeV / amu line) and 2.47 GeV (15-MeV / amu line) for Ho. Flux of approximately 10^5 ions / cm^2× s and a fluence of approximately 10^7 ions / cm^2 were used for the eight runs. Run duration to achieve this fluence was approximately two minutes (per 1 × 10^7 ions × cm^2). The two devices were powered up and exposed to the heavy-ions using the maximum recommended voltage of 14 V and maximum load of 3.5 A. No SEL events were observed during all eight runs, indicating that the TPS7H2211-SP is SEL-free. Table 7-1 lists the SEL test conditions and results. Figure 7-1 shows a typical plot of current versus time for an SEL testing.

Table 7-1. Summary of TPS7H2211-SP SEL Test Condition and Results

For all runs, the device was loaded with a load of approximately 3.5 amps.

Run Number	Unit Number	ION	LET_{EFF} (MeV × cm^2 / mg)	Flux (ions × cm^2 / s)	Fluence (ions × cm^2)	V_{IN} (V)
1	1	^{165}Ho	75	4.67×10^4	9.98×10^6	14
2	1	^{165}Ho	75	4.63×10^4	9.99×10^6	14
3	2	^{141}Pr	75	1.25×10^5	1.00×10^7	14
4	3	^{141}Pr	75	1.00×10^5	9.98×10^6	14
5	3	^{141}Pr	75	9.58×10^4	9.96×10^6	14
6	4	^{141}Pr	75	1.54×10^5	9.95×10^6	14
7	5	^{141}Pr	75	1.31×10^5	9.99×10^6	14
8	6	^{141}Pr	75	1.33×10^5	1.00×10^7	14

Using the MFTF method described in SLVK047 and combining (or summing) the fluences of the eight runs at 125°C (7.99 × 10^7 ions × cm^2), the upper-bound cross-section (using a 95% confidence level) is calculated as:

$$\sigma_{\text{SEL}} \leq 4.62 \times 10^{-8} \text{cm}^2/\text{device for LET}_{\text{EFF}} = 75\text{MeV} \times \text{cm}^2/\text{mg and T}_{\text{J}} = 125°\text{C}. \tag{1}$$

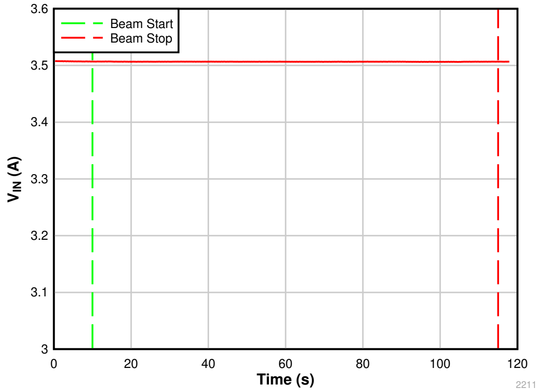


Figure 7-1. Current versus Time for Run 1 of the TPS7H2211-SP at T = 125°C

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

During the SEB/SEGR characterization, the device was tested at room temperature appromixately 25°C. The die temperature was monitored during the testing using a T-Type thermocouple attached to the thermal pad vias (on the bottom side of the EVM) with thermal paste. The thermocouple was held on place by using high temperature tape (kapton-tape). Die to thermocouple temperature was verified using an IR-camera.

The species used for the SEB testing was a Praseodymium (^{141}Pr) ion with an angle-of-incidence of 30° for an LET_{EFF} = 75 MeV × cm^2 / mg and a Homium (^{165}Ho) ion with an angle-of-incidence of 0° for an LET_{EFF} = 75 MeV × cm^2 / mg (for more details, see *Section 5*). The kinetic energy in the vacuum for these ions is 2.11 and 2.47 GeV (15-MeV / amu line) respectively. Flux of approximately 10^5 ions / cm^2× s and a fluence of approximately 10^7 ions / cm^2 were used for the 19 runs. Run duration to achieve this fluence was approximately two minutes (per 1 × 10^7 ions × cm^2). The TPS7H2211-SP was tested under enabled and disabled modes. The device was disabled by forcing 0 V on the EN pin with an SMU. The E-Load was connected, even when the device was disabled, to help differentiate if an SET momentarily activated the device under the heavy-ion irradiation. During SEB/SEGR testing using the ^{141}Pr ion with the device disabled or enabled and with ^{165}Ho under enabled mode no V_{OUT} transient or input current event was observed. During SEB/SEGR testing using the ^{165}Ho ion with the device disabled , operating the device with $V_{IN} \geq$ 13 V can result in permanent damage. This indicates that the TPS7H2211-SP is SEB/SEGR On-free, up to LET_{EFF} = 75 MeV × cm^2 / mg and V_{IN} up to 14 V with ^{141}Pr and ^{165}Ho. The TPS7H2211 is SEB/SEGR OFF-free up to LET_{EFF} = 75 MeV × cm^2/mg and V_{IN} up to 14 V when using ^{141}Pr, and up to VIN = 12.8 when using ^{165}Ho. Table 7-2 and Table 7-2 lists the SEB test conditions and results. Table 7-3 lists the upper-bound cross section at 95 % confidence interval for the SEB/SEGR On/Off with ^{141}Pr and ^{165}Ho. Figure 7-2 shows a plot of the current versus time for run nine (enabled) and Figure 7-3 for run 21 (disabled).

Table 7-2. Summary of TPS7H2211-SP SEB-On Test Condition and Results

For all runs the device was enabled and loaded with approximately 3.5 amps. *During all runs not a single device was damaged with EN = High.*

Run Number	Unit Number	Ion	LET_{EFF} (MeV × cm^2/ mg)	Flux (ions × cm^2/ s)	Fluence (ions × cm^2)	V_{IN} (V)	Number of SS Triggers	Number Of VOUT Triggers
9	1	^{165}Ho	75	4.78×10^4	1.00×10^7	14	0	0
10	7	^{165}Ho	75	3.75×10^4	1.00×10^7	14	0	0
11	8	^{165}Ho	75	1.20×10^5	1.00×10^7	14	0	0
12	9	^{165}Ho	75	1.20×10^5	1.00×10^7	14	0	0
13	10	^{165}Ho	75	1.20×10^5	1.00×10^7	14	0	0
14	11	^{141}Pr	75	1.20×10^5	9.96×10^6	14	0	0
15	12	^{141}Pr	75	1.20×10^5	9.97×10^6	14	0	0
16	13	^{141}Pr	75	1.20×10^5	1.00×10^7	14	0	0
17	14	^{141}Pr	75	1.20×10^5	9.95×10^6	14	0	0

Table 7-3. Summary of TPS7H2211-SP SEB-Off Test Condition and Results

For all runs, the device was disabled and loaded with a ≈ 3.5 amps using the CR mode on the E-Load.

Run Number	Unit Number	Ion	LET_{EFF} (MeV × cm^2 / mg)	FLUX (ions × cm^2 / s)	FLUENCE (ions × cm^2)	V_{IN} (V)	Pass
18	7	^{165}Ho	75	3.62×10^4	7.02×10^5	14	No
19	15	^{165}Ho	75	3.39×10^4	5.20×10^5	14	No
20	16	^{165}Ho	75	9.27×10^4	3.82×10^5	14	No
21	16	^{165}Ho	75	1.02×10^5	9.98×10^6	13.2	Yes
22	8	^{165}Ho	75	1.27×10^5	5.71×10^6	13.2	No
23	9	^{165}Ho	75	1.51×10^5	1.00×10^7	13	No
24	17	^{165}Ho	75	1.05×10^5	9.98×10^6	13	Yes
25	17	^{165}Ho	75	1.04×10^5	9.97×10^6	12.8	Yes
26	17	^{165}Ho	75	1.01×10^5	1.00×10^7	12.5	Yes
27	16	^{165}Ho	75	9.53×10^4	1.00×10^7	12	Yes
28	10	^{165}Ho	75	1.44×10^5	1.00×10^7	12	Yes
29	2	^{141}Pr	75	1.16×10^5	9.98×10^6	14	Yes
30	3	^{141}Pr	75	1.25×10^5	9.98×10^6	14	Yes
31	4	^{141}Pr	75	1.26×10^5	1.01×10^7	14	Yes
32	5	^{141}Pr	75	1.78×10^5	9.96×10^6	14	Yes

Using the MFTF method described in Single-Event Effects Confidence Interval Calculations and combining (or summing) the fluences of the runs with the same categories as described on the columns the SEB/SEGR upper-bound cross-section (using a 95% confidence level) is calculated as:

Table 7-4. SEB On/Off Upper-Bound-Cross-Sections

Ion	EN (Logic Value)	VIN (V)	LET_{EFF}	Total Fluence	Upper Bound X-Section (Cm^2 / device)
Ho	Low	14	75	1.60×10^6	5.47×10^{-6}
Ho	Low	13 ≤ VIN ≤ 13.2	75	3.57×10^7	2.87×10^{-7}
Ho	Low	VIN ≤ 12.8	75	4.00×10^7	9.22×10^{-8}
Pr	Low	14	75	4.00×10^7	9.22×10^{-8}
Ho	High	14	75	5.00×10^7	7.37×10^{-8}
Pr	High	14	75	3.99×10^7	9.25×10^{-8}

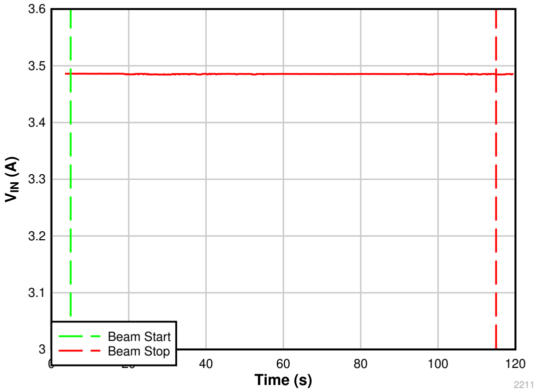


Figure 7-2. Current versus Time for Run 9 (Enabled) for the TPS7H2211-SP at T = 25°C

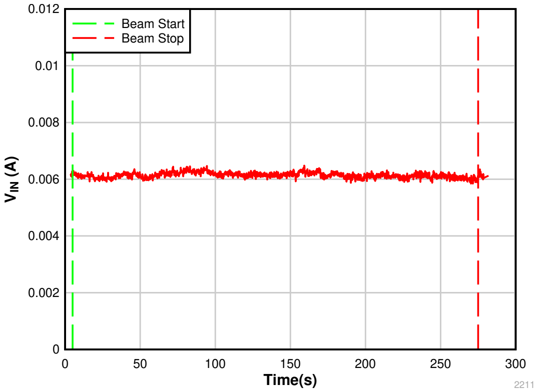


Figure 7-3. Current versus Time for Run 21 (Disabled) for the TPS7H2211-SP at T = 25°C

8 Single-Event Transients (SET) and Fast Trip Short Test

8.1 Single Event Transients

SETs are defined as heavy-ion-induced transients upsets on the V_{OUT} and the Soft-Start (SS) flag of the TPS7H2211-SP. SET testing was performed at room temperature (no external temperature control applied). The species used for the SET testing was a Praseodymium (^{141}Pr) ion with an angle-of-incidence of 0° and 30° for an LET_{EFF} = 65 and 75 MeV·cm^2/mg respectively, 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 19 SET runs.

V_{OUT} SETs were characterized using a window trigger of ±3% around the nominal output voltage (≈ 4.5 V and 14 V). The devices were characterized with input voltages ranging from V_{IN} = 4.5 V (minimum) to V_{IN} = 14 V (maximum). The output load was set to 3.5 amps for each run by using a Chroma Load on Constant-Resistance (CR) or Constant-Current (CC) mode. To capture the SETs one NI-PXI-5172 and one NI-PXI-5162 scope card, continuously monitoring the V_{OUT} and the SS were used, respectively. Each scope was operated independently. For the top units, the output voltage was monitored by using the TP5 and the TP7 test points on the EVM, while the SS was monitored using the TP8 test point. For the bottom units, the output voltage was monitored by using the TP20 and the TP22 test points on the EVM, while the SS was monitored using the TP23 test point. The scope triggering from SS was also monitoring the output voltage.

The scope triggering from V_{OUT} was programmed to record 20 k samples with a sample rate of 5-M samples per second (S/s) in case of a event (trigger). The scope triggering from SS was programmed with 30 ks and 5 MS/s. Both scopes were programmed to record 20% of the data before (pre) the trigger happen.

Not a single upset on V_{OUT} or SS was observed during the SET testing at room temperature with V_{IN} > 8 V for V_{OUT} SETs and 6 V for SS SETs. A window trigger with ±3% around the output nominal voltage (when the device was enabled) and a 500 mV edge/positive (when the device was disabled by using OVP) was used for the detection of upsets during the characterization. For the SS, an Edge/Postive at VIN-0.7 V when the device was enabled and Edge/Negative at VIN-0.3 V when the device was disabled, by using OVP, was used for the characterization. For upsets observed at V_{IN} ≤ 6 V, an SS SET occurred, in which the V_{OUT} drops to 0 V and recovers within the programmed soft start time. All upsets of this type self-recover and no external intervention was required Table 8-1 shows the SET test condition and results for all the data. Figure 8-1 shows the observed SETs for runs 42, 44, and 45. Figure 8-2 shows one of the observed SS SET for run 46 (because SS SETs look the same, only one upset is shown).

Table 8-1. Summary of TPS7H2211-SP SET Test Condition and Results

Run Number	Unit Number	Ion	LET_{EFF} (MeV.cm^2/mg)	Flux (ions·cm^2/s)	Fluence (ions·cm^2)	V_{IN} (V)	Enabled	$VOUT_{SET \geq \lvert 3\% \rvert}$ (Number) at 25 °C	SS_{SET} (Number) at 25 °C	Load Type (Chroma)	Load Value
33	2	^{141}Pr	75	1.09×10^5	9.97×10^6	14	Yes	0	0	CC	3.5
34	2	^{141}Pr	75	1.08×10^5	1.00×10^7	14	Yes	0	0	N/A	0
35	3	^{141}Pr	75	1.22×10^5	1.00×10^7	14	Yes	0	0	CR	3.5
36	3	^{141}Pr	75	1.20×10^5	1.00×10^7	14	Yes	0	0	N/A	0
37	4	^{141}Pr	75	9.92×10^4	1.00×10^7	14	Yes	0	0	CR	3.5
38	4	^{141}Pr	75	1.22×10^5	1.00×10^7	14	Yes	0	0	N/A	0
39	5	^{141}Pr	75	1.27×10^5	1.01×10^7	14	Yes	0	0	CR	3.5
40	5	^{141}Pr	75	1.32×10^5	9.99×10^6	14	Yes	0	0	N/A	0
41	2	^{141}Pr	75	1.24×10^5	9.95×10^6	10	Yes	0	0	CR	3.5
42	5	^{141}Pr	75	1.07×10^5	9.96×10^6	8	Yes	1	0	CR	3.5
43	5	^{141}Pr	75	1.34×10^5	1.00×10^7	7	Yes	0	0	CR	3.5
44	10	^{141}Pr	65	1.18×10^5	9.95×10^6	7	Yes	1	0	CR	3.5
45	5	^{141}Pr	75	1.20×10^5	9.97×10^6	6	Yes	3	16	CR	3.5
46	2	^{141}Pr	75	1.30×10^5	9.98×10^6	5	Yes	0	60	CR	3.5
47	10	^{141}Pr	75	1.30×10^5	1.99×10^7	4.5	Yes	0	0	CR	3.5
48	10	^{141}Pr	75	1.34×10^5	1.00×10^7	4.5	Yes	0	0	N/A	0
49	18	^{141}Pr	75	1.28×10^5	1.99×10^7	4.5	Yes	0	0	CR	3.5

Table 8-1. Summary of TPS7H2211-SP SET Test Condition and Results (continued)

Run Number	Unit Number	Ion	LET_{EFF} (MeV.cm^2/mg)	Flux (ions·cm^2/s)	Fluence (ions·cm^2)	V_{IN} (V)	Enabled	$VOUT_{SET\ \geq\ \|3\%\|}$ (Number) at 25 °C	SS_{SET} (Number) at 25 °C	Load Type (Chroma)	Load Value
50	18	^{141}Pr	75	1.32×10^5	9.97×10^6	4.5	Yes	0	0	N/A	0
51	16	^{141}Pr	65	1.32×10^5	9.94×10^6	4.5	Yes	0	0	CR	3.5

The upper-bound cross-section (using a 95% confidence level) is calculated by combining all runs above and below 8 V as:

$$\sigma_{SET} \leq 4.10 \times 10^{-8} cm^2/\text{device for } LET_{EFF} = 75 MeV \times cm^2/mg \text{ and } T_J = 25°C \text{ and } V_{IN} > 8V. \quad (2)$$

Since no VOUT or SS SETs were observed above 8 V, this cross section is valid for both cases.

$$\sigma_{SET-VOUT} \leq 8.99 \times 10^{-8} cm^2/\text{device for } LET_{EFF} = 75 MeV \times cm^2/mg \text{ and } T_J = 25°C \text{ and } V_{IN} \leq 8V. \quad (3)$$

$$\sigma_{SET-SS} \leq 7.33 \times 10^{-7} cm^2/\text{device for } LET_{EFF} = 75 MeV \times cm^2/mg \text{ and } T_J = 25°C \text{ and } V_{IN} \leq 8V. \quad (4)$$

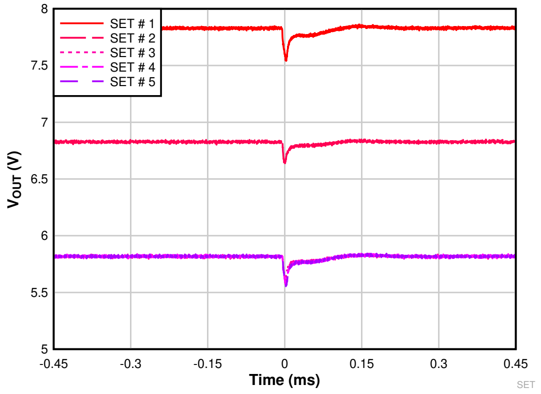
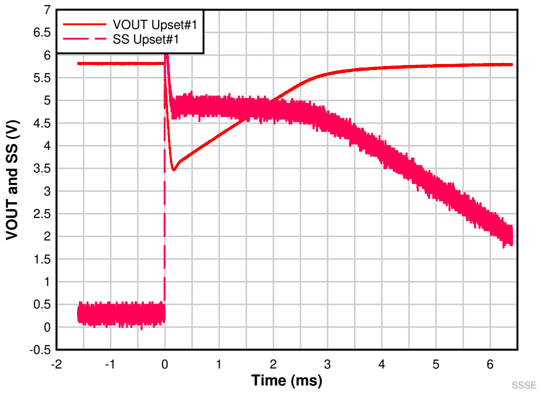


Figure 8-1. Runs 42 (SET 1), 44 (SET 2), 45 (SET 3–5) Typical V_{OUT} SET



All SS SETs recorded looked similar, so only one upset is shown.

Figure 8-2. Run 46 Typical SS SET

8.2 Fault Mode SET

The TPS7H2211-SP has an internal current-limiting mode, known as fast trip, in which the device limits the current in this state to protect the surrounding circuitry. To mimic this state during SEE testing, a short was applied to the output in the form of a 0.01- ohm power resistor. During the run, the input-current was monitored to make sure the device did not show a malfunction. During all runs, all units were tested up to 14 V, and all except for one did not show any failures. The one unit that showed a failure failed open, meaning the current monitored on the supply dropped to 0 amps.

Table 8-2. Summary of TPS7H2211-SP Fast Trip Short Test Condition and Results

Run Number	Unit Number	Ion	LET_{EFF} (MeV × cm^2/mg)	FLUX (ions × cm^2 / s)	FLUENCE (ions × cm^2)	V_{IN} (V)	Enabled	Load Type	Pass
52	2	^{141}Pr	75	1.32×10^5	Approximately 3 × 10^6	14	Yes	Discrete	No
53	4	^{141}Pr	75	1.67×10^5	9.93×10^6	14	Yes	Discrete	Yes
54	5	^{141}Pr	75	1.45×10^5	9.97×10^6	14	Yes	Discrete	Yes
55	18	^{141}Pr	75	1.22×10^5	1.00×10^7	14	Yes	CR	Yes
56	7	^{141}Pr	75	1.42×10^5	1.00×10^7	14	Yes	CR	Yes
57	6	^{141}Pr	75	1.35×10^5	1.01×10^7	14	Yes	CR	Yes
58	3	^{141}Pr	75	1.15×10^5	9.99×10^6	12	Yes	Discrete	Yes
59	10	^{141}Pr	65	1.29×10^5	9.99×10^6	12	Yes	CR	Yes

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 described in SLVK046. We assume a minimum shielding configuration of 100 mils (2.54 mm) of aluminum, and *worst-week* solar activity (this is similar to a 99% upper bound for the environment). Using the 95% upper-bounds for the SEL, SET and the SEB/SEGR, the event rate calculation for the SEL,SET and the SEB/SEGR is shown in Table 9-1 and Table 9-2, respectively.

Table 9-1. SEL Event Rate Calculations for Worst-Week LEO and GEO Orbits

The SEL Event Rate is for reference only as not a Single Unit during any Run shown a Latch-up event.

Orbit Type	Onset LET$_{EFF}$ (MeV-cm^2 / mg)	CREME96 Integral FLUX (/ day / cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	75	6.26×10^{-5}	4.62×10^{-8}	2.89×10^{-12}	1.20×10^{-4}	9.47×10^{8}
GEO		1.77×10^{-4}		8.17×10^{-12}	3.40×10^{-4}	3.35×10^{8}

Table 9-2. SEB/SEGR Event Rate Calculations for Worst-Week LEO and GEO Orbits

Because we saw damage with ^{165}Ho at 75 MeV·cm^2/mg and did not see any damage at 65 MeV·cm^2/mg with ^{141}Pr, the onset was determined by taking a middle point between the two LET values.

Orbit Type	Onset LET$_{EFF}$ (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	70	8.62×10^{-5}	5.47×10^{-6}	4.71×10^{-10}	1.97×10^{-2}	5.81×10^{6}
GEO		2.45×10^{-4}		1.34×10^{-9}	5.58×10^{-2}	2.04×10^{6}

Table 9-3. VOUT and SS SET Event Rate Calculations for Worst-Week LEO and GEO Orbits for VIN > 8-V

Orbit Type	Onset LET$_{EFF}$ (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/ day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	75	6.26×10^{-5}	4.1×10^{-8}	2.57×10^{-12}	1.07×10^{-4}	1.07×10^{9}
GEO		1.77×10^{-4}		7.24×10^{-12}	3.02×10^{-4}	3.78×10^{8}

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 TPS7H2211-SP Load Switch. Heavy-ions with LET_{EFF} = 75 MeV × cm^2 / mg were used for the SEE test campaign. Flux of 10^5ions / cm^2 × s and fluences ranging from 9.97 × 10^6 to 1 × 10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H2211-SP is SEL and SEB/SEGR (Enable)-free up to LET_{EFF} = 75 MeV × cm^2 / mg up to 14 V when using ^{141}Pr and ^{165}Ho heavy-ions. The device is SEB/SEGR (disable)-free up 12.8 V when using ^{165}Ho, and up to 14 V when using ^{141}Pr. The device is SET-free up to LET_{EFF} = 75 MeV × cm^2/mg with VIN > 8 V when using ^{141}Pr. For $V_{IN} \leq 8$ V, the device has a cross section on the 10^{-7} cm^2 / device order, showing robustness to SET over the whole electrical and radiation range. CREME96-based worst-week event-rate calculations for LEO (ISS) and GEO orbits are also shown for reference.

11 Total Ionizing Dose from SEE Experiments

The TPS7H2211-SP is rated for a total ionizing dose (TID) of 100 krad (Si). In the course of the SEE testing, the heavy-ion exposure delivered approximately 10 krad (Si) per 10^7 ions / cm^2 run. The cumulative TID exposure for all units was controlled to be below the 100 krad (Si) rating of the part.

12 References

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13 Revision History

Changes from Revision * (August 2021) to Revision A (December 2023) **Page**

- Updated to include QMLP device.. 1

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