Heavy-Ion Test Report of the Radiation Hardened High Voltage Synchronous Step-Down Controller MSK5055RH

Abbreviated Report, Revision “b”

Sana Rezgui[1], Paul Musil[2], Bryan Horton[2], Fred Freytag[2], Tom Sheehan[1], Jeff Witt[1], and Rocky Koga[3]

[1]Linear Technology, [2]Anaren Inc. - MSK Products, [3]The Aerospace Corporation

Acknowledgements

The authors would like to thank Steve Bielat and Jeffrey George from The Aerospace Corporation for their assistance with the beam experiments. Also, special thanks for the Aerospace Corporation team, mainly David Meshel, and Rocky Koga, for their expediting these experiments.

Please contact Linear Technology if you wish to receive the full SEE test report of the MSK5055RH.

Executive Summary

This report summarized the heavy-ion test experiments performed on the MSK5055-1RH [3] at the Lawrence Berkeley National Labs (LBNL). The MSK5055-1RH is a hermetically packaged MIL-PRF-38534 qualified hybrid microcircuit manufactured with the RH3845MKDICE, a Radiation Hardened High Voltage Synchronous Current Mode Step-Down Controller with Adjustable Operating Frequency [1, 3]. Heavy-ion induced Single Event Effect (SEE) experiments included Single Event Transient (SET), Single Event Upset (SEU) and Single Event Latchup (SEL) tests up to an LET of 117.6 MeV.cm^2/mg, at room as well as at elevated temperatures (to case temperatures of 100°C). At the tested input voltages less than or equal to 30V, the MSK5055-1RH showed sensitivities only to SETs up to an LET of 117.6 MeV.cm^2/mg. The measured SET sensitive saturation cross-section was about 3.4x10^{-4} cm^2, about 4% of the total die's cross-section, while the SET threshold LET was about 2.4 MeV.cm^2/mg. For input voltages of 40V, 50V and 60V, destructive events were seen at LET of 58.78 MeV.cm^2/mg.

With input voltages less than or equal to 30V, up to an LET of 117.6 MeV.cm^2/mg, the SET pulse widths were less than 40 us, and their delta amplitudes varied between -110mV and +20mV. The 20 mV positive amplitudes were due to slightly under-damped control loop recovery following the occurrence of the negative SET, the original effect created by the ion bombardment. However, for SEE tests with input voltages greater than or equal to 40V, negative SETs as well as positive SETs have been observed (at an input voltage of 60V). The amplitude of the first positive SET was about 200mV while the second one was about 400 mV and was destructive to the application circuit.

These results may vary with the selected peripheral component characteristics. To approximate circuit performance using the selected peripheral component parasitic, Linear Technology Inc. recommends that the designer simulates their design by injecting SETs at the circuit's inputs/outputs, as wide as the observed SETs in this report. This can be accomplished using the LTSpice tool offered by Linear Technology. Most of the Linear LT parts spice models are offered [4].

1. Overview

This report details the heavy-ion test experiments performed on the MSK5055-1RH [3] at the Lawrence Berkeley National Labs (LBNL). The MSK5055-1RH is a hermetically packaged MIL-PRF-38534 qualified hybrid microcircuit manufactured with the Radiation Hardened RH3845MKDICE [1, 2]. This RH DICE is a high voltage, synchronous, current mode controller for medium to high power, high efficiency supplies. It offers a wide 4 to 60V input range (7.5V minimum start-up voltage), with adjustable fixed operating frequency synchronizable to an external clock for noise sensitive applications and gate drivers capable of driving large N-channel MOSFETs. Additional features include a precision undervoltage lockout, low shutdown current, short-circuit protection, and programmable soft-start. The wide input range, programmable output voltage and switching frequency, make these regulators suitable for a wide variety of medium to high power applications. The adjustable operating frequency provides the flexibility to keep the switching noise out of sensitive frequency bands, and when synchronized, can be ganged out of phase with other controllers for reduced noise and component size.

The RH3845MKDICE wafer lots are processed to Linear Technology's in house Class S flow to yield circuits usable in stringent military and space applications. The MSK5055RH is manufactured using the RH3845MKDICE and is hermetically sealed in a 16 pin flatpack available with straight or gull wing leads. More details are given about this RH-Controller in [1-3]. This is a 4µm technology using exclusively bipolar transistors. The part's block diagram is shown in Fig. 1. The package pin designation is given in Fig. 2.

Absolute Maximum Ratings

(Note 1)

Vin Input Voltage	65V
V_{BOOST} BOOST Voltage (BOOST)	80V
SW Switch Voltage	65V, –2V
Differential Boost Voltage (BOOST TO SW)	24V
VCC Bias Supply Voltage	24V
V_{SENSE} SENSE+ and SENSE- Voltages	40V
Differential Sense Voltage	+/-1V
SYNC, VC, VFB, CSS and SHDN	5V
SHDN Pin Currents	1mA
Lead Temperature Range (10 Seconds)	300°C
Operating Junction Temperature Range	–55°C to 125°C
Storage Temperature Range	–65°C to 150°C
ESD Rating	1C

Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability.

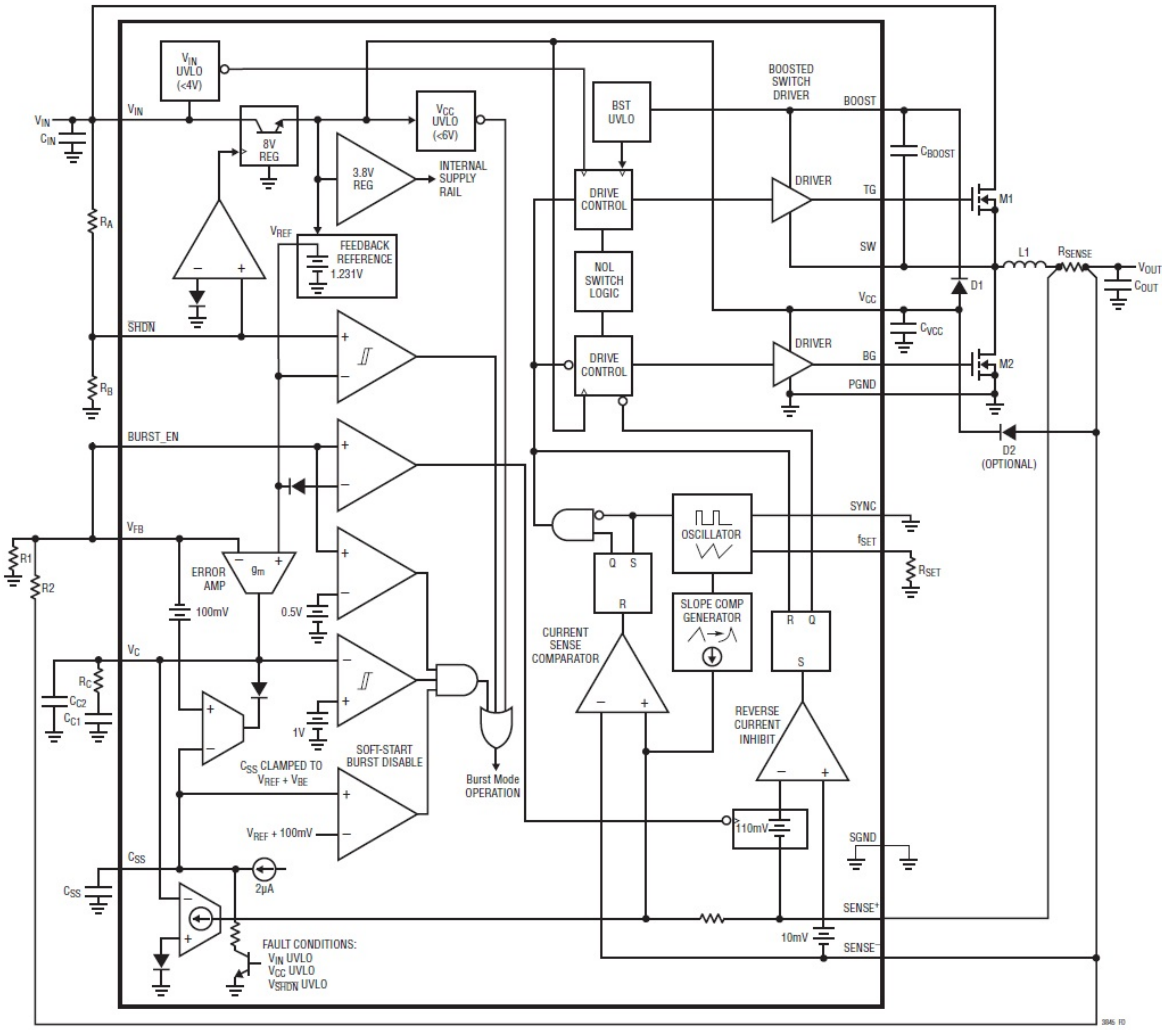


Fig. 1: Block Diagram of the RH3845MKDICE and the required peripherals for the Controller Operation

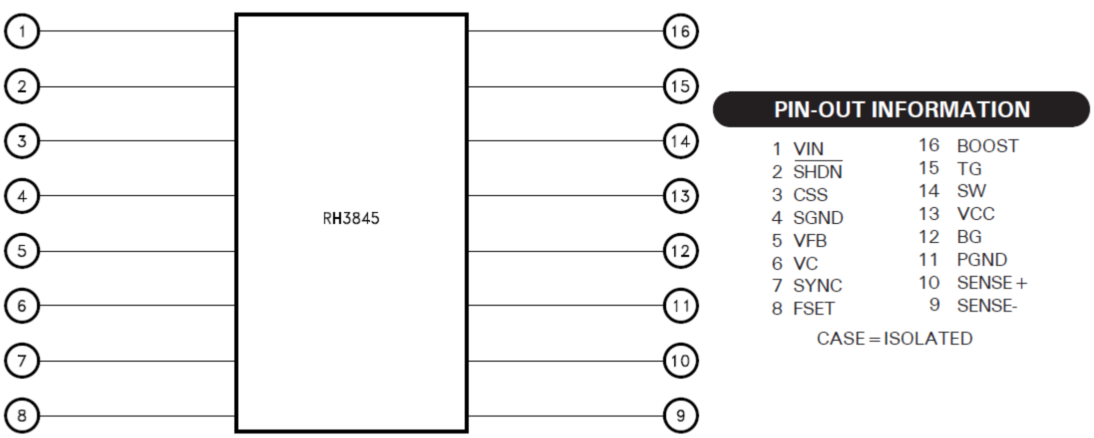


Fig. 2: MSK5055RH PIN-OUT

The MSK5055RH is offered in two versions -1 and -2 allowing two different operational modes at light loads. The different modes are internally configured at the MSK factory and are identified by the “dash number.”

Part Number	Mode Internal Connection	Reverse Current Mode
MSK5055-1RH	VFB	Disabled (DCM)
MSK5055-2RH	VCC	Enabled (CCM)

MSK5055-1RH disables the reverse current capability at light loads. This configuration is more efficient than configuration “-2.” It allows the inductor current to go discontinuous and the PWM will skip pulses to maintain regulation at light loads. This configuration will have a minimum load current requirement, typically 1mA. MSK5055-2RH allows reverse current in the synchronous switch at light loads. This configuration is less efficient at light loads but operates in continuous conduction mode at light loads. Only the MSK5055-1RH has been evaluated in these Heavy Ion tests. For SEE data on the MSK5055-2RH configured in the CCM mode, the user is advised to refer to the MSK5063RH SEE test report [5].

Table 1 summarizes the parts’ features and the electrical test equipment.

Table 1: MSK5055-1RH Test and Part’s Information

Generic Part Number	MSK5055-1RH
Package Marking	MSK5055-1RH Fabrication Lot: WD005797.1
Manufacturer	Anaren Inc. - MSK products / Linear Technology
Quantity tested	3
Dice Dimension	124 mils x 113 mils≈ 9.04 mm^2
Part Function	Radiation Hardened High Voltage Synchronous Current Mode Step-Down Controller with Adjustable Operating Frequency
Part Technology	BIPU405 (4um)
Package Style	Hermetically sealed 16-Pin Flatpack
Test Equipment	Power supply, oscilloscope, multimeter, Decade Resistive Load Box, and computer
Temperature and Tests	SET, SEU and SEL @ Room Temp. and 100°C

2. Test Setup

Custom SEE boards were built for heavy-ion tests by the MSK team. The MSK5055-1RH parts were tested at LBNL on June 17 & 18, 2014 at two different temperatures; at room temperature and at case temperature of 100°C. The junction temperature was indirectly monitored and controlled. Temperature control is provided by the conductive cooling plate and the external adjustable heating element within the test setup.

The SEE board contains:

- The DUT (MSK5055-1RH) with open-top (package de-capped)
- The input and output filtering capacitors
- Two FDD8632 N-channel MOSFETs
- The 2N3904 bipolar transistor to sense the board's temperature, placed as close as possible to the DUT.

Fig. 5 shows the SEE test board schematics. The test board BOM and configuration details are available by request. The photograph of this test board, as used in the testing, is given in Fig. 6.

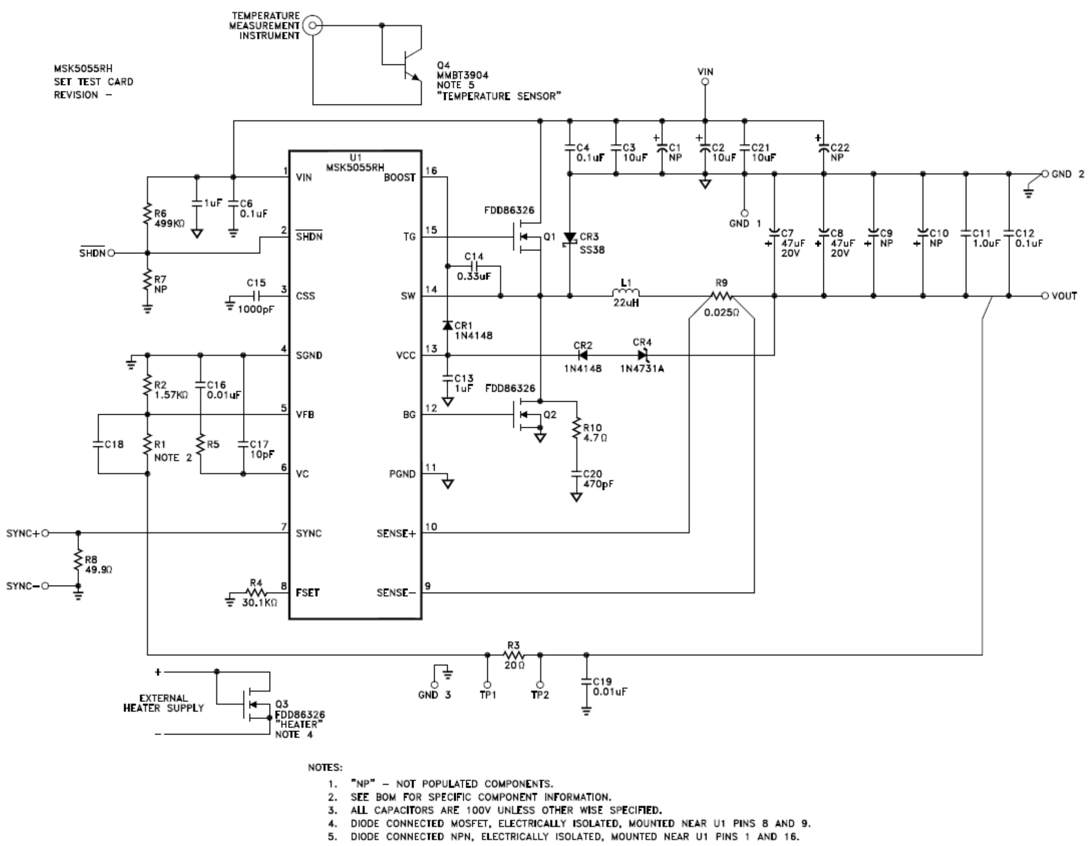


Fig. 5: Schematics of the MSK5055-1RH SEE Test Board

To minimize the distortion of the measured SET pulse-width (PW), the test setup was placed as close as possible to the vacuum chamber.

The SW (output switch signal), V_C (output of the error amplifier) and V_{OUT} (output) signals were connected each to a scope channel. In this case, the capacitive load of the cable was about 120pF. The scope was set with 1MOhms termination.

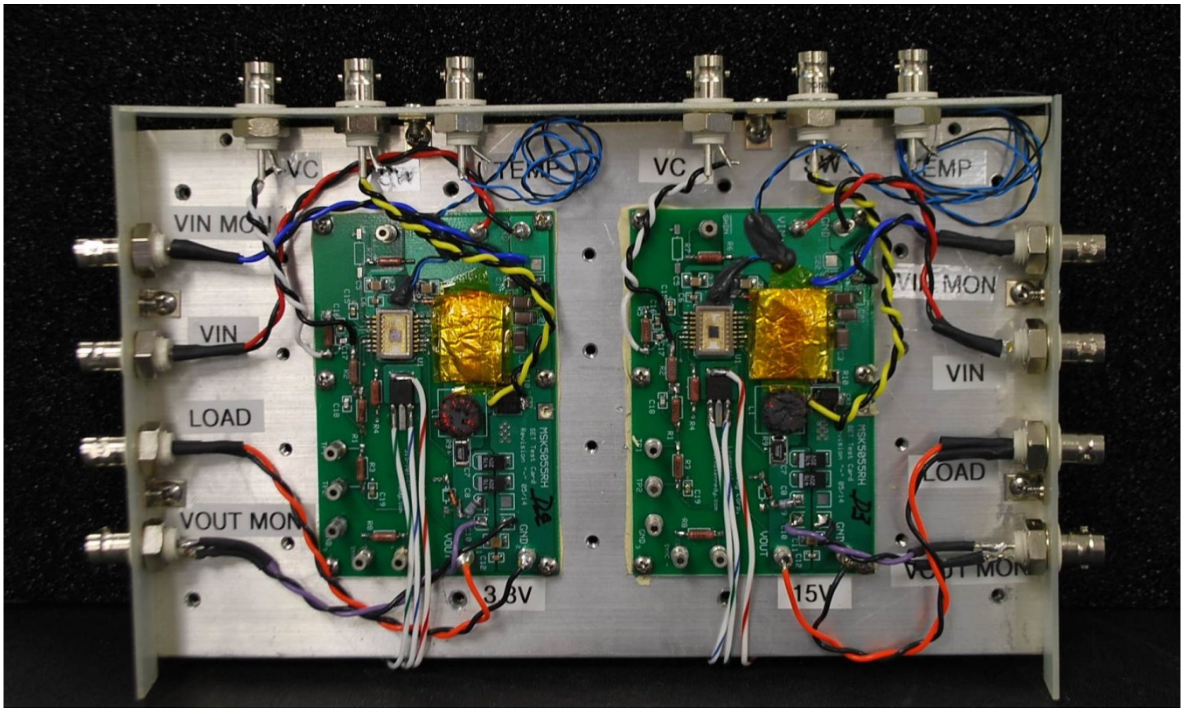


Fig. 6: Photograph of the MSK5055-1RH SEE Test Board showing the open-top DUT and the cooling plate underneath the SEE boards added to dissipate the heat through conduction in the Heavy-Ion Vacuum Chamber

3. Heavy-Ion Beam Test Conditions

The selected beam energy is 10MeV/nucleon, which correlates with beam ions delivered at a rate of 7.7 MHz (eq. to a period of 130 ns).

The higher the beam's frequency or the flux; the higher is the likelihood to have more than one particle hitting the DUT in a very short time (within hundreds of nanoseconds.) To avoid overlapping of events, it is important then that the error-events last less than 130 ns or that the flux is much reduced.

The recovery time of the DUT output following an ion strike determines the maximum test flux. The closed loop response of the DUT is determined, in part, by the frequency compensation network attached to the Vc pin. Monitoring this pin in situ was required to identify the causal relationship between an ion strike and resulting SEE. A consequence of this monitoring requirement is an additional parasitic load due to interconnect cabling. It is estimated that an additional capacitive load of approximately 120pF was present on the Vc pin during these Heavy Ion experiments.

The run fluxes are reported in Table 5. During runs where high fluence was required, beam flux was also high to keep test times reasonable. There is a higher probability of overlapping events during the high flux runs.

4. Radiation Test Results

Heavy-ion SEE experiments included SET, SEU and SEL tests up to a Linear Energy Transfer (LET) of 117.6 MeV.cm^2/mg at elevated temperatures (to case temperatures of 100°C). In 46 runs, the MSK5055-1RH parts were irradiated with various input voltages, ranging between 10 and 60V, two different output voltage biases (15V and 3.3V), and at three different loads (1A, 1.1A and 3.3A). The input/output bias voltages and load settings are summarized in Table 2. All the raw radiation test results are provided in Table 5.

Table 2: MSK5055-1RH Test Bias Conditions (Input, and Output Voltages and Load Currents)

V_{IN} (V)	V_{OUT} (V)	I_{OUT} (A)	R_{Load} (Ohms)
10	3.3	1.1	3
15	3.3	1.1	3
10	3.3	3.3	1
15	3.3	3.3	1
30	15	1	15
40	15	1	15
50	15	1	15
60	15	1	15

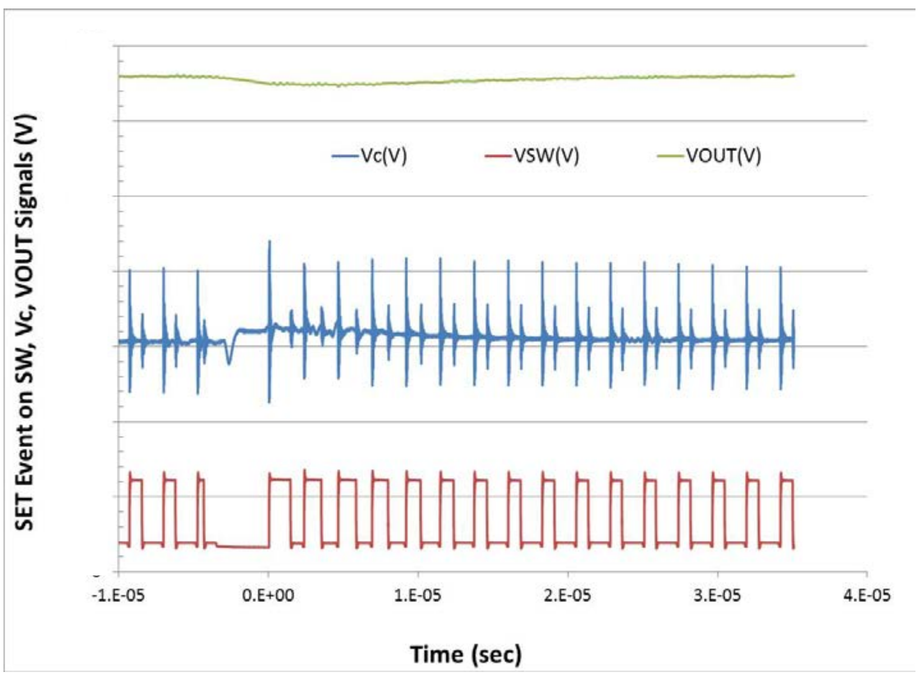
For SET detection, the scope was set to trigger on positive and negative SETs as a result of a change in the output signal V_{OUT} exceeding +/-10 mV (+/-0.3 %). The pulse widths were however calculated based on +/-20mV levels. Positive amplitudes lower than 20mV were observed after the negative SETs because of ripple effect on the output signal. Hence, the reported SET-PW is always smaller than the SET base width (from the time it starts till it ends). All the waveforms were saved during the beam tests and are available to the reader per his/her request.

Since destructive events have been seen for input voltages equal or higher than 40V input voltage, the beam data will be presented in two subsections: 4.1) V_{IN} equal or less than 30V and 4.2) V_{IN} equal or greater than 40V.

4.1 *Beam Test Results with Vin equal or less than 30V: No Destructive Events Nor SELs*

For an input voltage equal or less than 30V, neither SEU nor SEL nor destructive events have been observed during all the tests; all detected events were SET, negative transients, with various pulse amplitudes and widths that depended on the LET, as shown below in Appendix A. Furthermore, the negative going output transient lasted for less than 40 microseconds in all cases and were followed by small positive amplitude recovery overshoot (less than 20mV), as shown in Fig. 8. It can be observed that the underlying SET is a truncated and then skipped switch node pulse, total duration < 5µS. The DUT control loop then takes ≈35µS to recover and settle. This information can be used to appropriately size the output filtering components to satisfy a particular application's requirements. Under Xenon ions, Figs. 9 and 10 show examples of cumulative distributions of the SET amplitudes and widths with the beam run time, while Fig. 11 shows the SET pulse-amplitudes versus the SET pulse-widths.

Additionally, all of the negative transients were small in amplitude (less than 160 mV) and were initiated at the SW output signal and then seen on the Vc and V_{OUT} output signal. The V_{OUT} SET waveform shapes are dependent on the LC filtering circuitry (L1 & C7-12 of Fig. 5) and loading. Given the low level of SET effect, no additional mitigation techniques will be needed and the current application circuit may be used AS IS. It should be noted that the application circuits herein were developed primarily to overcome the numerous challenges of conducting Heavy Ion experiments while achieving full range operation from the extremely flexible MSK5055RH. Most real applications operate within well defined and narrower conditions. This enables various performance optimizations.



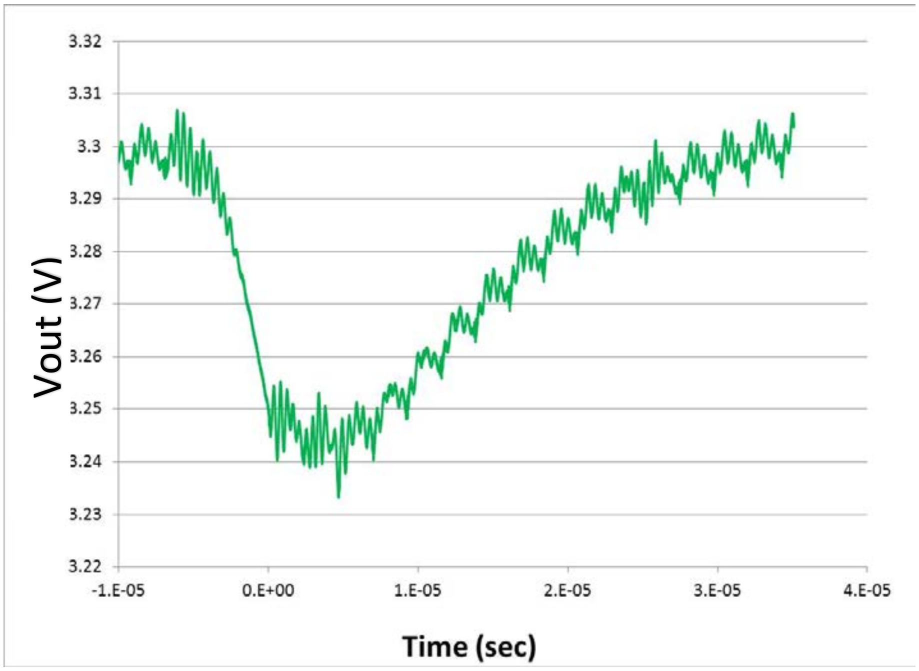


Fig. 8: Negative SET Pulse vs. Beam Time on SW, Vc, V_{OUT} output signals, Run 28, Waveform 4

-

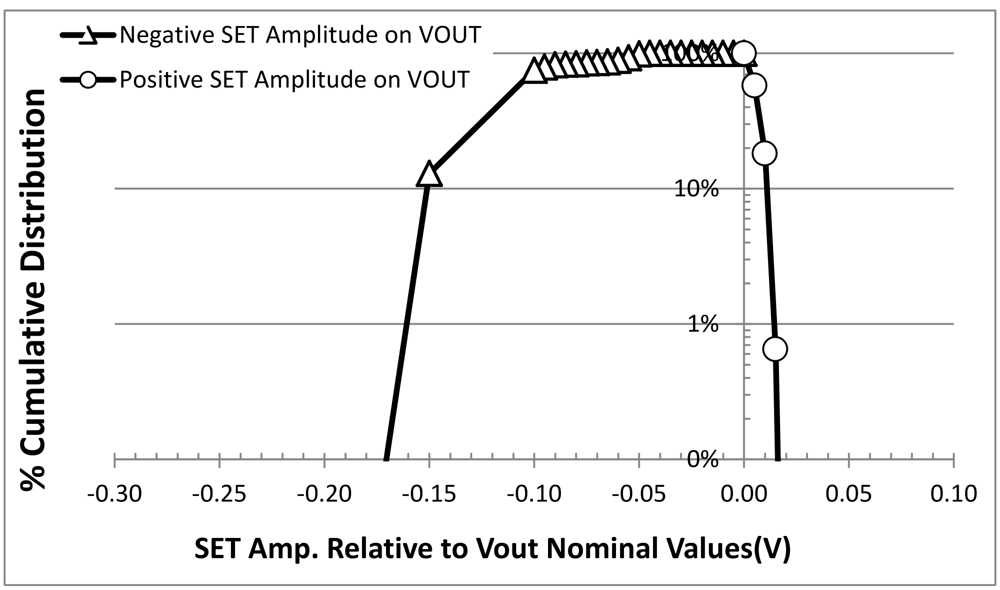


Fig. 9: % Cumulative Distributions vs. SET Pulse-Amplitudes
Runs# (30, 33, 41, 42); Vin=30V, Vout=15V, Iout=1A; Room Temp.; Xenon Ions with LET=58.78 MeV.cm^2/mg

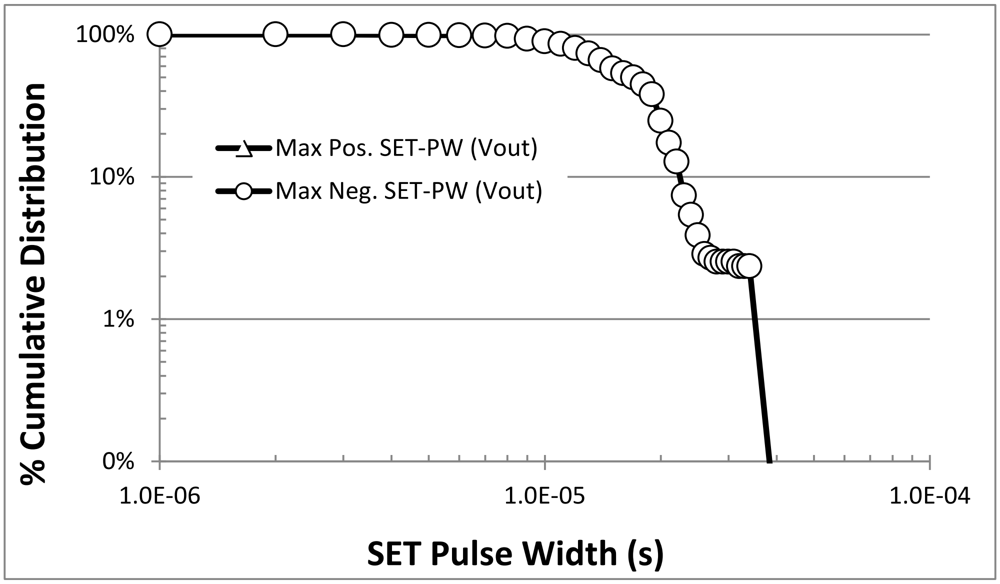


Fig. 10: % Cumulative Distributions vs. SET Pulse-Widths
Runs# (30, 33, 41, 42); Vin=30V, Vout=15V, Iout=1A; Room Temp.; Xenon Ions with LET=58.78 MeV.cm^2/mg

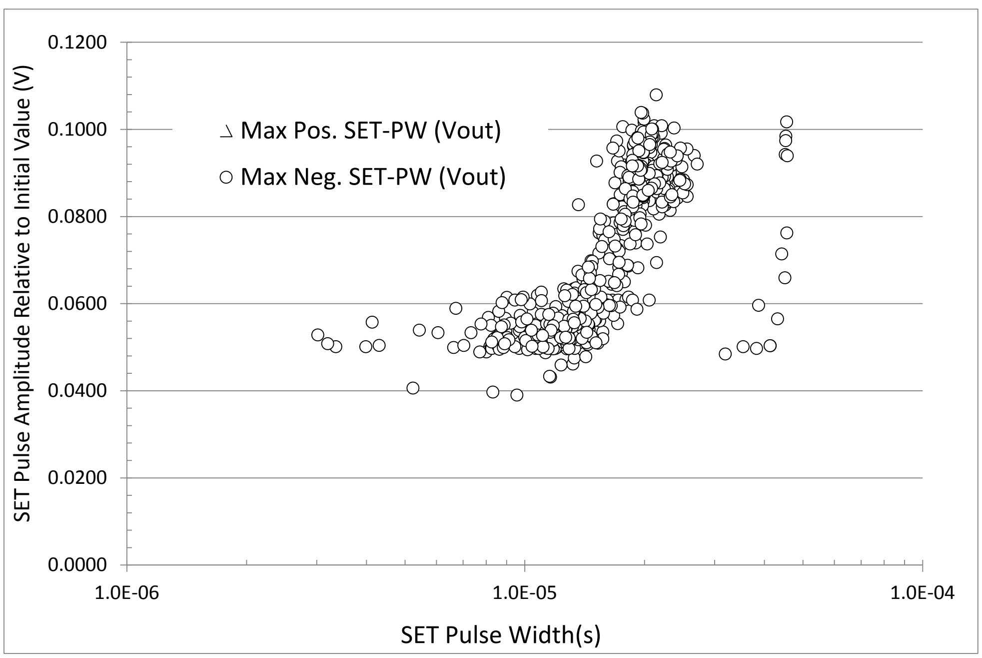


Fig. 11: % SET Pulse-Amplitudes vs. SET Pulse-Widths
Runs# (30, 33, 41, 42); Vin=30V, Vout=15V, Iout=1A; Room Temp.; Xenon Ions with LET=58.78 MeV.cm^2/mg

Furthermore, and as shown in Fig. 12, in all run heavy-ions beam experiments, the SET cross-sections varied with the input/output voltages and the load current as well as with the used LETs. Application specific parameters control the DUT power dissipation and hence its junction temperature. It is expected that the SET cross section will vary accordingly.

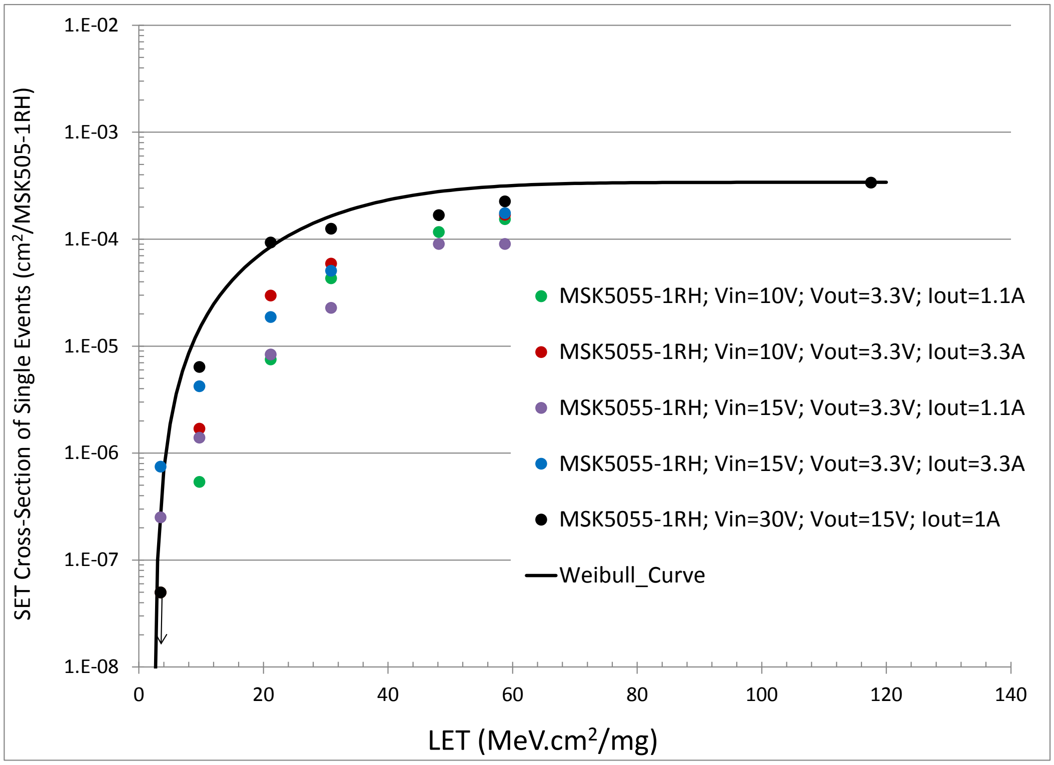


Fig. 12: Measured in-beam SET Cross-Sections vs. LET

4.2 Beam Test Results with Vin equal or greater than 40V

For heavy-ions tests with input voltage greater or equal to 40V, three DUTs have been used and were beam-damaged. The parts could not provide the output voltage after this detected destructive event. Visual inspection revealed that the VIN and SGND bond wires had fused on two of the three failed devices. The third device shows signs of thermal stress in the area near the VIN and SGND bond pads. Figures 15 and 16 both exhibit a sharp transient input current spike. This evidence suggests SEL occurred on the input side of the controller die. For applications operating above 30V, a simple voltage dropping network connected to the VIN pin may be sufficient to preclude destructive SEL and would have negligible impact on performance. Table 3 summarizes the test conditions in which this radiation effect happened. For instance, in the case where the input voltage was set at 60V (Run 4), in addition to the negative SETs, two consecutive positive SETs were also observed, after which the output voltage dropped permanently from 14.8V to 14.34V. Fig. 13 (Waveform 3) and Fig. 14 (Waveform 4) display the two SET shapes captured by the scope consecutively.

Table 3: Beam Bias Test Conditions during the Destructive Events

Under Xenon Ions, LET (0˚) = 58.78 MeV.cm²/mg

Run#	LET (MeV.cm²/mg)	V_{IN} (V)	V_{OUT} (V)	I_{OUT} (V)	Observed Destructive Effect
4-DUT1	58.78	60	15	1	Fig. 13: V_{OUT} dropped permanently from 14.76V to 14.34V
32-DUT2	58.78	40	15	1	Fig. 15: Input Current dropped from 421mA to about 10mA

46-DUT3	117.6	50	15	1	Fig. 16: Input Current dropped from 346mA to about 2mA

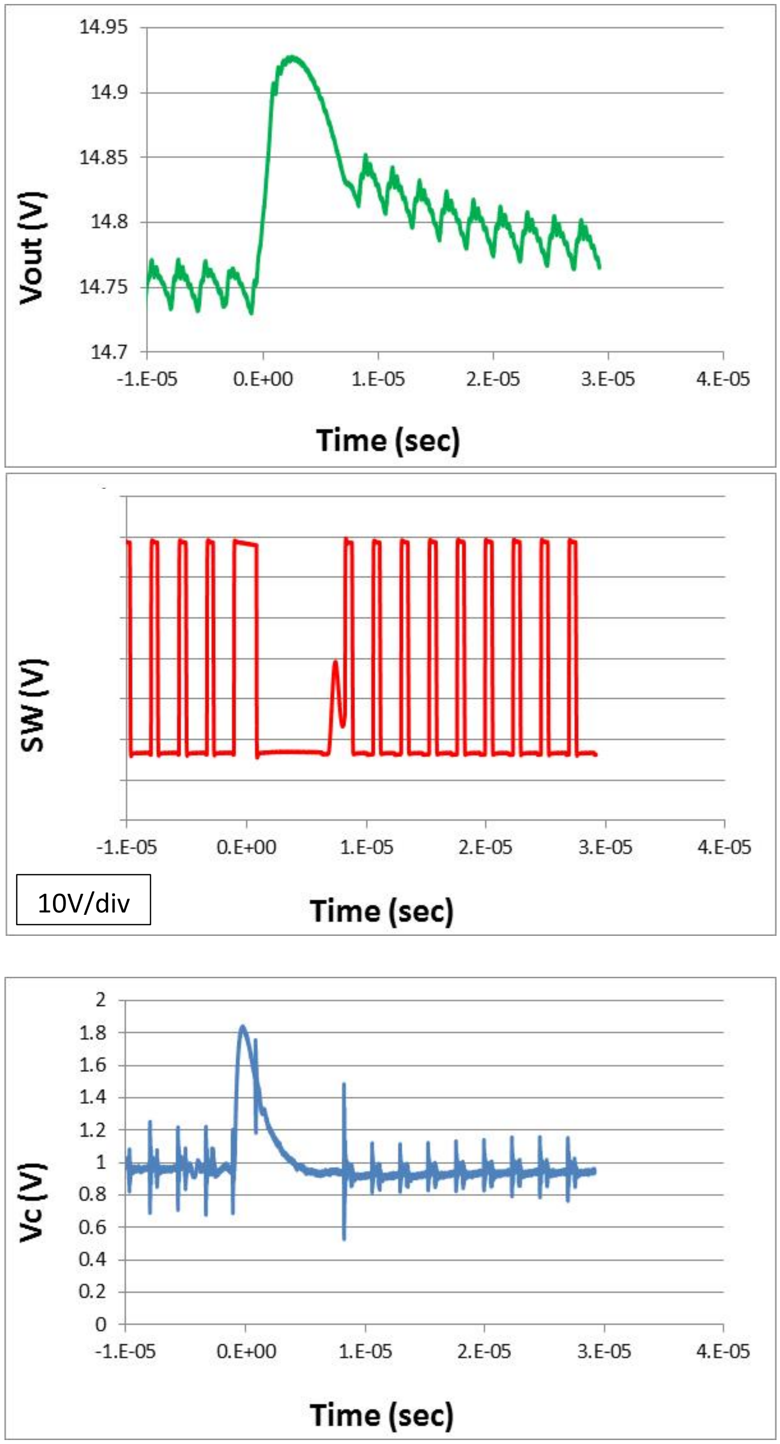


Fig. 13: Positive SET Pulse vs. Beam Time on V_{OUT}, SW and V_C signals, respectively. Run 4, Wfr. #3

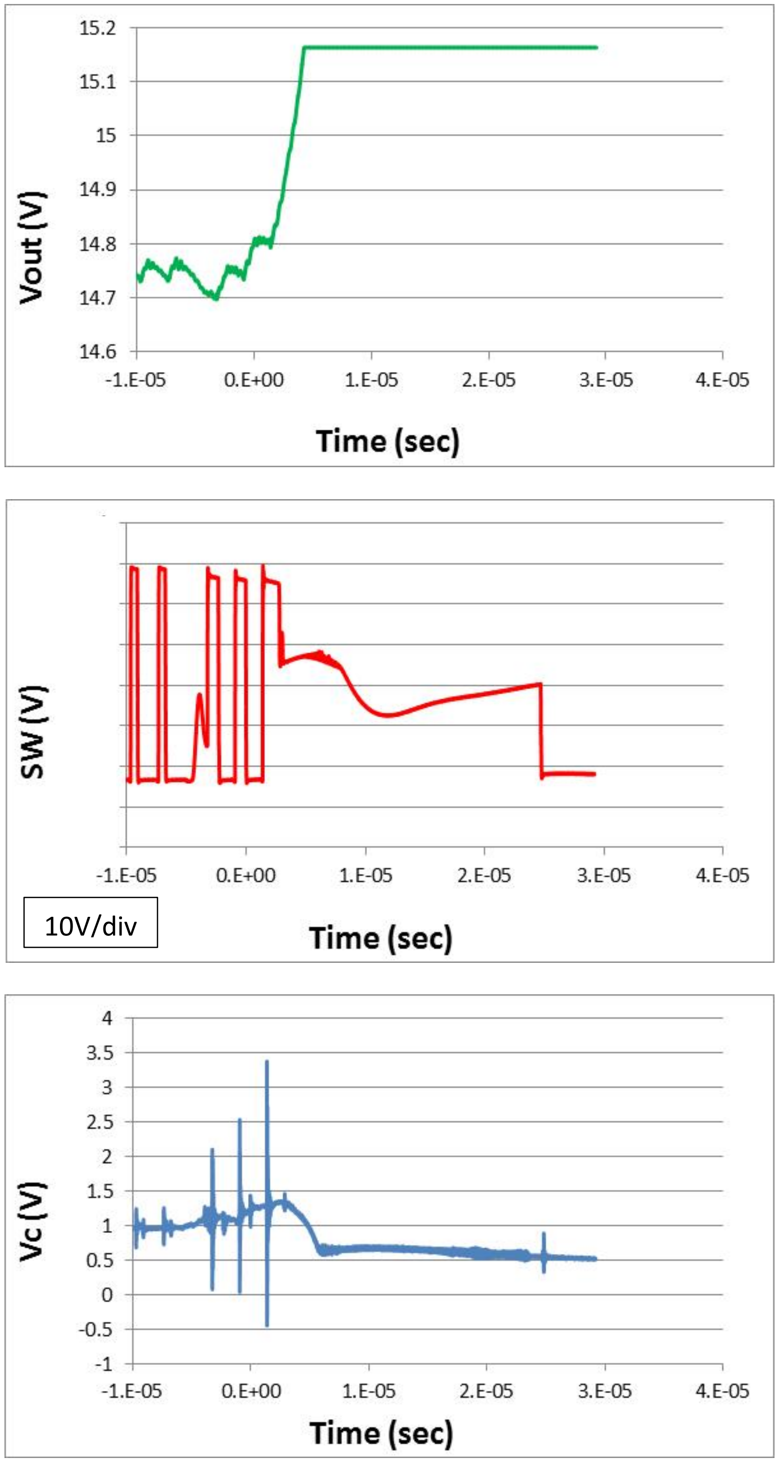


Fig. 14: Positive SET Pulse vs. Beam Time on V_{OUT}, SW and V_C signals, respectively. Run 32

Furthermore, Fig. 15 and Fig. 16 show the input current and the sensed input voltage versus beam time at the time of the destructive event occurrence, with V_{IN}=40V and with V_{IN}=50V, respectively. In the case of an input supply voltage of 40V, the input voltage dropped to 30V, and the input current increased from

0.421A to 5.52A. For an input supply voltage of 50V, the input voltage dropped to 37V and the input current increased from 0.346A to 2.74A.

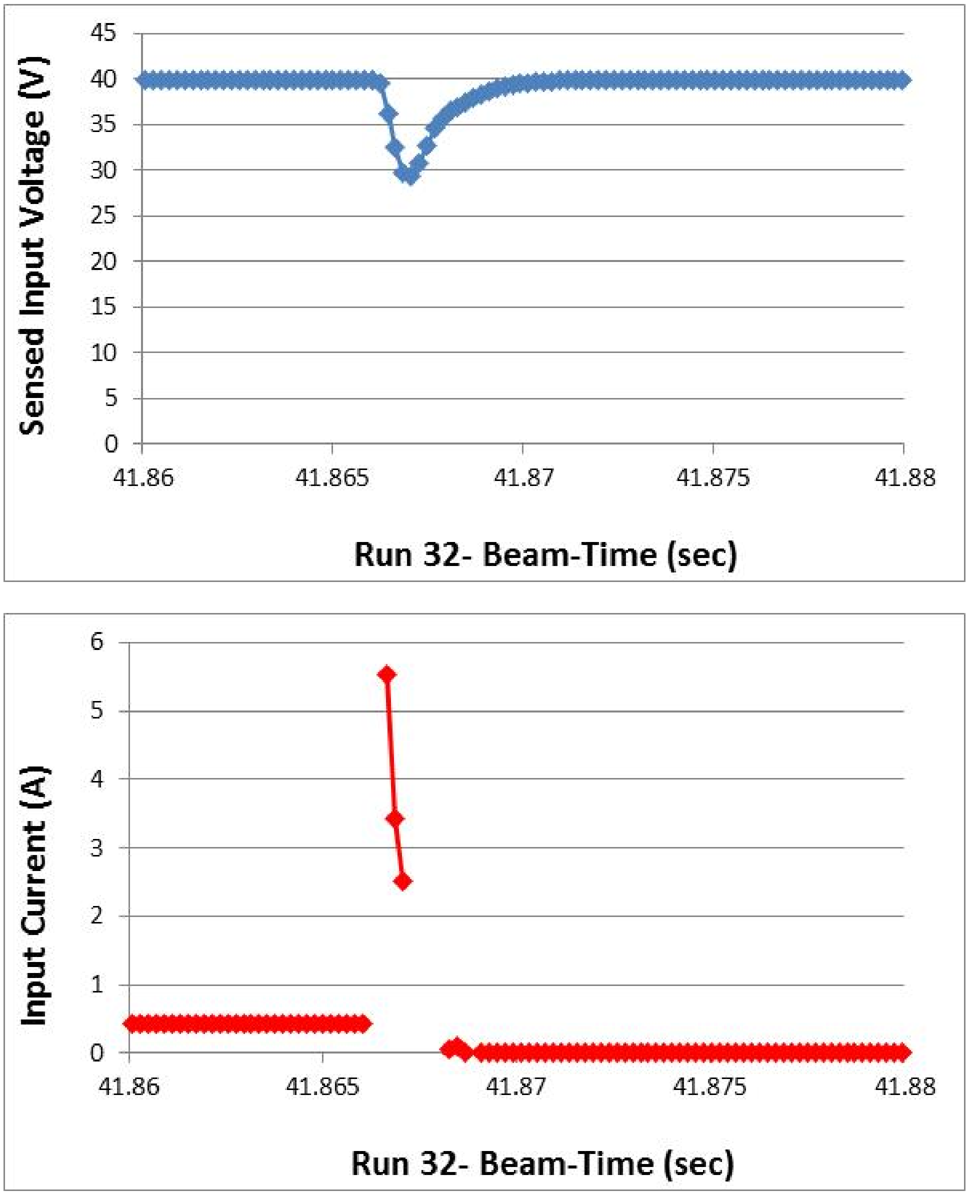
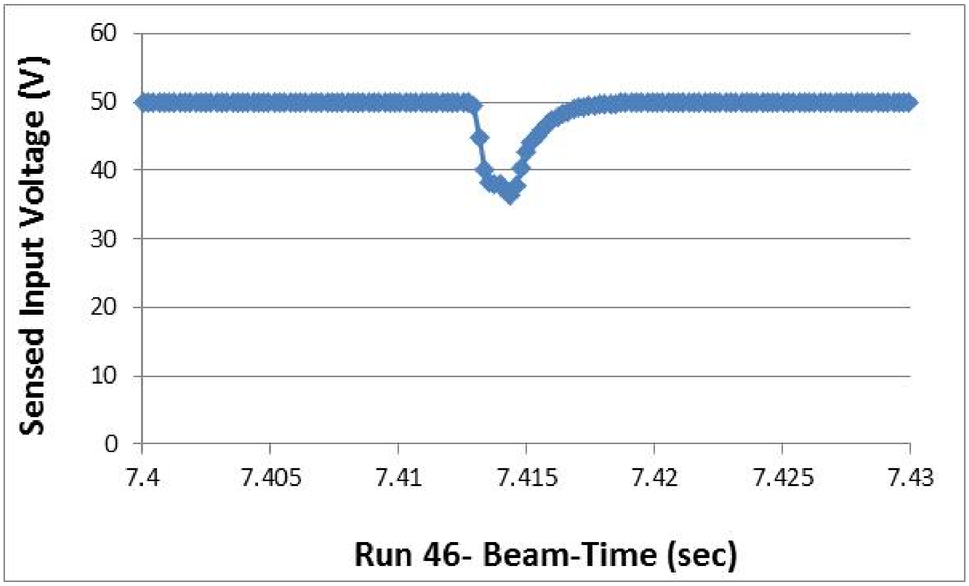


Fig. 15: Representation of the Sensed Controller Input Voltage and Input Current (w/o user intervention) during the Destructive Event vs. Beam Time, Run 32

V_{IN}=40V, I_{IN}=0.421A; V_{OUT}=15V; I_{OUT}=1A, Room Temperature (Vacuum)



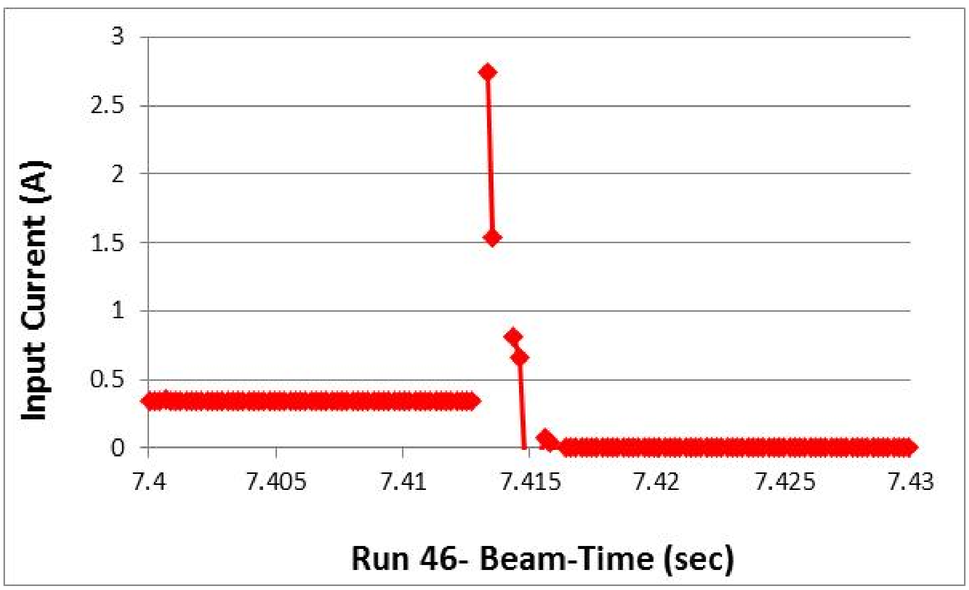


Fig. 16: Representation of the Sensed Controller Input Voltage and Input Current during the Destructive Event vs. Beam Time, Run 46

V_{IN}=50V, I_{IN}=0.346A; V_{OUT}=15V; I_{OUT}=1A, Case Temp=100C

4.3 Weibull Parameters for Orbital Error-Rates Calculations

Fig. 12 shows the SET cross-sections at different test bias conditions and the Weibull curve, which fitting parameters are provided in Table 4, as demonstrated in Eq. 4. Customers may use these parameters to determine the MSK5055-1RH orbital error rates in their space flight designs.

Table 4: Weibull Parameters Used for the MSK5055-1RH SEE Cross-Section and the Calculation of Orbital Error Rates

L_0	W	S	σ_0
(MeV / mg-cm^2)	(MeV / mg-cm^2)		(cm^2)
2.4	35	2	3.4x 10^{-4}

$$\sigma = \sigma_0 \left[1 - e^{-((L-L_0)/W)^S}\right] \qquad (4)$$

In summary, under heavy-ion irradiations, and at input voltages equal or less than 30V, the MSK5055-1RH showed sensitivities only to SETs. The measured underlying SET sensitive cross-section (all events added) is about 3.4x10^{-4} cm^2 (about 4% of the physical die cross-section), while the threshold LET is about 2.4 MeV.cm^2/mg.

4.4 SEL Immunity at Hot (100°C) (at 30V Input Voltage, 15 V Output Voltage and 1A Output Current)

The SEL tests were run at output voltage of 15V, load current of 1A and at various input voltages 30V, 40V and 50V. In the former two bias test conditions (30V (Runs 43-44) and 40V (Run 45)), at high temperature (100°C) at the DUT case, the DUT did not exhibit any sensitivity to SELs up to an LET of 117.6 MeV.cm^2/mg (red dot with arrow pointing down in Fig. 17). The SET cross-sections at 30V input voltage at hot are shown in black dots. However, destructive event has been seen at 50V (Run 46) at low Xenon fluence (10^7 particles/cm^2) with LET of 117.6 MeV.cm^2/mg.

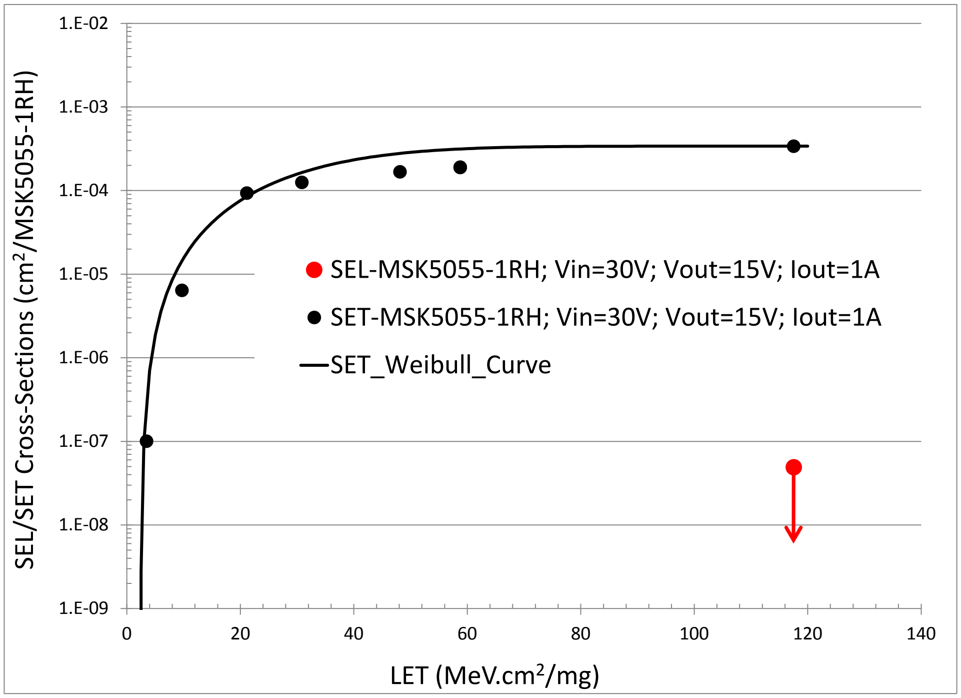


Fig. 17: Measured SEL Cross-Sections vs. LET, showing the MSK5055-1RH immunity to Destructive Events including SELs at VIN=30V, VOUT=15V, IOUT=1A

Arrows pointing down are indication of no observed SETs up to that fluence at tested LET

Table 5: Raw Data for the Heavy-Ion Beam Runs

Run	DUT	Tc (Vacuum)	Vin	Vout	Iout	Ion	Total Effective Fluence	Average Flux	Maximum Flux	Tilt Angle	Eff. LET	TID (Run)	TID (Cum.)	SET	Dest. Event	SET-XS	XS-SET
#	#	C	(V)	(V)	(A)		p/cm2	p/sec/cm2	p/sec/cm2	Degrees	MeV.cm2/mg	rads(Si)	rads(Si)			cm^2/DUT	cm2/DUT
1	1	24	30	15.0	1	Xe 58.78	1.05E+05	3.36E+02	1.70E+03	0	58.8	9.88E+01	9.88E+01	178	0	1.70E-03	1.70E-03
2	1	24	30	15.0	1	Xe 58.78	7.57E+04	3.62E+02	4.69E+02	0	58.8	7.12E+01	1.70E+02	107	0	1.41E-03	1.41E-03
3	1	24	50	15.0	1	Xe 58.78	1.69E+05	3.61E+02	4.83E+02	0	58.8	1.59E+02	3.29E+02	170	0	1.01E-03	1.01E-03
4	1	24	60	15.0	1	Xe 58.78	1.10E+04	1.12E+02	4.67E+02	0	58.8	1.03E+01	3.41E+02	4	1	3.64E-04	3.64E-04
5	2	24.5	10	3.3	1.1	Xe 58.78	6.98E+05	7.07E+02	2.56E+03	-0.1	58.8	6.56E+02	6.56E+02	119	0	1.70E-04	1.70E-04
6	2	24.5	10	3.3	1.1	Xe 58.78	7.72E+05	2.51E+03	3.08E+03	-0.1	58.8	7.26E+02	1.38E+03	107	0	1.39E-04	1.39E-04
7	2	27	15	3.3	1.1	Xe 58.78	1.00E+06	2.26E+03	2.94E+03	-0.1	58.8	9.40E+02	2.32E+03	90	0	9.00E-05	9.00E-05
8	2	27	15	3.3	1.1	Ag 48.15	1.00E+06	3.98E+03	6.54E+03	-0.1	48.2	7.70E+02	3.09E+03	90	0	9.00E-05	9.00E-05
9	2	27	10	3.3	1.1	Ag 48.15	9.55E+05	4.18E+03	1.08E+04	-0.1	48.2	7.36E+02	3.83E+03	111	0	1.16E-04	1.16E-04
10	2	27	10	3.3	1.1	Kr 30.86	2.00E+06	5.01E+03	2.09E+04	-0.1	30.9	9.88E+02	4.82E+03	86	0	4.30E-05	4.30E-05
11	2	27	15	3.3	1.1	Kr 30.86	5.40E+06	5.20E+03	7.73E+03	-0.1	30.9	2.67E+03	7.48E+03	123	0	2.28E-05	2.28E-05
12	2	27	15	3.3	1.1	Cu 21.17	7.01E+06	1.48E+04	1.99E+04	-0.1	21.2	2.37E+03	9.86E+03	64	0	9.13E-06	9.13E-06
13	2	27	15	3.3	1.1	Cu 21.17	1.00E+07	1.83E+04	1.06E+05	-0.1	21.2	3.39E+03	1.32E+04	78	0	7.80E-06	7.80E-06
14	2	27	10	3.3	1.1	Cu 21.17	1.00E+07	5.52E+04	6.68E+04	-0.1	21.2	3.39E+03	1.66E+04	75	0	7.50E-06	7.50E-06
15	2	27	10	3.3	1.1	Ar 9.74	2.05E+07	3.18E+05	7.45E+05	-0.1	9.7	3.19E+03	1.98E+04	11	0	5.37E-07	5.37E-07
16	2	27	15	3.3	1.1	Ar 9.74	2.01E+07	5.20E+04	1.10E+05	-0.1	9.7	3.13E+03	2.30E+04	28	0	1.39E-06	1.39E-06
17	2	27	15	3.3	1.1	Ne 3.49	2.00E+07	5.61E+04	6.49E+04	-0.1	3.5	1.12E+03	2.41E+04	5	0	2.50E-07	2.50E-07
18	2	27	10	3.3	1.1	Ne 3.49	2.01E+07	6.33E+04	7.49E+04	-0.1	3.5	1.12E+03	2.52E+04	0	0	4.98E-08	4.98E-08
19	2	27	10	3.3	3.3	Ne 3.49	4.06E+06	4.47E+04	8.31E+04	-0.1	3.5	2.27E+02	2.54E+04	Invalid Run			
20	2	27	10	3.3	3.3	Ne 3.49	2.01E+07	8.28E+04	8.56E+04	-0.1	3.5	1.12E+03	2.65E+04	0	0	4.98E-08	4.98E-08
21	2	27	15	3.3	3.3	Ne 3.49	2.01E+07	8.28E+04	8.62E+04	-0.1	3.5	1.12E+03	2.77E+04	15	0	7.46E-07	7.46E-07
22	2	27	15	3.3	3.3	Ar 9.74	2.00E+07	3.40E+04	5.95E+04	-0.1	9.7	3.12E+03	3.08E+04	84	0	4.20E-06	4.20E-06
23	2	27	10	3.3	3.3	Ar 9.74	2.01E+07	3.80E+04	8.56E+04	-0.1	9.7	3.13E+03	3.39E+04	34	0	1.69E-06	1.69E-06
24	2	27	10	3.3	3.3	Cu 21.17	4.01E+06	6.09E+03	4.52E+04	-0.1	21.2	1.36E+03	3.53E+04	119	0	2.97E-05	2.97E-05
25	2	27	15	3.3	3.3	Cu 21.17	4.01E+06	1.18E+04	1.34E+04	-0.1	21.2	1.36E+03	3.66E+04	75	0	1.87E-05	1.87E-05
26	2	27	15	3.3	3.3	Kr 30.86	2.18E+06	4.92E+03	1.18E+04	-0.1	30.9	1.08E+03	3.77E+04	110	0	5.05E-05	5.05E-05
27	2	27	10	3.3	3.3	Kr 30.86	2.00E+06	4.97E+03	5.91E+03	-0.1	30.9	9.88E+02	3.87E+04	118	0	5.90E-05	5.90E-05

Run	DUT	Tc (Vacuum)	Vin	Vout	Iout	Ion	Total Effective Fluence	Average Flux	Maximum Flux	Tilt Angle	Eff. LET	TID (Run)	TID (Cum.)	SET	Dest. Event	SET-XS	XS-SET
#	#	C	(V)	(V)	(A)		p/cm2	p/sec/cm2	p/sec/cm2	Degrees	MeV.cm2/mg	rads(Si)	rads(Si)	#	#	cm^2/DUT	cm2/DUT
28	2	27	10	3.3	3.3	Xe 58.78	7.89E+05	1.05E+03	2.99E+03	-0.1	58.8	7.42E+02	3.94E+04	133	0	1.69E-04	1.69E-04
29	2	27	15	3.3	3.3	Xe 58.78	6.28E+05	6.88E+02	1.64E+03	-0.1	58.8	5.91E+02	4.00E+04	110	0	1.75E-04	1.75E-04
30	2	27	30	15.0	1	Xe 58.78	4.00E+05	3.10E+03	9.17E+03	0.5	58.8	3.76E+02	4.04E+04	157	0	3.93E-04	3.93E-04
31	2	27	30	15.0	1	Xe 58.78	1.01E+06	7.11E+03	8.66E+03	0.5	58.8	9.50E+02	4.14E+04	29	0	2.87E-05	2.87E-05
32	2	27	40	15.0	1	Xe 58.78	1.04E+05	6.82E+03	1.48E+04	0.5	58.8	9.78E+01	4.14E+04		1		
33	3	27	30	15.0	1	Xe 58.78	9.37E+05	3.67E+03	4.13E+03	-0.1	58.8	8.81E+02	8.81E+02	176	0	1.88E-04	1.88E-04
34	3	27	30	15.0	1	Ag 48.15	6.40E+05	1.06E+03	2.25E+04	-0.1	48.2	4.93E+02	1.37E+03	107	0	1.67E-04	1.67E-04
35	3	27	30	15.0	1	Kr 30.86	1.00E+06	4.54E+03	5.40E+03	-0.1	30.9	4.94E+02	1.87E+03	125	0	1.25E-04	1.25E-04
36	3	27	30	15.0	1	Cu 21.17	1.98E+06	8.46E+03	2.20E+04	-0.1	21.2	6.71E+02	2.54E+03	184	0	9.29E-05	9.29E-05
37	3	42	30	15.0	1	Ar 9.74	5.03E+06	2.43E+04	3.71E+04	-0.1	9.7	7.84E+02	3.32E+03	32	0	6.36E-06	6.36E-06
38	3	42	30	15.0	1	Ne 3.49	1.01E+07	9.49E+04	1.44E+05	-0.1	3.5	5.64E+02	3.89E+03	0	0	9.90E-08	9.90E-08
39	3	74.5	30	15.0	3	Ne 3.49	6.20E+06	2.94E+04	3.52E+04	-0.1	3.5	3.46E+02	4.23E+03	135	0	2.18E-05	2.18E-05
40	3	39.5	30	15.0	1	Ne 3.49	1.00E+07	3.79E+04	4.27E+04	-0.1	3.5	5.58E+02	4.79E+03	0	0	1.00E-07	1.00E-07
41	3	39.5	30	15.0	1	Xe 58.78	9.01E+05	2.64E+03	4.10E+03	-0.1	58.8	8.47E+02	5.64E+03	171	0	1.90E-04	1.90E-04
42	3	44.5	30	15.0	1	Xe 58.78	3.17E+05	8.75E+02	1.72E+04	60	117.6	5.96E+02	6.23E+03	107	0	3.38E-04	3.38E-04
43	3	99.5	30	15.0	1	Xe 58.78	1.02E+07	2.38E+05	5.82E+05	60	117.6	1.92E+04	2.54E+04	131	0	1.28E-05	1.28E-05
44	3	99.5	30	15.0	1	Xe 58.78	1.02E+07	5.40E+05	5.51E+05	60	117.6	1.92E+04	4.46E+04	65	0	6.37E-06	6.37E-06
45	3	99.5	40	15.0	1	Xe 58.78	1.02E+07	5.99E+05	6.10E+05	60	117.6	1.92E+04	6.38E+04	58	0	5.69E-06	5.69E-06
46	3	99.5	50	15.0	1	Xe 58.78	5.25E+05	5.82E+05	5.16E+05	60	117.6	9.88E+02	8.30E+04	1	1	1.90E-06	1.90E-06

*Tb is the temperature sensed by the transistor on the board (as shown in Fig. 5); Energy Cocktail = 10MeV/nucleon

References:

[1] RH3845MKDICE Landing Page: http://www.linear.com/product/RH3845MK

[2] LT3845 Landing Page: http://www.linear.com/product/LT3845

[3] MSK5055RH Landing Page: http://mskennedy.com/products/Switching-Regulators/MSK5055RH.prod

[3.1] DLA SMD# 5962-14223 link: http://www.landandmaritime.dla.mil/Downloads/MilSpec/Smd/14223.pdf

[4] LTSpice: http://www.linear.com/designtools/software/#LTspice

[5] MSK5063RH SEE test report,