# Test Report for Heavy Ion Testing of the TPS7A4901 Low Dropout Voltage Regulator

PI: Dakai Chen, Hak Kim TE: Anthony Phan
MEI Technologies, c/o NASA-GSFC, Greenbelt, MD

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## I. Introduction

This purpose of this test was to examine the heavy-ion induced single event effects (SEE) susceptibility of the TPS7A4901 low dropout voltage regulator from Texas Instruments. The test was conducted at the Lawrence Berkeley National Laboratory SEE Test Facility.

## II. Device Description

The TPS7A4901 is a low dropout regulator, capable of sourcing 150 mA with a dropout voltage of 400 mV. The device features extremely low output noise of 15 $\mu V_{RMS}$ with a bandwidth of 10 Hz to 100 kHz. Table 1 displays the part and test information. Figure 1 shows the pin configurations for the device.

Table I. Test and part information.

| | |
|---|---|
| **Generic Part Number** | TPS7A4901 |
| **Package Marking** | 9BTI<br>490 |
| **Manufacturer** | Texas Instruments |
| **Lot Date Code (LDC)** | To be determined |
| **Quantity tested** | 2 |
| **Part Function** | Low dropout regulator |
| **Part Technology** | BiCOM3 |
| **Package Style** | DGN MSOP-8 |
| **Test Equipment** | Power supply, digital oscilloscope, multimeter, and computer |

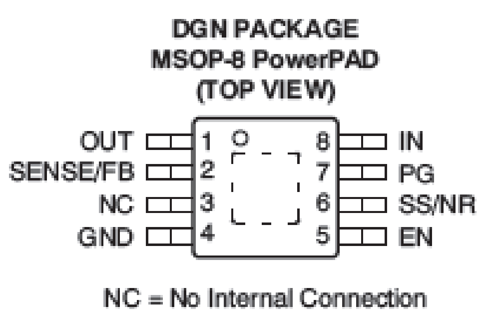


Figure 1. Pin configuration for the TPS7A4901.

## III. Test Facility

**Facility:** Lawrence Berkeley National Laboratory
**Beam Energy:** 10 MeV/amu
**Flux:** $1 \times 10^3$ to $1 \times 10^5$ particles/cm$^2$/s
**Fluence:** $\leq 2 \times 10^6$ ions/cm$^2$
**Ions:** Shown in Table II.

Table II. Heavy-ion information.

| Ion | Initial LET in air (MeV·cm$^2$/mg) | Range in Si (μm) |
|---|---|---|
| Ne | 3.49 | 174.6 |
| Ar | 9.74 | 130.1 |
| Xe | 58.78 | 90.0 |

## IV. Test Methods

Figure 2 shows the schematic diagram of the application circuit. The input supply voltage ($V_{in}$) can vary from 3 to 35 V, although we will only test for $V_{in}$ = 5 and 12 V. We can select the output voltage ($V_{out}$) from the resistor divider network: 1.8, 2.5, 3.0, 3.3, or 5.0 V. Only 3.3 V and 1.8 V outputs will be tested. An electronic load will supply the proper output load during irradiation. Figure 3 shows a schematic of the test setup. The oscilloscope is connected directly at the device output to monitor SETs. A current meter measures the temperature of the device through the thermistor. A LabVIEW program manages the temperature of the device to within 0.1$^o$C. Figure 4 shows a photograph of the test board mounted inside the irradiation chamber.

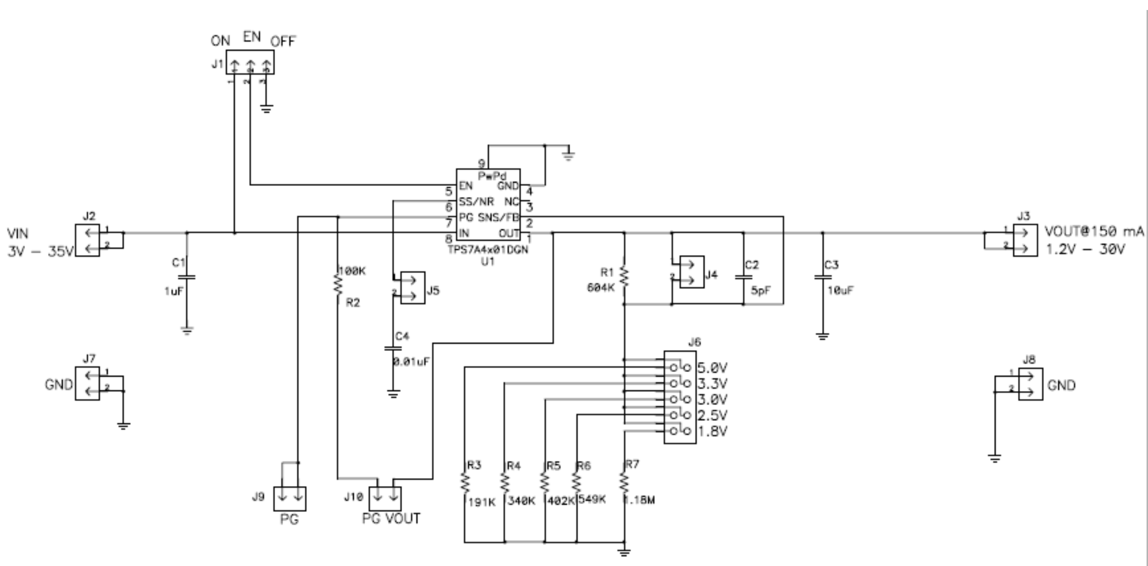


Figure 2. Application circuit schematic.

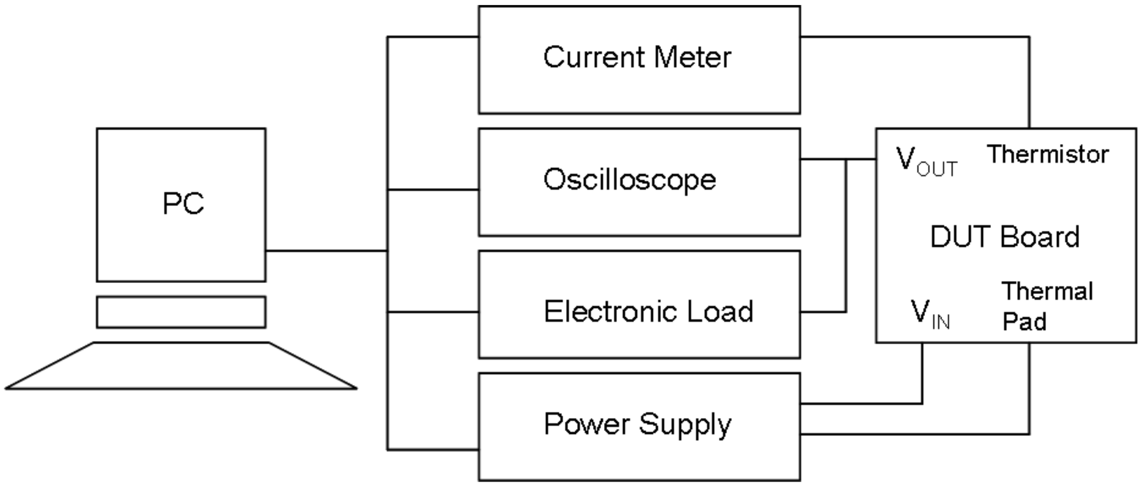


Figure 3. Block diagram of the testing setup.

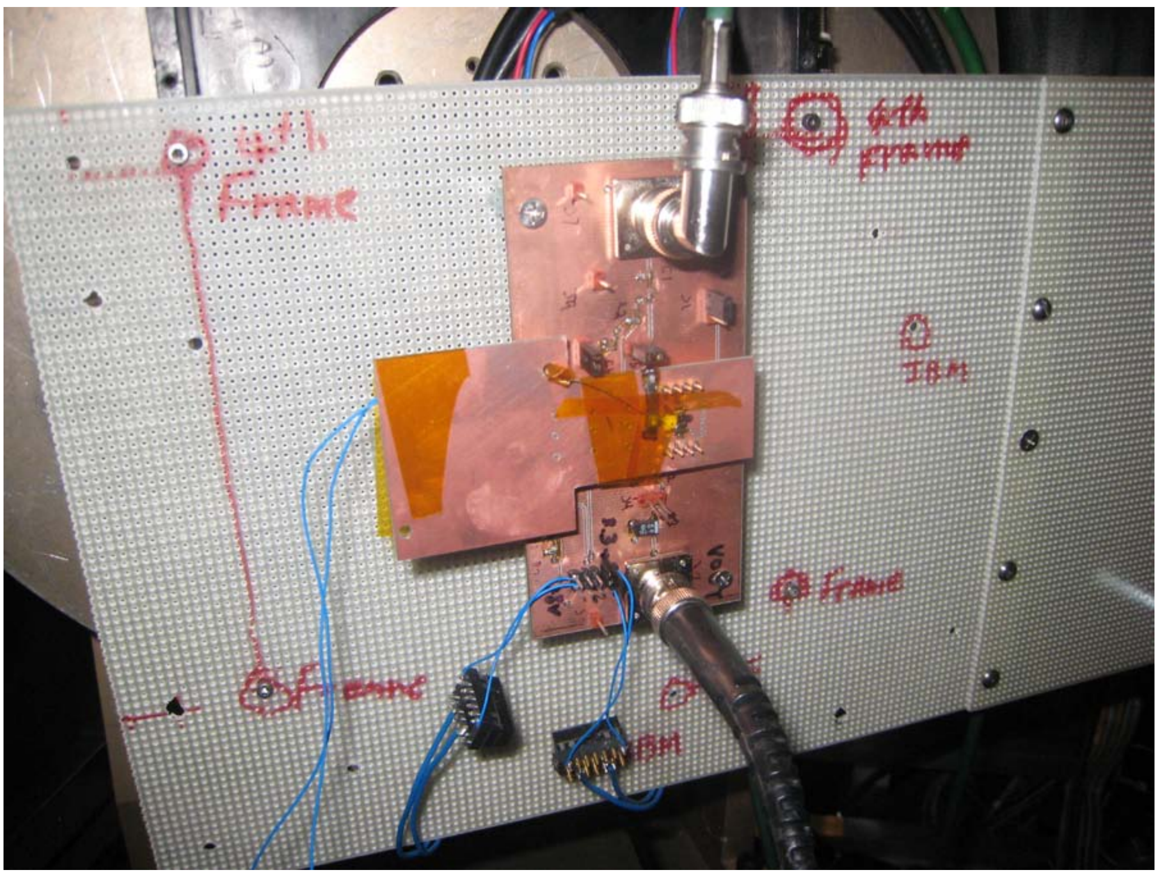

Figure 4. Photograph of the test board, with device mounted, inside the irradiation chamber.

## Test Conditions

**Test Temperature:** Room temperature
**Operating Frequency:** DC
**Power Supply:** $V_{in}$ = 5 V

| | |
|---|---|
| **Output Voltage:** | $V_{out}$ = 1.8 and 3.3 V |
| **Output Load:** | $I_{out}$ = 5 to 150 mA |
| **Angles of Incidence:** | $0^o$ (normal), $60^o$, and $80^o$ |
| **Parameters:** | 1) Output voltage |
| | 2) Output current |
| | 2) Input current |
| | 3) Device case temperature |
| **Beam Hours:** | **6.5** |

## V. Results

We irradiated two devices with heavy-ion beams in an enclosed vacuum environment. We found that the devices are susceptible to single event transients. We only observed SETs for the 150 mA output load. The 5 mA output load did not upset. The magnitude and duration of most of the SETs were significant. Figure 5 shows the distribution of the amplitude and width of the transients. Most events produced a full rail to rail drop in the output voltage, either from 3.3 V or 1.8 V to 0 V. The duration of these transients varied from approximately a few milliseconds to over a second. Figure 6 and 7 show worst case SETs with the device operating at 1.8 V and 3.3 V, respectively. There were also a few transients with much smaller amplitudes of approximately 0.3 – 0.5 V. These transients also had much shorter durations of approximately 10 – 40 µs. Figure 8 shows an example of such an SET.

We observed that the SET pulse width depended on the output voltage. Figure 9 shows the pulse width vs. the effective LET, for 1.8 V and 3.3 V output voltage. The majority of the transients for the 1.8 V output consist of pulse widths ranging from 100 ms to 1 s. On the other hand, the majority of the transients at 3.3 V output consist of pulse widths ranging from 10 ms to 100 ms. Even though the distribution of the pulse widths is relatively broad, we observed approximately one order of magnitude difference between the SET pulse widths at 1.8 V and 3.3 V output.

Furthermore, the 1.8 V output also produced a larger event cross section than at the 3.3 V output, as shown in Figure 10. We include Weibul fits for cross sections of each set of test conditions. We estimated the SET LET threshold ($LET_{th}$) and saturation cross section ($Sigma_{asm}$) values as follows. DUT1_1.8V: $LET_{th}$ = 14 MeV·cm$^2$/mg, $Sigma_{asm}$ = $5 \times 10^{-5}$ cm$^{-2}$; DUT2_1.8V: $LET_{th}$ = 16 MeV·cm$^2$/mg, $Sigma_{asm}$ = $4.5 \times 10^{-5}$ cm$^{-2}$; DUT1_3.3V: $LET_{th}$ = 18 MeV·cm$^2$/mg, $Sigma_{asm}$ = $2 \times 10^{-5}$ cm$^{-2}$.

We also found a considerable amount of variance between the two devices. Figure 11 shows the SET pulse width vs. effective LET for two devices. One device (DUT1) produced significantly longer transients than the other (DUT2). DUT1 also had a larger SET event cross section than DUT2.

Figure 12 shows the input current as a function of time during a run. The input current dropped at each transient event. Figure 13 shows the device case temperature during the same run. The temperature drops during each SET event. The temperature remained within the specification limits throughout the test.

A detailed summary of the irradiation runs is shown in Table III. in the Appendix.

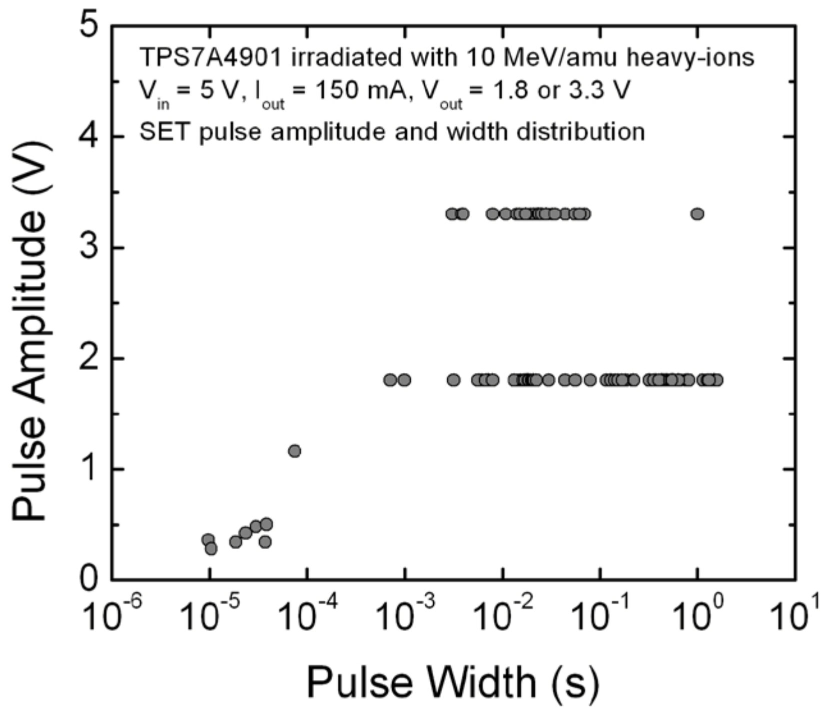


Figure 5. Single event transient pulse amplitude vs. pulse width for the TPS7A4901 irradiated with 10 MeV/amu heavy-ions, with $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 1.8 V or 3.3 V.

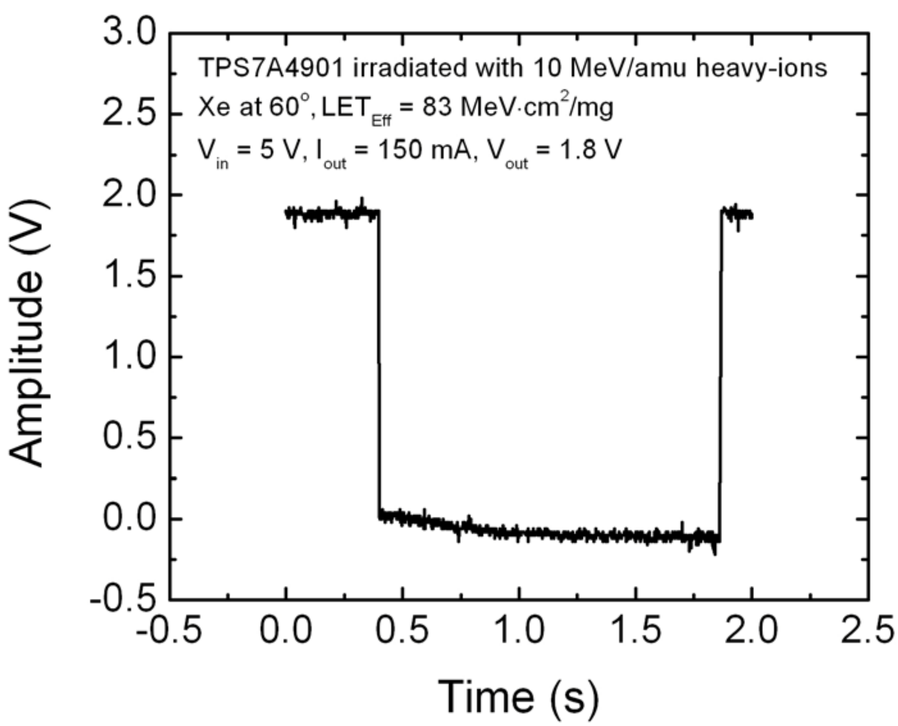


Figure 6. Single event transient pulse amplitude vs. time for the TPS7A4901 irradiated with 10 MeV/amu Xe at 60$^{o}$ with effective LET = 83 MeV·cm$^2$/mg, and $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 1.8 V.

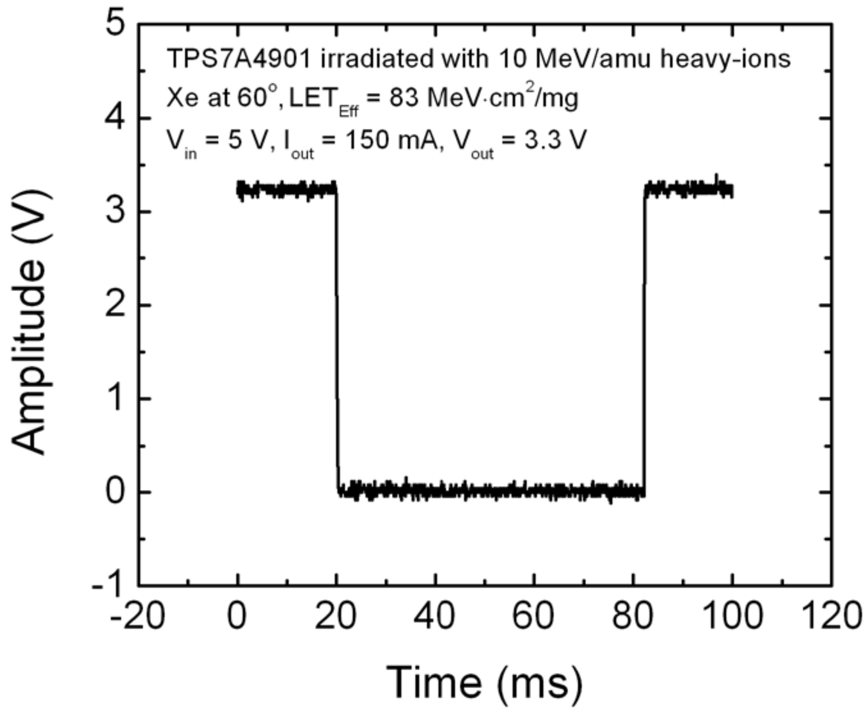


Figure 7. Single event transient pulse amplitude vs. time for the TPS7A4901 irradiated with 10 MeV/amu Xe at 60$^{o}$ with effective LET = 83 MeV·cm$^{2}$/mg, and $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 3.3 V.

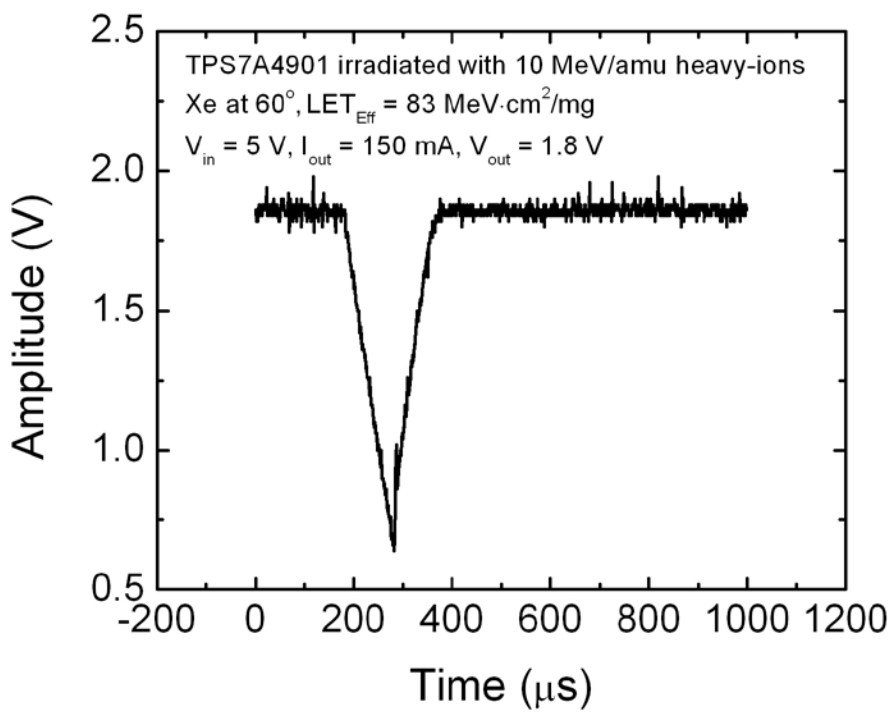


Figure 8. Single event transient pulse amplitude vs. time for the TPS7A4901 irradiated with 10 MeV/amu Xe at 60$^{o}$ with effective LET = 83 MeV·cm$^{2}$/mg, and $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 1.8 V.

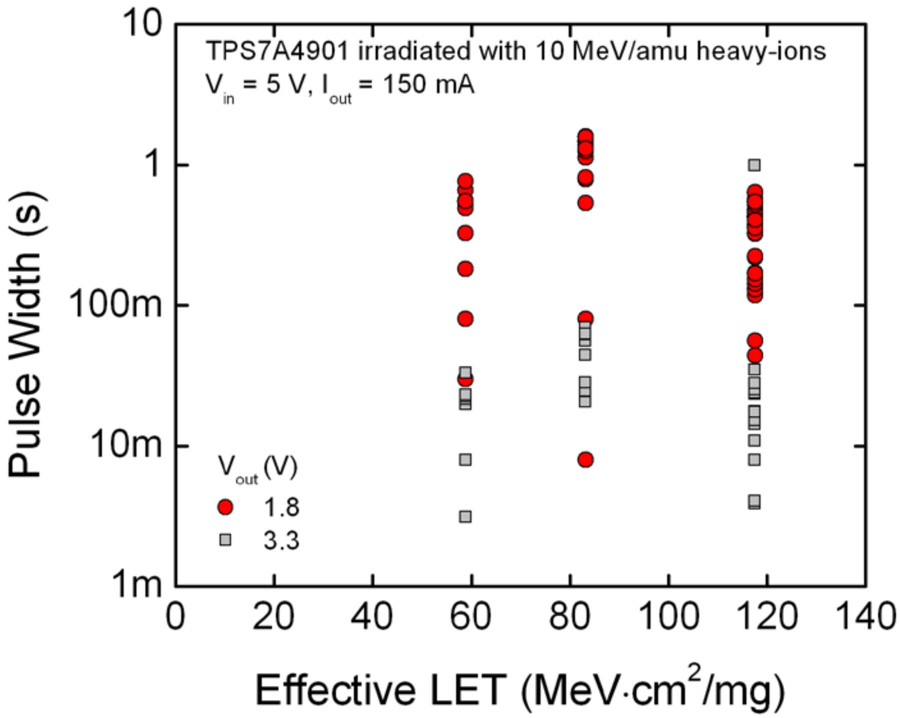


Figure 9. Single event transient pulse amplitude vs. effective LET for the TPS7A4901 irradiated with 10 MeV/amu heavy-ions, with $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 1.8 V or 3.3 V.

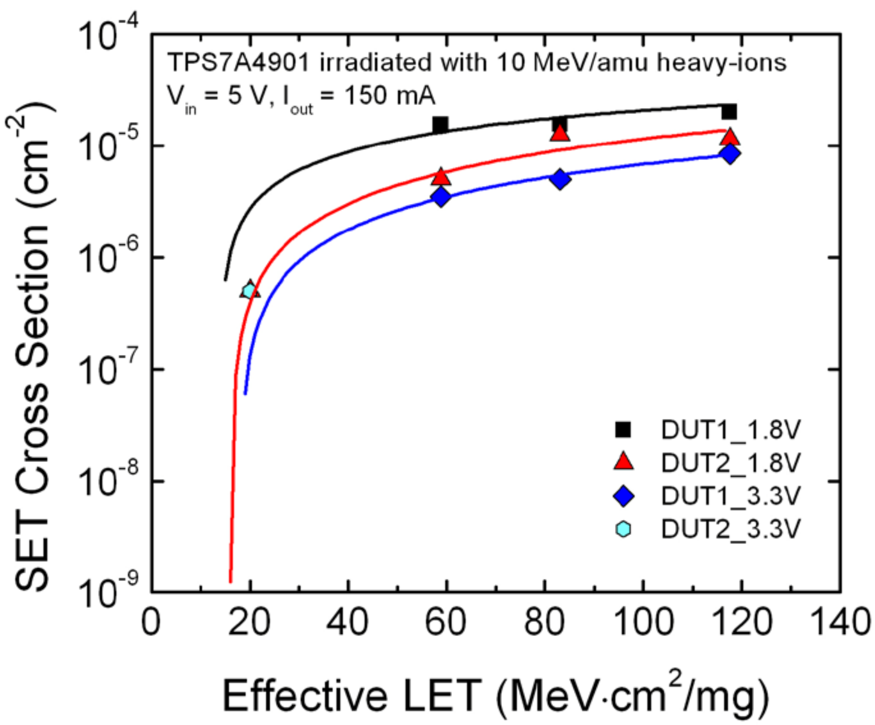


Figure 10. Single event transient cross section vs. effective LET for the TPS7A4901 irradiated with 10 MeV/amu heavy-ions, with $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 1.8 V or 3.3 V.

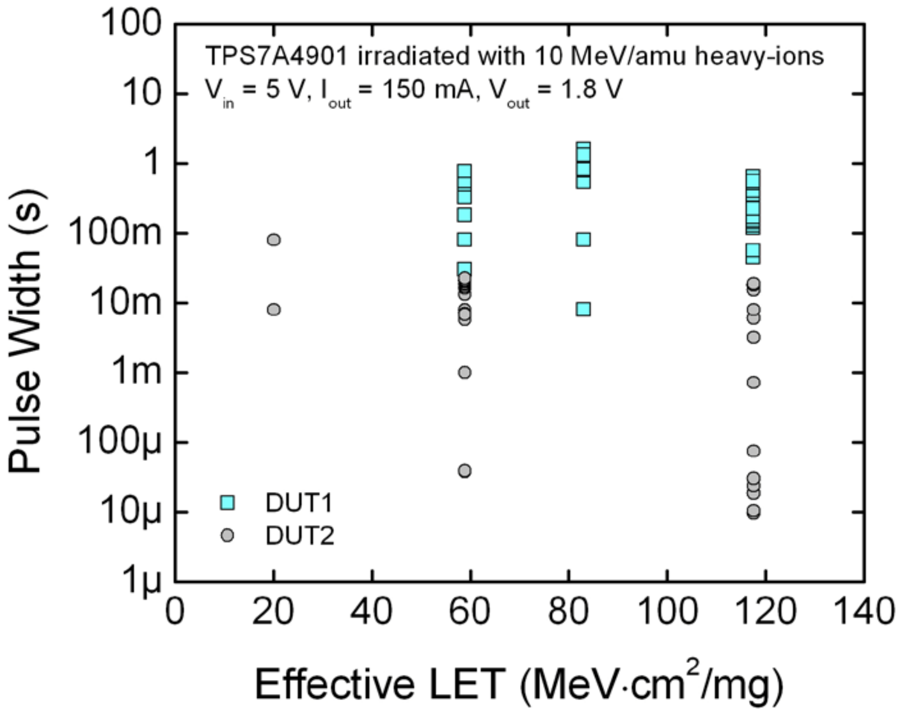


Figure 11. Single event transient pulse amplitude vs. pulse width for the TPS7A4901 irradiated with 10 MeV/amu heavy-ions, with $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 1.8 V, for two devices.

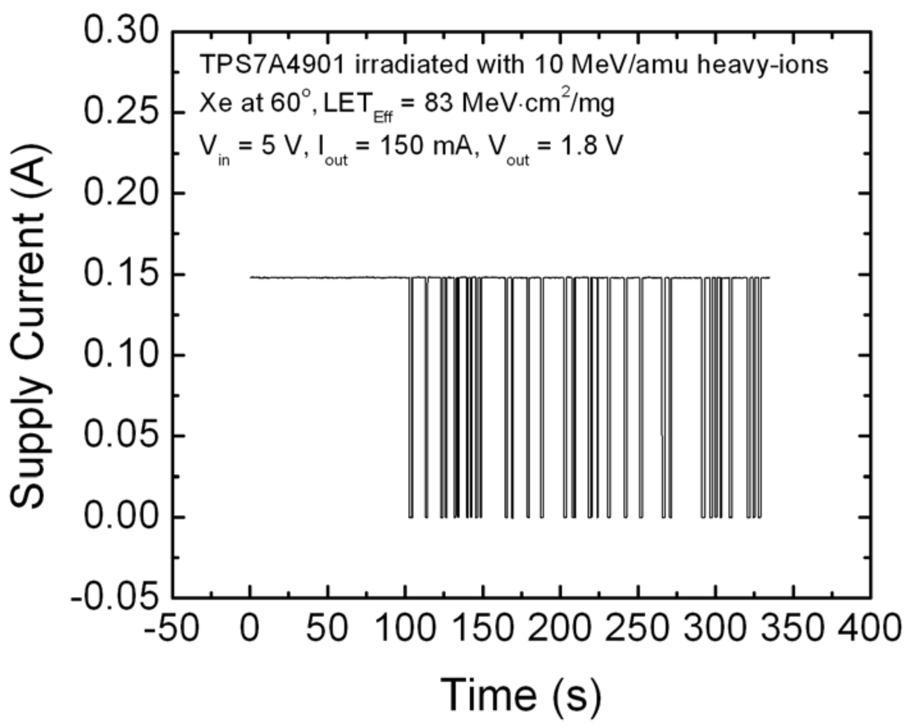


Figure 12. Input supply current vs. time for the TPS7A4901 during one irradiation run with 10 MeV/amu Xe at 60$^{o}$ with effective LET = 83 MeV·cm$^{2}$/mg, with $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 1.8 V.

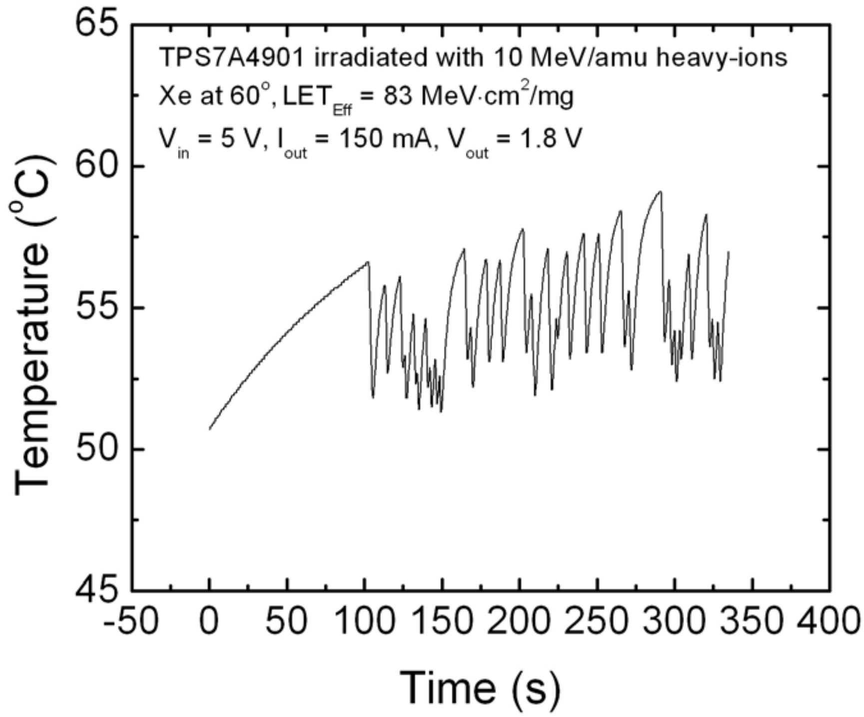


Figure 13. Device case temperature vs. time for the TPS7A4901 during one irradiation run with 10 MeV/amu Xe at 60° with effective LET = 83 MeV·cm$^2$/mg, with $V_{in}$ = 5 V, $I_{out}$ = 150 mA, and $V_{out}$ = 1.8 V.

## VI. Conclusions

We found that the TPS7A4901 low dropout voltage regulator is susceptible to heavy ions-induced single event transients, with the device operating at $V_{in}$ = 5 V and $I_{out}$ = 150 mA. The device did not upset for the 5 mA output load. Most of the transient events resulted in rail to rail drops from an output voltage of 3.3 V or 1.8 V to 0 V. These transients also had pulse widths which varied from 100 ms to 1 s for an output voltage of 1.8 V, and 10 ms to 100 ms for an output voltage of 3.3 V. The SET cross section showed an SET LET threshold of $\leq$ 20 MeV·cm$^2$/mg for both output levels. The cross section at an effective LET of 117.6 was approximately $2 \times 10^{-5}$ cm$^{-2}$.

Future studies may involve investigations into the locations of the vulnerable circuit elements. This can be performed with pulsed laser, provided with the schematic layout of the integrated circuit.

# VII. Appendix

Table III. Heavy-ion irradiation run summary for the TPS7A4901 operating with $V_{in}$ = 5 V. 10 MeV/amu beam cocktail.

| Run | Device S/N | Vout | Iout | Ion | Energy | LET | Angle | Effective LET | Acc Dose | Ave. Flux | Effective Fluence | SETs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | | *V* | *A* | | *MeV* | *MeV·cm2/mg* | *deg* | *MeV.cm2/mg* | rad(Si) | *#/cm2/sec* | *#/cm2* | |
| 1 | 1 | 1.8 | 150 | Xe | 10 | 58.78 | 0 | 58.8 | 1.88E+03 | 1.18E+04 | 2.00E+06 | 40 |
| 2 | 1 | 1.8 | 5 | Xe | 10 | 58.78 | 0 | 58.8 | 3.76E+03 | 1.21E+04 | 2.00E+06 | 0 |
| 3 | 1 | 1.8 | 150 | Xe | 10 | 58.78 | 0 | 58.8 | 5.64E+03 | 1.18E+04 | 2.00E+06 | 35 |
| 4 | 1 | 3.3 | 150 | Xe | 10 | 58.78 | 0 | 58.8 | 7.52E+03 | 1.10E+04 | 2.00E+06 | 9 |
| 5 | 1 | 3.3 | 5 | Xe | 10 | 58.78 | 0 | 58.8 | 9.40E+03 | 1.19E+04 | 2.00E+06 | 0 |
| 6 | 1 | 1.8 | 150 | Xe | 10 | 58.78 | 45 | 83.1 | 1.21E+04 | 1.07E+04 | 2.00E+06 | 0 |
| 7 | 1 | 1.8 | 150 | Xe | 10 | 58.78 | 45 | 83.1 | 1.47E+04 | 1.15E+04 | 2.00E+06 | 33 |
| 8 | 1 | 1.8 | 5 | Xe | 10 | 58.78 | 45 | 83.1 | 1.74E+04 | 1.13E+04 | 2.00E+06 | 0 |
| 9 | 1 | 3.3 | 150 | Xe | 10 | 58.78 | 45 | 83.1 | 2.00E+04 | 1.14E+04 | 2.00E+06 | 11 |
| 10 | 1 | 3.3 | 5 | Xe | 10 | 58.78 | 45 | 83.1 | 2.27E+04 | 1.09E+04 | 2.00E+06 | 0 |
| 11 | 1 | 1.8 | 150 | Xe | 10 | 58.78 | 60 | 117.6 | 2.65E+04 | 2.09E+04 | 2.00E+06 | 44 |
| 12 | 1 | 1.8 | 5 | Xe | 10 | 58.78 | 60 | 117.6 | 3.02E+04 | 2.26E+04 | 2.00E+06 | 0 |
| 13 | 1 | 3.3 | 150 | Xe | 10 | 58.78 | 60 | 117.6 | 3.40E+04 | 2.05E+04 | 2.00E+06 | 17 |
| 14 | 1 | 3.3 | 5 | Xe | 10 | 58.78 | 60 | 117.6 | 3.78E+04 | 2.07E+04 | 2.00E+06 | 0 |
| 15 | 2 | 1.8 | 150 | Xe | 10 | 58.78 | 0 | 58.8 | 1.88E+03 | 1.12E+04 | 2.00E+06 | 10 |
| 16 | 2 | 1.8 | 5 | Xe | 10 | 58.78 | 0 | 58.8 | 3.76E+03 | 1.11E+04 | 2.00E+06 | 0 |
| 17 | 2 | 3.3 | 150 | Xe | 10 | 58.78 | 0 | 58.8 | 5.64E+03 | 1.11E+04 | 2.00E+06 | 0 |
| 18 | 2 | 3.3 | 5 | Xe | 10 | 58.78 | 0 | 58.8 | 7.52E+03 | 1.14E+04 | 2.00E+06 | 0 |
| 19 | 2 | 1.8 | 150 | Xe | 10 | 58.78 | 45 | 83.1 | 1.02E+04 | 1.15E+04 | 2.00E+06 | 25 |
| 20 | 2 | 1.8 | 5 | Xe | 10 | 58.78 | 45 | 83.1 | 1.28E+04 | 1.16E+04 | 2.00E+06 | 0 |
| 21 | 2 | 3.3 | 150 | Xe | 10 | 58.78 | 45 | 83.1 | 1.55E+04 | 1.14E+04 | 2.00E+06 | 0 |
| 22 | 2 | 3.3 | 5 | Xe | 10 | 58.78 | 45 | 83.1 | 1.82E+04 | 1.10E+04 | 2.00E+06 | 0 |
| 23 | 2 | 1.8 | 150 | Xe | 10 | 58.78 | 60 | 117.6 | 2.19E+04 | 2.23E+04 | 2.00E+06 | 28 |
| 24 | 2 | 1.8 | 5 | Xe | 10 | 58.78 | 60 | 117.6 | 2.57E+04 | 2.22E+04 | 2.00E+06 | 0 |
| 25 | 2 | 3.3 | 150 | Xe | 10 | 58.78 | 60 | 117.6 | 2.94E+04 | 2.22E+04 | 2.00E+06 | 0 |
| 26 | 2 | 3.3 | 5 | Xe | 10 | 58.78 | 60 | 117.6 | 3.32E+04 | 2.24E+04 | 2.00E+06 | 0 |
| 27 | 2 | 1.8 | 150 | Ar | 10 | 10 | 0 | 10.0 | 3.35E+04 | 1.64E+04 | 2.00E+06 | 0 |
| 28 | 2 | 3.3 | 150 | Ar | 10 | 10 | 0 | 10.0 | 3.39E+04 | 1.55E+04 | 2.00E+06 | 0 |
| 29 | 2 | 3.3 | 150 | Ar | 10 | 10 | 0 | 10.0 | 3.42E+04 | 1.70E+04 | 2.00E+06 | 0 |
| 30 | 2 | 1.8 | 150 | Ar | 10 | 10 | 60 | 20.0 | 3.45E+04 | 1.53E+04 | 1.00E+06 | 0 |
| 31 | 2 | 3.3 | 150 | Ar | 10 | 10 | 60 | 20.0 | 3.48E+04 | 1.68E+04 | 1.00E+06 | 0 |
| 32 | 2 | 3.3 | 150 | Ar | 10 | 10 | 60 | 20.0 | 3.51E+04 | 2.37E+04 | 1.00E+06 | 0 |
| 33 | 2 | 1.8 | 150 | Ar | 10 | 10 | 60 | 20.0 | 3.55E+04 | 2.73E+04 | 1.00E+06 | 4 |
| 34 | 1 | 1.8 | 150 | Ar | 10 | 10 | 0 | 10.0 | 3.81E+04 | 1.29E+04 | 2.00E+06 | 0 |
| 35 | 1 | 3.3 | 150 | Ar | 10 | 10 | 0 | 10.0 | 2.20E+03 | 1.29E+04 | 2.00E+06 | 0 |
| 36 | 1 | 1.8 | 150 | Ar | 10 | 10 | 60 | 20.0 | 4.40E+03 | 2.90E+04 | 2.00E+06 | 3 |
| 37 | 1 | 1.8 | 150 | Ar | 10 | 10 | 60 | 20.0 | 6.28E+03 | 2.90E+04 | 2.00E+06 | 4 |
| 38 | 1 | 3.3 | 150 | Ar | 10 | 10 | 60 | 20.0 | 8.16E+03 | 2.82E+04 | 2.00E+06 | 1 |