SEE Test Report V1.0
Heavy ion SEE test of TPS75003 from Texas Instruments

Christian Poivey[1], Hak Kim[1]

[1] MEI Technologies

Test Date(s): May 7-8, 2007 Report Date: August 23, 2007

I. Introduction

This study was undertaken to determine the single event destructive and transient susceptibility of the TPS75003 triple supply power management IC for transient interruptions in the output signal and for destructive events induced by exposing it to a heavy ion beam at the TEXAS A&M Cyclotron Single Event Effects Test Facility. This test was performed in the frame of NEPP project.

II. Devices Tested

TPS75003 is multi-channel power integrated circuit (IC). The device has two 3A buck controllers and a 300mA low dropout linear regulator. Input voltage range is between 2.2V and 6.5V. Buck controllers can provide output voltages between 1.2V and 6.5V. LDO regulator can provide output voltages between 1V and 6.5V. Buck controllers require external circuitry (power MOSFET,…).

The sample size of the testing was three devices. Two devices were exposed and one served as a control sample. The device technology is 1 µm BiCMOS (LBC3S). The device is packaged in a 20-pin TSSOP Power-PAD (PWP) package. The test samples lot date code is unknown. Package marking on the test samples is as follows:

75003
TI 67W
MH 7L

For these tests we used TI TPS75003EVM evaluation module. TPS75003EVM is shown in Fig.1. The two buck regulators deliver output voltage levels of 1.2V (Vout1) and 3.3V (Vout2). Maximum output current is 2A. LDO regulator delivers a 2.5V output voltage and a maximum output current of 300 mA (Vout3). Devices under test (DUT) were prepped for test by delidding.

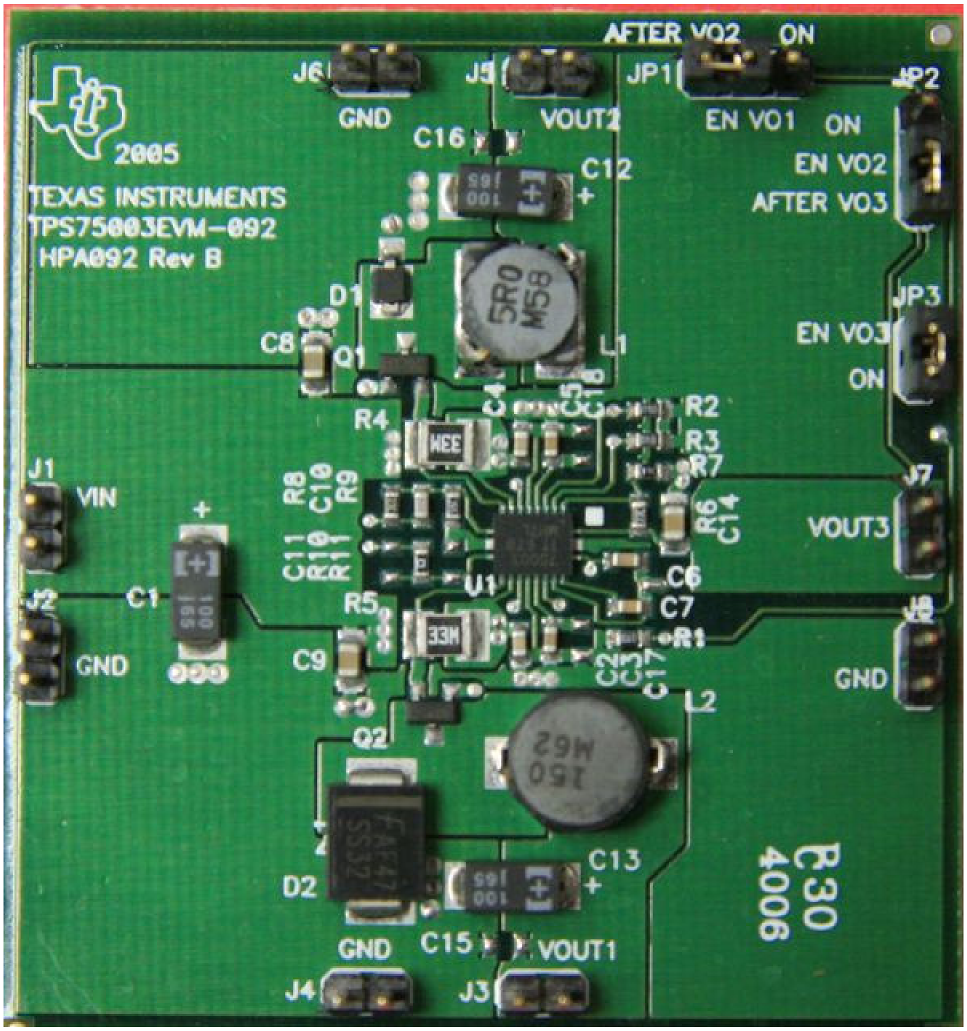

Fig. 1: TPS75003EVM

III. Test Facility

Facility: TEXAS A&M Cyclotron Single Event Effects Test Facility, 15 MeV/u beams

Flux: 5×10^3 to 5×10^4 particles/cm^2/s.

Fluence: For destructive events, all tests were run to 1×10^7 p/cm^2 or until destructive events occurred

For non destructive events, all tests were run to 1×10^6 p/cm^2 or until a sufficient (>100) number of transient events occurred.

The ions and LET used for these tests are shown in Table 1.

Table 1: Ions and LET values used for the tests

Ion	Energy (MeV)	LET on target ($MeVcm^2/mg$)	Range on target (μm)
Kr	850	30.1	106.9
Xe	1177	54.8	92.6

IV. Test Conditions and Error Modes

Test Temperature: Room Temperature

Bias conditions Vin = 5V

Devices were biased as shown in Figure 2. Different test conditions are presented in Table 2. Active loads were used to adjust the load output load currents.

Table 2: Test conditions

Vin1,2,3 (V)	Vout1 (V)	Iout1 (mA)	Vout2 (V)	Iout2 (mA)	Vout3 (V)	Iout3 (mA)
5	1.2	10	3.3	10	2.5	10
5	1.2	500	3.3	500	2.5	100
5	1.2	1000	3.3	1000	2.5	200
5	1.2	2000	3.3	2000	2.5	300

PARAMETERS OF INTEREST: Power supply currents, output voltage

SEE Conditions: SEL, SEGR, SET

V. Test Methods

Test circuit for the triple supply power management IC contains a power supply for the input voltage, a resistive load for drawing current, and a digital scope for capturing any output anomalies. Once one of the three device outputs is present and the load conditions are set, the digital scope is set to trigger on and voltages that are above or below a predetermined threshold. Each device output was tested one after each other. Trigger level threshold varied from +/-100 to 180mV for 1.2V output (Vout1). Trigger level was set at +/-100mV for 2.5V output (Vout2). Trigger level was set at +/- 400mV for 2.5V output (Vout3).

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Fig. 2: TPS75003EVM Schematic

VI. Test Results

Test log is shown in Appendix. No destructive failure was observed up to the last test run on 1.2V output with 2A load at an effective LET of 77.5 MeVcm^2/mg. At the end of the run 114, 1.2V output was oscillating as shown in Fig. 3. We have no explanation for this phenomenon. If these oscillations are heavy-ion induced , cross-section at LET of 77.5 MeVcm^2/mg is about $2x10^{-7}$ cm^2. This event was not observed at the LET of 54.8 MeVcm^2/mg up to a test fluence of $5x10^6$ #/cm^2. Therefore, in-flight error rate will be quasi-negligible.

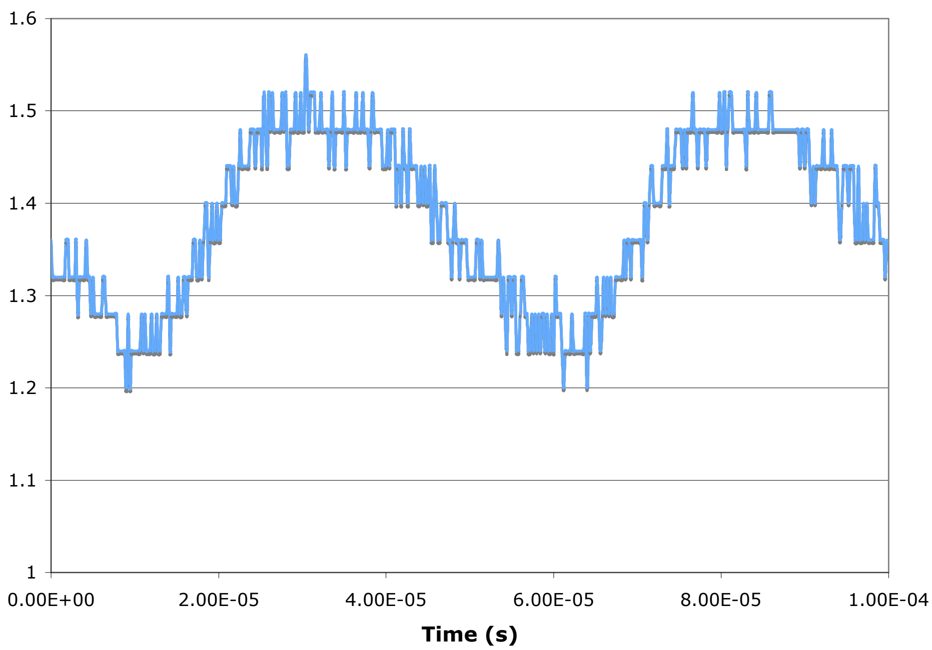

Fig. 3: Oscillations on Vout1 after irradiation run #114

SET cross-sections for 1.2V output are shown in Fig. 4. Cross-sections increase with increasing output current. However, for the smallest load, SETs are so small that their count is not accurate.

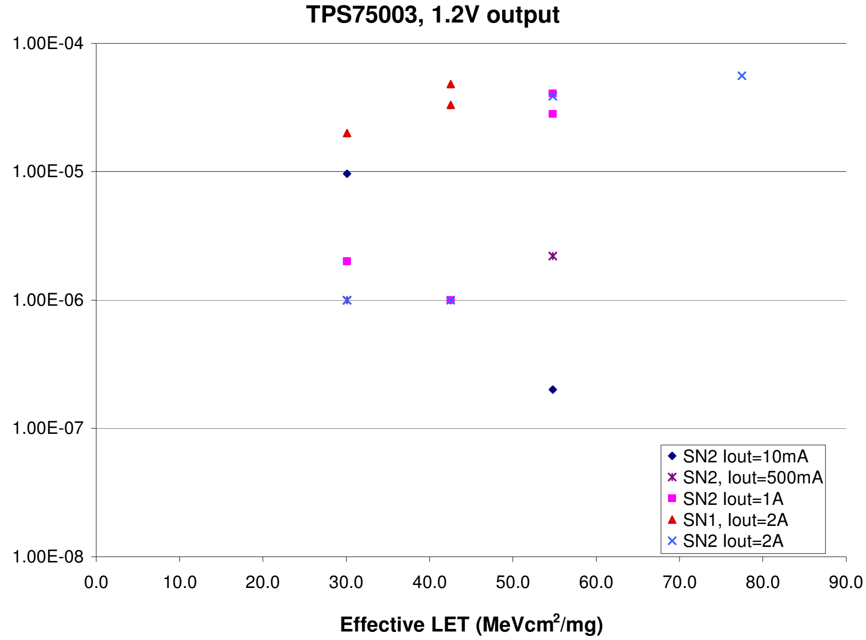

Fig. 4: Vout 1 (1.2V output) SET cross-section curve

For the small load conditions of 10mA and 500mA, SETs transients are small whatever the LET value. SETs are either bipolar or positive going. Maximum transient amplitude is about 200 mV. SET duration is very small too. Maximum duration is of the order of 5 ns. Worst case transient is shown in Fig. 5.

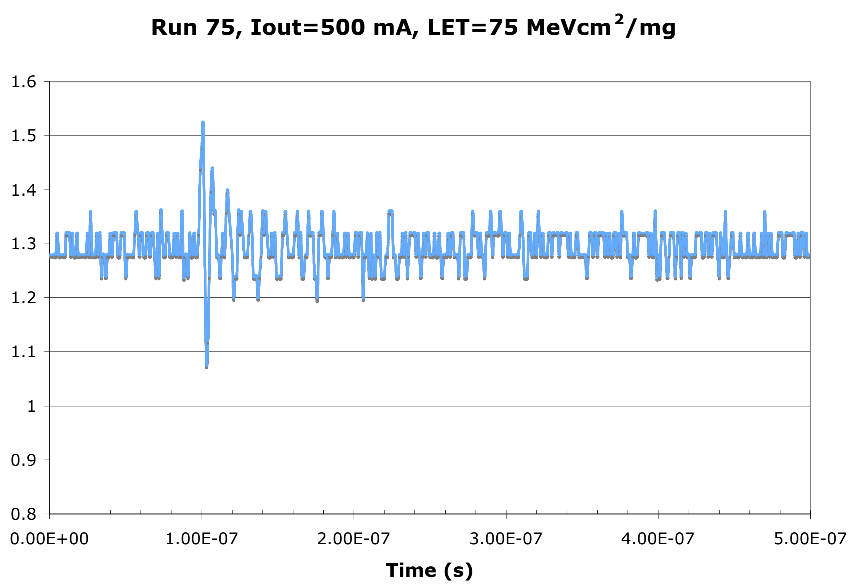

Fig. 5: worst case transient on Vout1 for loads 10mA and 500mA

For the load conditions of 1A and 2A, SET characteristics depend on LET. Up to the LET of 42.5 $MeVcm^2/mg$, SETs are similar to the one shown in Fig. 5. Then, for higher LET values, we see larger negative going transients as shown in Fig. 6. Maximum SET amplitude is around 300 mV. Maximum duration is around 12 µs.

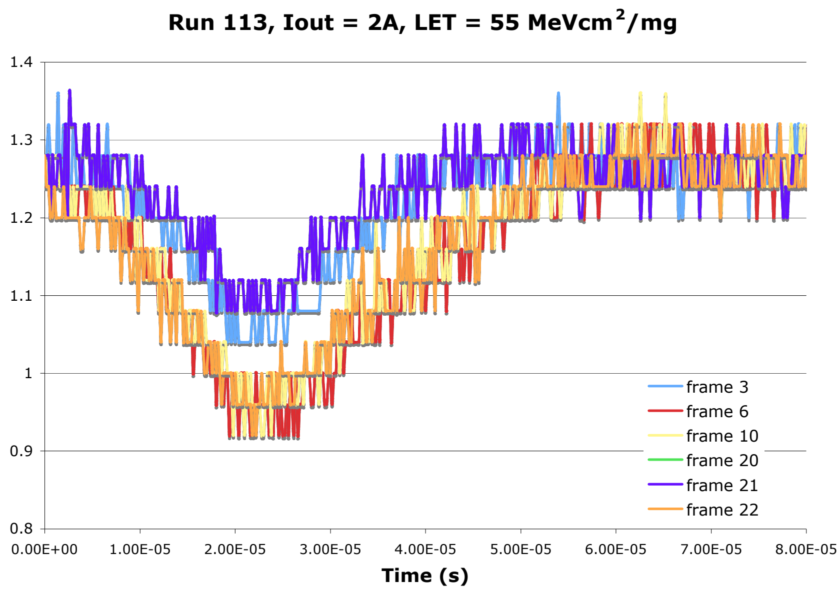

Fig. 6: worst case transient on Vout1 at high LET and loads > 1A

SET cross-section curve for 3.3V output are shown in Fig. 7. We can see significant increase of sensitivity with increasing output current. For the lowest output current of 10 mA, maximum measured cross-section is around 10^{-6} cm^2, and LET threshold is higher than 43 MeVcm^2/mg. For the load of 500 mA, maximum measured cross-section is about 10^{-6} cm^2 and LET threshold is higher than 30 MeVcm /mg. For the largest load conditions of 1A and 2A LET threshold is lower than 30 MeVcm^2/mg and SET cross-section is still increasing significantly. Maximum measured SET cross-section is about 10^{-5} cm^2 for the 1A load, and it is 7×10^{-5} cm^2 for the 2A load.

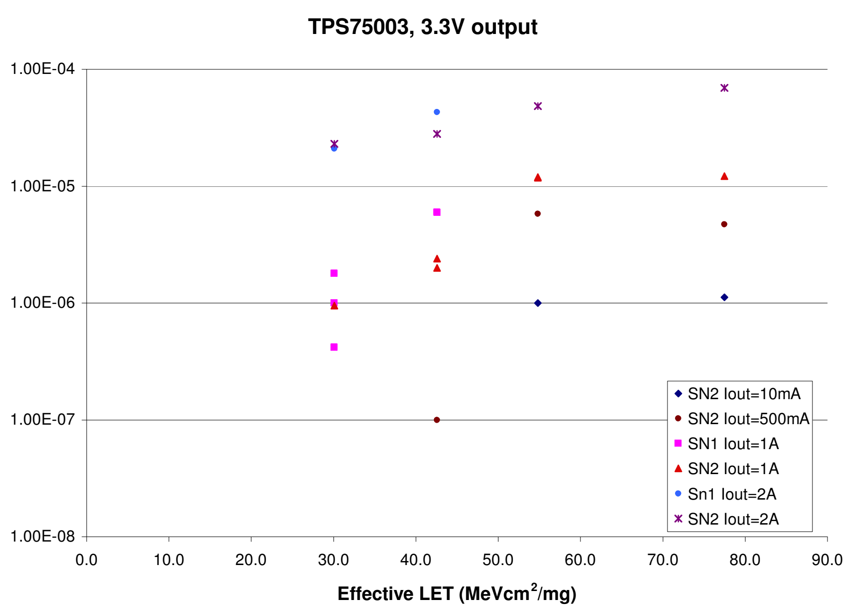

Fig. 7: SET cross-section on Vout2 3.3V output

SET waveforms are somewhat similar to the ones observed on output 1. Up to 500 mA load and a LET of 55 MeVcm^2/mg, SET are small and similar to the SET shown in Fig. 5. For small load (up to 500 mA) and high LET (77.5 MeVcm^2/mg) or intermediate load (1A) and small LET (30 MeVcm^2/mg), we obtain small amplitude (~250-300mV) and long duration (~ 3-5 μs) positive going SETs as shown in Fig. 8. For the interrnediate load at highest LET we still a few positive going SET as shown in Fig. 8, but the dominating SETs are larger amplitude longer duration negative going SETs as shown in Fig. 9. Maximum transient amplitude is 400 mV and maximum duration is about 30 μs.

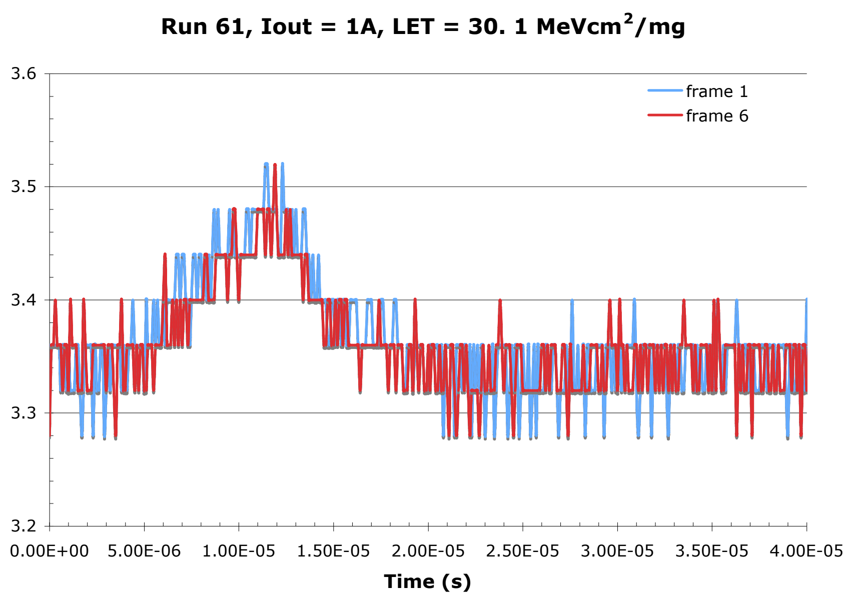

Fig. 8: typical SETs on Vout2 for small load/high LET or intermediate load/low LET

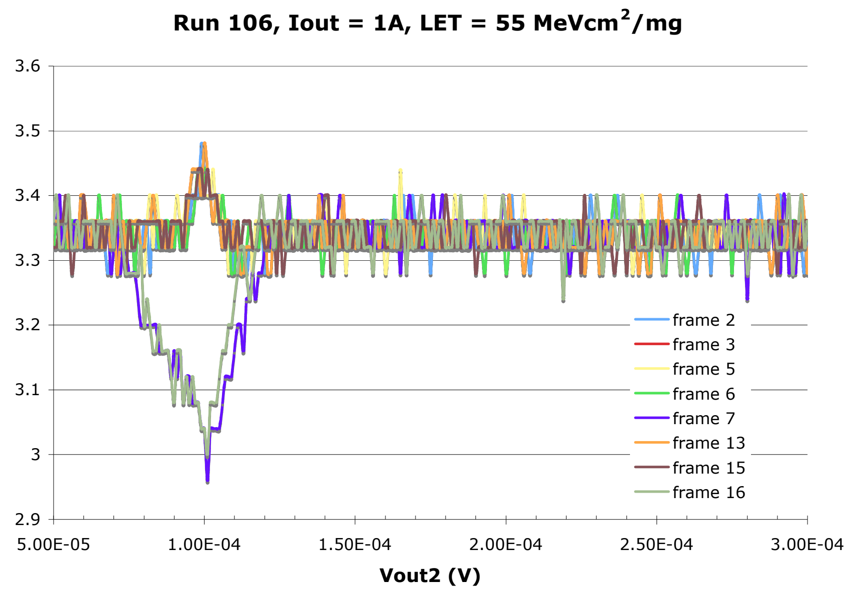

Fig. 9: Typical SETs obtained on Vout2 with 1A load at high LET

For the highest load of 2A, whatever the LET value, all transients are negative going with a larger amplitude and a longer duration as shown in Fig. 10. Maximum measured amplitude is around 500 mV and maximum measured duration is around 30 µs.

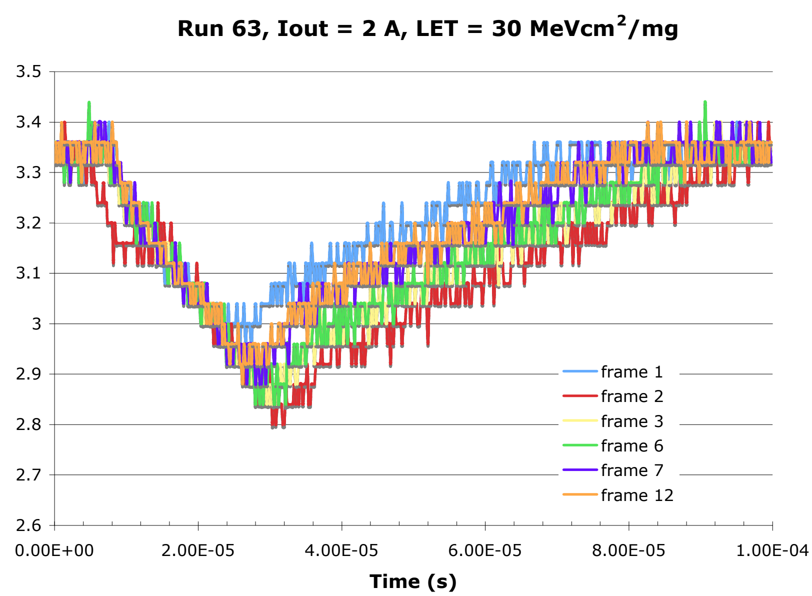

Fig. 10: Typical SET for the largest load of 2A

SET cross-section for Vout3 (2.5V) are shown in Fig. 11. We can see that the cross-sections measured for this output are the highest. They do not depend on the load. However, SET waveforms depend strongly on the load.

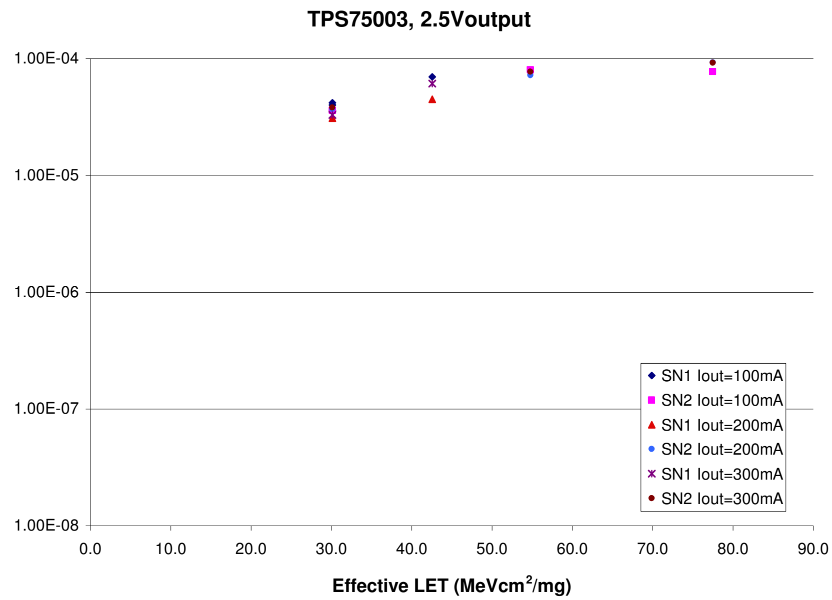

Fig. 11: SET cross-sections for Vout3, 2.5V

For the lowest load of 10 mA, SETs are small amplitude (around 500-600 mV) and very long duration (~2-4 ms) positive going pulses as shown in Fig. 12. SET characteristics do no change with LET.

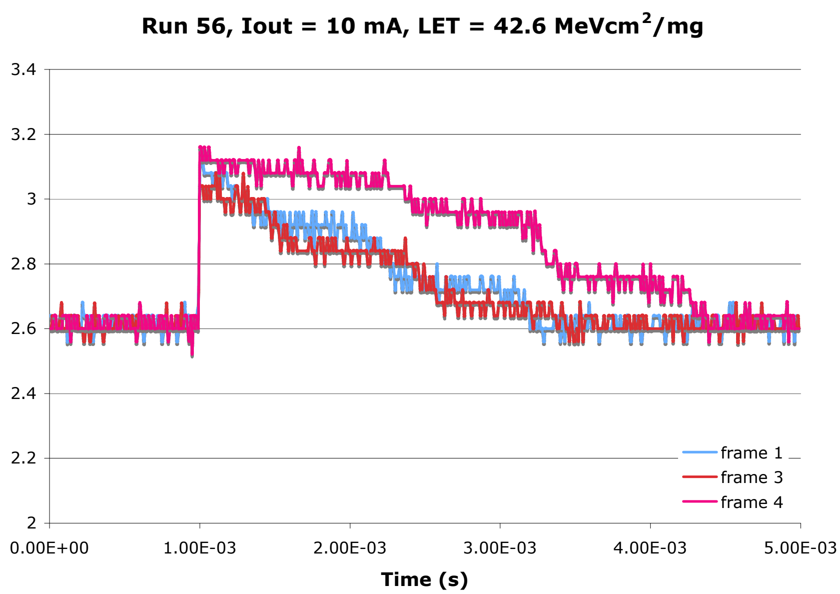

Fig. 12: Typical SETs on Vout3, for the lowest load of 10 mA

For the highest load conditions of 100 mA and 200 mA, we still have a few positive going or bipolar SETs of shorter duration, but most SETs are large amplitude (~500 mV to 1.5V) long duration (50 to 100 µs) negative going pulses. Typical SET waveforms are shown in Fig. 13. When LET increases, amplitude of negative going SET increases. Worst case negative SET is shown in Fig.14. Its amplitude is around 1.5V.

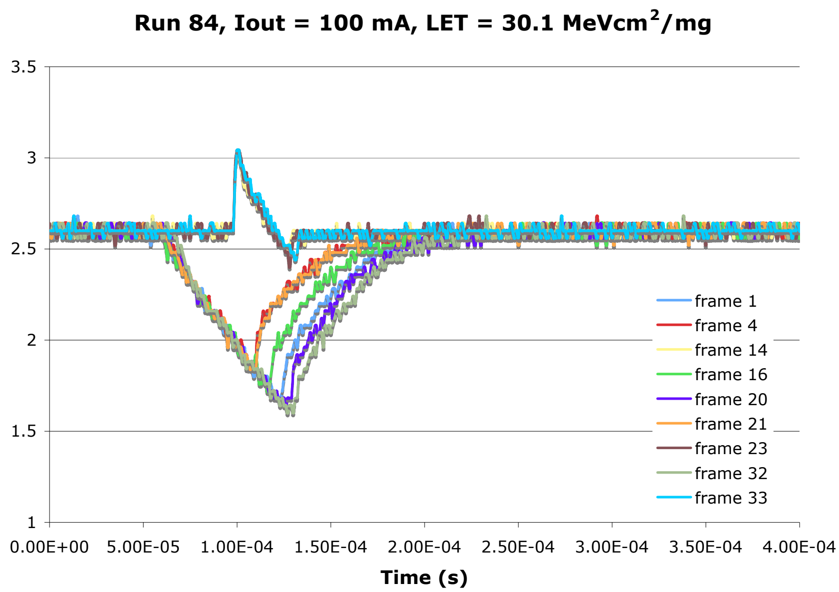

Fig. 13: Typical SETs on Vout3 for high load and lowest LET tested

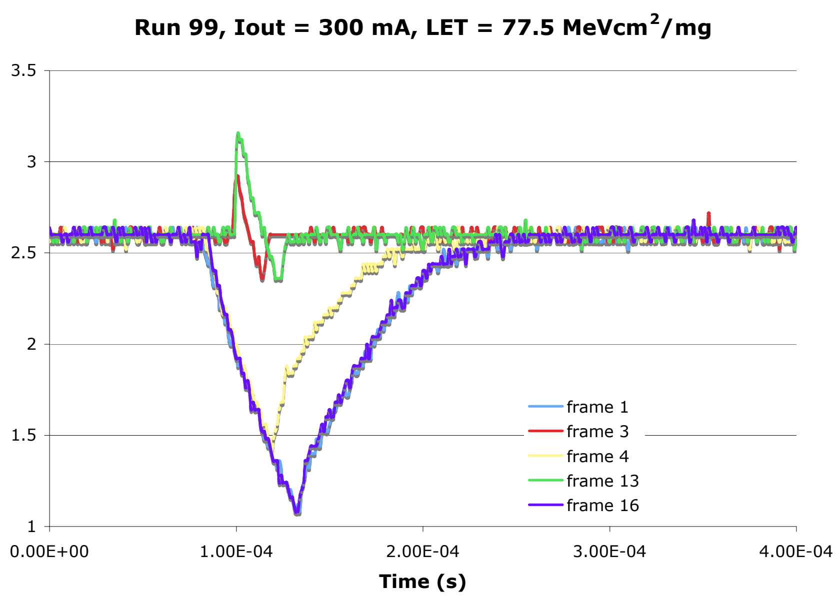

Fig. 14: Typical SETs on Vout3 for high load and highest tested LET

VII. Conclusions

Failure observed at higher LET on one of the buck regulators needs more investigation. However, even though it is confirmed that this failure is due to heavy ions, the probability of failure is orbit will be low.

SET sensitivity of buck regulators is low. However, SETs observed at high load conditions and high LET will cause disruption in typical applications of this part (FPGA power supply). Occurrence rate may be low enough to be acceptable in most cases. Short duration transients may cause disruptions as well. More testing at lower LET is recommended to get the LET threshold of these small short duration SETs.

LDO regulator is by far the most sensitive function of this device, and for any LET tested, large SETs were observed. More testing at lower LET is recommended to get a better assessment on LDO regulator.

Appendix: Test log

Run #	Output	trigger	DUT #	Load	Ion	Energy	Angle	LET	Eff LET	Flux	Fluence	# errors	#download	sigma	Comment
33	1.2V	+/-100mV	1	10mA	Kr	850	0	30.1	30.1	5.00E+03	1.00E+06	1	1	1.00E-06	1 erreur or glitch when beamm turned on
34	1.2V	+/-100mV	1	500mA	Kr	850	0	30.1	30.1	6.00E+03	1.00E+06	3	3	3.00E-06	
36	1.2V	+/-100mV	1	1A	Kr	850	0	30.1	30.1	6.00E+03	1.00E+06	29	29	2.90E-05	
37	1.2V	+/-100mV	1	2A	Kr	850	0	30.1	30.1	7.00E+03	1.00E+06	20	20	2.00E-05	
38	1.2V	+/-100mV	1	2A	Kr	850	45	30.1	42.6	6.00E+03	1.00E+06	48	48	4.80E-05	50ns/div
39	1.2V	+/-100mV	1	2A	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	33	33	3.30E-05	500ns/div
40	1.2V	+/-100mV	1	1A	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	0	0	0.00E+00	50ns/div
41	1.2V	+/-100mV	1	500mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	1	1	1.00E-06	
42	2.5V	+/-400mV	1	10mA	Kr	850	0	30.1	30.1	4.00E+04	7.45E+05	3	3	4.03E-06	50ns/div
43	2.5V	+/-400mV	1	10mA	Kr	850	0	30.1	30.1	4.00E+04	1.55E+06	0	0	0.00E+00	1us/div, result does not make sense
44	2.5V	+/-400mV	1	10mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	0	0	0.00E+00	
45	2.5V	+/-400mV	1	100mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	36	35	3.60E-05	
46	2.5V	+/-400mV	1	100mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	42	39	4.20E-05	10us/div
47	2.5V	+/-400mV	1	100mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	40	38	4.00E-05	50us/div
48	2.5V	+/-400mV	1	200mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	31	30	3.10E-05	
49	2.5V	+/-400mV	1	300mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	33	33	3.30E-05	
50	2.5V	+/-400mV	1	300mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	61	60	6.10E-05	
51	2.5V	+/-400mV	1	200mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	45	42	4.50E-05	
52	2.5V	+/-400mV	1	100mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	70	65	7.00E-05	
53	2.5V	+/-400mV	1	10mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	1	1	1.00E-06	long transient
54	2.5V	+/-400mV	1	10mA	Kr	850	45	30.1	42.6	4.00E+04	3.70E+06	3	3	8.11E-07	100us/div
55	2.5V	+/-400mV	1	10mA	Kr	850	45	30.1	42.6	4.00E+04	3.25E+06	3	3	9.23E-07	1ms/div
56	2.5V	+/-400mV	1	10mA	Kr	850	45	30.1	42.6	4.00E+04	4.93E+06	4	4	8.11E-07	500us/div
57	3.3V	+/-100mV	1	10mA	Kr	850	0	30.1	30.1	4.00E+04	1.23E+06	0	0	0.00E+00	100ns/div
58	3.3V	+/-100mV	1	500mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	1	1	1.00E-06	
59	3.3V	+/-100mV	1	1A	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	1	1	1.00E-06	
60	3.3V	+/-100mV	1	1A	Kr	850	0	30.1	30.1	4.00E+04	2.38E+06	1	1	4.20E-07	500ns/div
61	3.3V	+/-100mV	1	1A	Kr	850	0	30.1	30.1	4.00E+04	1.00E+07	18	18	1.80E-06	5us/div
62	3.3V	+/-100mV	1	2A	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	21	20	2.10E-05	
63	3.3V	+/-100mV	1	2A	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	21	21	2.10E-05	10us/div
64	3.3V	+/-100mV	1	2A	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	43	42	4.30E-05	
65	3.3V	+/-100mV	1	1A	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	6	6	6.00E-06	
66	3.3V	+/-100mV	1	500mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	0	0	0.00E+00	
67	3.3V	+/-100mV	2	500mA	Kr	850	0	30.1	30.1	4.00E+04	5.33E+06	0	0	0.00E+00	
68	3.3V	+/-100mV	2	1A	Kr	850	0	30.1	30.1	4.00E+04	5.25E+06	5	5	9.52E-07	
69	3.3V	+/-100mV	2	2A	Kr	850	0	30.1	30.1	4.00E+04	1.13E+06	26	25	2.30E-05	
70	3.3V	+/-100mV	2	2A	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	28	28	2.80E-05	
71	3.3V	+/-100mV	2	1A	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	2	2	2.00E-06	
72	3.3V	+/-100mV	2	1A	Kr	850	45	30.1	42.6	4.00E+04	5.00E+06	12	12	2.40E-06	
73	3.3V	+/-100mV	2	500mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+07	1	1	1.00E-07	
74	1.2V	+/-100mV	2	10mA	Kr	850	0	30.1	30.1	4.00E+04	1.04E+06	10	10	9.62E-06	50ns/div
75	1.2V	+/-150mV	2	500mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	1	1	1.00E-06	
76	1.2V	+/-150mV	2	1A	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	2	2	2.00E-06	
77	1.2V	+/-180mV	2	2A	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	1	1	1.00E-06	
78	1.2V	+/-180mV	2	2A	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	0	0	0.00E+00	
79	1.2V	+/-180mV	2	1A	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	0	0	0.00E+00	
80	1.2V	+/-150mV	2	500mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	0	0	0.00E+00	
81	1.2V	+/-100mV	2	10mA	Kr	850	45	30.1	42.6	4.00E+04	1.00E+06	1	1	1.00E-06	
82	2.5V	+/-400mV	2	300mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	38	33	3.80E-05	50us/div
83	2.5V	+/-400mV	2	200mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	37	36	3.70E-05	
84	2.5V	+/-400mV	2	100mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	36	35	3.60E-05	
85	2.5V	+/-400mV	2	10mA	Kr	850	0	30.1	30.1	4.00E+04	1.00E+06	1	1	1.00E-06	500us/div
90	2.5V	+/-400mV	2	300mA	Xe	1177	0	54.8	54.8	9.00E+03	1.00E+06	77	75	7.70E-05	
91	2.5V	+/-400mV	2	200mA	Xe	1177	0	54.8	54.8	9.00E+03	1.00E+06	72	72	7.20E-05	
92	2.5V	+/-400mV	2	100mA	Xe	1177	0	54.8	54.8	8.00E+03	1.00E+06	80	70	8.00E-05	
93	2.5V	+/-400mV	2	10mA	Xe	1177	0	54.8	54.8	8.00E+03	1.00E+06	2	2	2.00E-06	1ms/div
94	2.5V	+/-400mV	2	10mA	Xe	1177	0	54.8	54.8	8.00E+03	1.89E+06	5	5	2.65E-06	
96	2.5V	+/-400mV	2	10mA	Xe	1177	45	54.8	77.5	5.00E+04	5.00E+06	17	17	3.40E-06	
97	2.5V	+/-400mV	2	100mA	Xe	1177	45	54.8	77.5	5.00E+04	1.00E+06	77	68	7.70E-05	50us/div
98	2.5V	+/-400mV	2	200mA	Xe	1177	45	54.8	77.5	5.00E+04	1.00E+06	93	83	9.30E-05	
99	2.5V	+/-400mV	2	300mA	Xe	1177	45	54.8	77.5	5.00E+04	1.00E+06	92	77	9.20E-05	
100	3.3V	+/-100mV	2	10mA	Xe	1177	0	54.8	54.8	5.00E+04	1.00E+06	1	1	1.00E-06	50ns/div
101	3.3V	+/-100mV	2	500mA	Xe	1177	0	54.8	54.8	5.00E+04	3.79E+06	22	22	5.80E-06	
102	3.3V	+/-100mV	2	1A	Xe	1177	0	54.8	54.8	5.00E+04	5.00E+06	60	60	1.20E-05	
103	3.3V	+/-100mV	2	1A	Xe	1177	0	54.8	54.8	5.00E+04	5.00E+06	59	57	1.18E-05	500us/div
104	3.3V	+/-100mV	2	2A	Xe	1177	0	54.8	54.8	5.00E+04	5.00E+06	243	221	4.86E-05	
105	3.3V	+/-100mV	2	2A	Xe	1177	45	54.8	77.5	5.00E+04	2.07E+06	144	132	6.96E-05	100us/div
106	3.3V	+/-100mV	2	1A	Xe	1177	45	54.8	77.5	5.00E+04	2.30E+06	28	28	1.22E-05	50us/div
107	3.3V	+/-100mV	2	500mA	Xe	1177	45	54.8	77.5	5.00E+04	2.34E+06	11	11	4.70E-06	10us/div
108	3.3V	+/-100mV	2	10mA	Xe	1177	45	54.8	77.5	5.00E+04	2.68E+06	3	3	1.12E-06	
109	1.2V	+/-100mV	2	10mA	Xe	1177	0	54.8	54.8	5.00E+04	5.00E+06	1	1	2.00E-07	50ns/div
110	1.2V	+/-100mV	2	500mA	Xe	1177	0	54.8	54.8	5.00E+04	5.00E+06	11	11	2.20E-06	1us/div
111	1.2V	+/-100mV	2	1A	Xe	1177	0	54.8	54.8	5.00E+04	4.68E+05	19	17	4.06E-05	500ns/div
112	1.2V	+/-100mV	2	1A	Xe	1177	0	54.8	54.8	5.00E+04	2.63E+06	74	73	2.81E-05	10us/div
113	1.2V	+/-150mV	2	2A	Xe	1177	0	54.8	54.8	5.00E+04	5.00E+06	194	175	3.88E-05	
114	1.2V	+/-150mV	2	2A	Xe	1177	45	54.8	77.5	5.00E+04	5.00E+06	279	263	5.58E-05	we get oscillations without beam at the end