Heavy-Ion Test Results of the Radiation-Hardened Adjustable 2.8A Single Resistor Low Dropout Regulator RH3083MK

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Executive Summary

This report summarized the heavy-ion test experiments performed on the RH3083MK [1] at the Lawrence Berkeley National Labs (LBNL). The RH3083MK is a 2.8A Low Dropout linear regulator with a unique architecture [1, 2] featuring a precision current source and voltage follower which allows the output to be programmed to any voltage between 0V and 36V, with a single-resistor. The wafer lots are processed to Linear Technology's in house Class S flow to yield circuits usable in stringent military and space applications. Heavy-ions 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 117.5 MeV.cm^2/mg at room temp and at elevated temperatures (to case temperatures of 100°C.) Under various test conditions, the RH3083MK showed sensitivities only to SETs. This heavy ion beam experiment confirmed the immunity of RH3083MK to destructive SEE up to a LET of 58.78 MeV·cm^2/mg under the tested conditions. The measured SET sensitive saturation cross-section is about 9E-4 cm^2, about 1.8% of the total die's cross-section, while the SET threshold LET was about 3 MeV.cm^2/mg. Note that the RH3083MK SET sensitive cross-section is very similar to the RH3080MK [3], as they share very similar reference circuitry.

The beam data showed that up to an LET of 58.78 MeV·cm^2/mg, the Vout and SET pin transient pulse widths were less than 200 µs and 95% of the time was less than 20 µs. The amplitude of the transient pulse for the set pin was between -0.4V and +0.2V and the amplitude of the Vout pin was between -0.1V and 0.2V.

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 RH3083MK at the Lawrence Berkeley National Labs (LBNL). The RH3083MK is a 2.8A Low Dropout linear regulator with a unique architecture featuring a precision current source and voltage follower which allows the output to be programmed to any voltage between 0Vand 36V, with a single-resistor. Multiple regulators can be used in parallel to increase the total output current and sufficiently dissipate heat without a heat sinking. The pass transistor collector can be brought out independently of the circuit supply voltage to allow dropout voltage to approach the saturation limit of the pass transistor. A small 2.2μF capacitor on the output with an ESR of less than 0.5Ω is adequate to insure stability. Applications with large output load transients require a larger output capacitor value to minimize output voltage change. Input circuitry insures output safe operating area current limiting and thermal shutdown protection. The rated output current of an RH3083-based part is fixed by internal wire length/resistance. Linear Technology dice element evaluations are based on parts rated for 2.8A output current. The wafer lots are processed to Linear Technology's in house Class S flow to yield circuits usable in stringent military and space applications.

The device is qualified and available in TO3-4 Leads (K) hermetically sealed package. More details are given about this RH-LDO in [1]. This is a 1.5um technology using exclusively bipolar transistors. The part’s block diagram is shown in Fig. 1. The K package designation is given in Fig. 2.

Absolute Maximum Ratings

(Note 1) (All voltages relative to VOUT)

VCONTROL Pin Voltage	28V
IN Pin Voltage	18V, –0.3V
No Overload or Short-Circuit	23V, –0.3V
SET Pin Current (Note 3)	25mA
SET Pin Voltage (relative to VOUT, Note 3)	10V
Output Short-Circuit Duration	Indefinite
Operating Junction Temperature Range (Note 2, 4)	–55°C to 125°C
Storage Temperature Range	–65°C to 150°C

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 and lifetime.
Note 2: Unless otherwise specified, all voltages are with respect to VOUT. The RH3083MK DICE is tested and specified under pulse load conditions such that TJ ≅ TA.
Note 3: The SET pin is clamped to the output with diodes through 1k resistors. These resistors and diodes only carry current under transient overloads.
Note 4: This IC includes over-temperature protection that is intended to protect the device during momentary overload conditions. Junction temperature exceeds the maximum operating junction temperature when over-temperature protection is active. Continuous operation above the specified maximum operating junction temperature may impair device reliability.

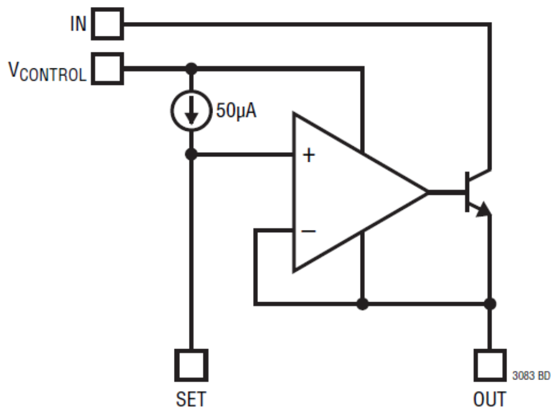

Figure 1: Block Diagram of the RH3083M DIE

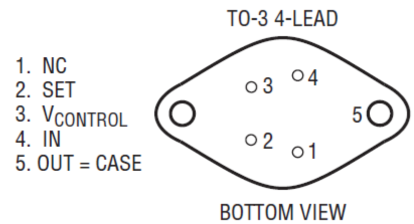

Figure 2: RH3083M in K Package

Third Party Vendor Availability

Linear Technology partners with third party vendors who assemble and test packaged products with LTC RH Dice inside are listed in Table 1. Table 2 summarizes the part features and the electrical test apparatus.

Table 1: MS Kennedy and Aeroflex Parts' Availabilities

Part Number	Description
MSK5983RH	2.8A Adjustable, LDO Regulator, Split Bias, 16 PIN FLATPACK
MSK5984RH	2.8A Adjustable Positive LDO Regulator, 3 PIN POWER TOP TAB
MSK5985RH	2.8A Adjustable Positive LDO Regulator, 5 PIN POWER TOP TAB
MSK5986RH	2.8A Adjustable Positive LDO Regulator, 3 PIN Ceramic Power SMD
VRG8697/VRG8698	Dual 3A Adjustable Positive Ultra Low Dropout LDO Regulator, Split Bias
VRG8669	3A Adjustable Positive Ultra Low Dropout LDO Regulator, Split Bias

Table 2: RH3083MK Test and Part Information

Generic Part Number	RH3083MK
Package Marking	RH3083MK Fabrication Lot: HP201494.1, Wfr#2
Manufacturer	Linear Technology
Quantity tested	2
Dice Dimension	66 mils x 113 mils≈ 4.81 mm^2
Part Function	Radiation-Hardened Adjustable 2.8A Single Resistor Low Dropout Regulator
Part Technology	RHBIPC150 (1.5um)
Package Style	Hermetically sealed TO3-4Leads (K)
Test Equipment	Power supply, oscilloscope, multimeter, 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 Linear Technology team. The RH3083MK parts were tested at LBNL on April 2014 at two different temperatures; at room temperature and at 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 (RH3083MK) with open-top (K package de-capped)
- The input (C2) and output (C5) filtering ceramic capacitors with 10uF each
- All capacitors were not populated except for C2, and C5, as they are needed to insure the stability of the LDO [2]. Although it is recommended to add 0.1uF on the SET pin, C4 was not used in order to preserve the true SET events on the SET pin output. In this configuration, the transient seen at Vout is a direct product of the ion strike effect on the error amplifier, with minimum filtering at the input of the unity gain error amp (SET pin.) For that reason, transients on the SET pin were sharper and shorter than on the output signal (V_{OUT}) which has a 10uF at its output.
- The scope termination is set at 1MOhms.
- The 2N3904 bipolar transistor to sense the board's temperature, placed as close as possible to the DUT.

Fig. 3 shows the SEE test board schematics. The picture of this board is given in Fig. 4.

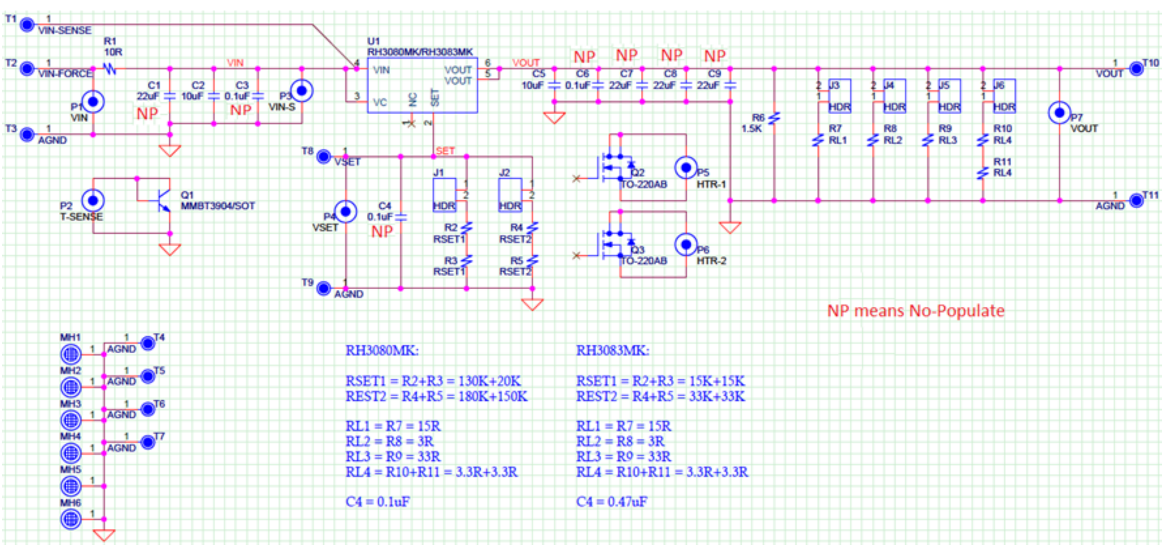

Figure 3: Block Diagram of the RH3083MK SEE Test Board*

*Note that the same board with changes to some of the passive elements (R_{SET}) was also used to test the 0.9A-RH-LDO RH3080MK to SEEs under heavy-ions. Hence, the labeling referring to the RH3080MK part on the SEE board.

The SEE tests were run with V_{OUT} = 1.5V, with R_{SET} = RH3083MK-R_{SET1} = 30 KOhms and with various output loads, Iout=0.1A (R_{Load} = 15 Ohms), 0.5A (R_{Load} = 3 Ohms), and 1.5A (R_{Load} = 1 Ohm, 2 Watts).

Four input voltage V_{IN} bias conditions have been applied during beam tests, 3.3V, 5V, 10V, and 16V. All radiation test results are provided in Table 5.

Note that for the beam runs with V_{IN} equal to 16V, V_{OUT} set at 1.5V, and I_{OUT} set at 1.5A, the high power dissipation in the vacuum caused the raise of the DUT to exceed the thermal shutdown temperature. The data generated with this condition was considered unreliable. Despite the attempts to cool the DUT with the cooling plate provided at LBNL. The SETs generated by such condition was believed to be magnified by the thermal effect, rather than the ion strike effect. These SETs should be smaller in space environment, if adequate cooling mechanisms are employed.

The test setup is connected with two 3 feet long BNC cables to two Agilent power supplies (PS) (N6705B) and to a LeCroy Oscilloscope (Waverunner HRO 66Zi, 600 MHz, 2 GS/s) with extended monitor/cables to view the SET and the V_{OUT} output signals. The first PS supplies the input voltages to the SEE test board and allows the automated logging and storage every 1 ms of the current input supplies (Iin), as well as the automation of power-cycles after the detection of a current spike on the input current that exceeds the current limit set by the user. The second PS is used for sensing the voltages of the input power supplies. This was done to avoid any interference from the power supplies that might cause widening of the transients upon the occurrence of an SET.

The SET signal and VOUT output signals were connected each to a scope channel with 3 feet BNC cable (vacuum chamber feed-through) and a scope probe of 11pF. For better accuracy, the equivalent capacitive load of the BNC cable and the scope probe should be calculated and accounted for, as it might affect the SET pulse width and shape. In this case, the cables' capacitive load was about 120pF. The scope was set with 1MOhms termination.

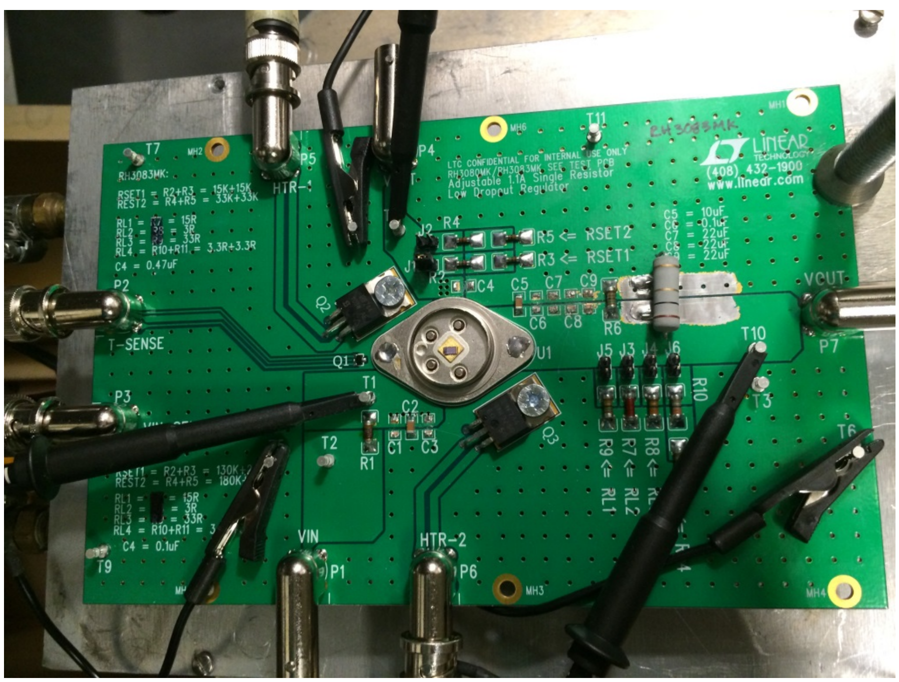

Figure 4a) Photograph of the RH3083MK SEE test board showing the exposed die. The cooling plated ended up not helping to dissipate heat due to a failing thermal conductive path from the test board to the cooling plate

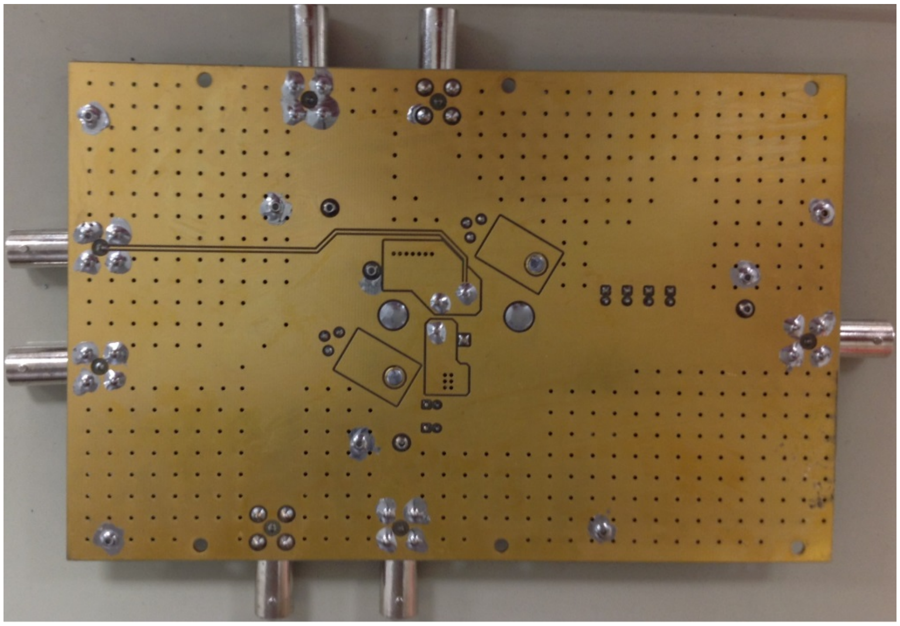

Figure 4b: Photograph of the bottom side of SEE test board showing the high number of Thermal Vias that were added to dissipate the heat through Conduction in the Heavy-Ion Vacuum Cell

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 that the flux is adjusted so that one error-event can fully dissipated before another event can form.

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-ions SEE experiments included SET, SEU and SEL tests up to a Linear Energy Transfer (LET) of 117 MeV.cm^2/mg at elevated temperatures (to case temperatures of 100°C). In 111 runs, the RH3083MK parts were irradiated with a fixed output voltage bias (1.5V.) The various bias conditions consist of a load resistor (depended on Iout selected) and a set of input supply bias points between 3.3 and 16V, as shown in Table 3. As this is a floating LDO, the differential input to output bias voltage (Vin-Vout) is the most important parameter. Extra care was taken to best select the bias test conditions (the differential voltage

(Vin-Vout) and the output load current (Iout)) to not to exceed the current limit value during all beam experiments (Fig. 5.) Note that other factors should be considered in these calculations, such as:

1. Poor cooling mechanism in-beam allowing heating of the part which will increase the DUT current consumption.
2. SETs that may cause the typical (off-beam) current to exceed current limit in-beam. As an example, during the beam experiments with 14.5 V differential voltage and 1.5A load current, we did exceed the current limit a few times at high LETs, with none of these events being destructive. This effect was the result of a combination of the DUT heating and the SETs. This type of events require power-cycling to resume operation.

Table 5 shows the raw data for all beam runs. No destructive event was observed during all tests; all events were transients (SET), with various amplitudes and pulse widths that depended on the LET. The SET cross-sections were independent of the input to output differential voltage in all run heavy-ions beam experiments. They were slightly dependent on the load current, which is mostly due to the increased power dissipation (thermal effect on the DUT). For the integrity of this experiment, higher load currents were applied to a set of runs. With this worst case conditions, no destructive event was observed.

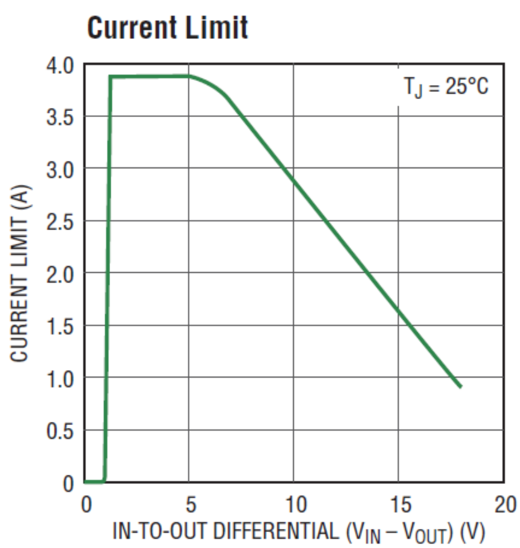

Figure 5: LT3083 Current Limit, extracted from LT3083 datasheet, Typical Performance Characteristics, page 6*

Table 3: RH3083MK Bias Test Conditions (Bias, Input, and Output Voltage and Load Currents)

RH-LDO Output Voltage (Vout)	1.5V
Output Load Current (A) / RH-LDO Load Resistor	0.1A / 15 Ohms, 0.5A / 3 Ohms, 1.5A / 1 Ohm (1 Watt)
RH-LDO Input Voltage	3.3V, 5V, 10V and 16V

The SET pulse width on the DUT output is the sum of the prompt effect from the injected SET and the DUT response time to the event. The SET amplitude will vary with the injected charge (eq. to LET) and its diffusion in the bombarded transistor and adjacent transistors to it. Most observed SETs started at the SET output and then propagated to the V_{OUT} output signal.

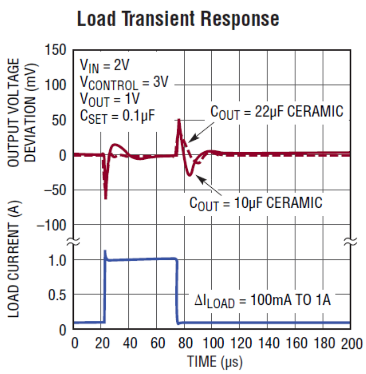

Fig. 6: Load Transient Response vs. Settling Time

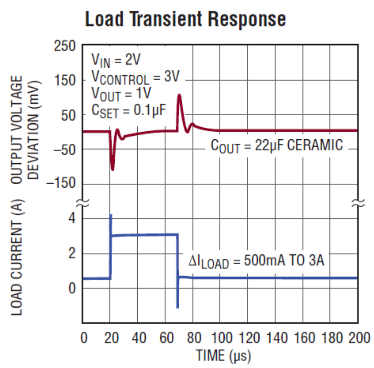

Fig. 7: Load Transient Response vs. Settling Time

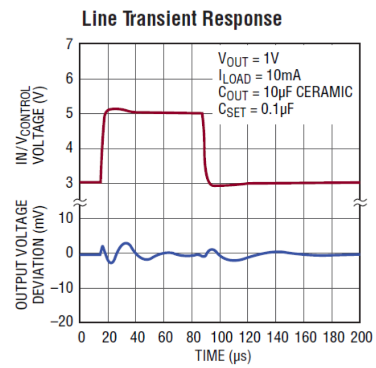

Fig. 8: Line Transient Response Time vs. Settling Time

Figs. 6, 7 and 8, have been extracted from the Typical Performance Characteristics of the LT3083 datasheet, pg. 7.

For SET detection, the scope was set to trigger on positive and negative SETs as a result of a change in the SET, V_{OUT}, and V_{IN} signals exceeding +/-20 mV (+/-1.3%). The pulse widths were calculated based on these levels as well. Therefore, 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 request.

Most of the Single Event Transients started at the SET output with a negative transient pulse (smaller than 44 microseconds in all cases), and remained negative (Fig. 9) or were followed with a positive pulse (Fig. 10.) Transients on the SET circuitry affected the V_{OUT} output signal in three different ways:

1) negative transient (Fig. 9)

2) negative and then positive transient on the V_{OUT} signal (Fig. 10 to 12)

3) Positive and then negative transient on the V_{OUT} signal (Fig. 13)

Although transient pulse is wider due to filtering capacitor (10uF) at the output signal, most of the transients on the SET signal were small in amplitudes (less than 200mV positive transients and less than 400mV negative transients). On the V_{OUT} output signal, the positive transients were smaller than 400mV and the negative ones smaller than 400mV, within ±12% of the nominal output signal. Additionally, when all beam runs are taken into account, 90% of them with the amplitude smaller than 10% (150mV) of the output V_{OUT} signal.

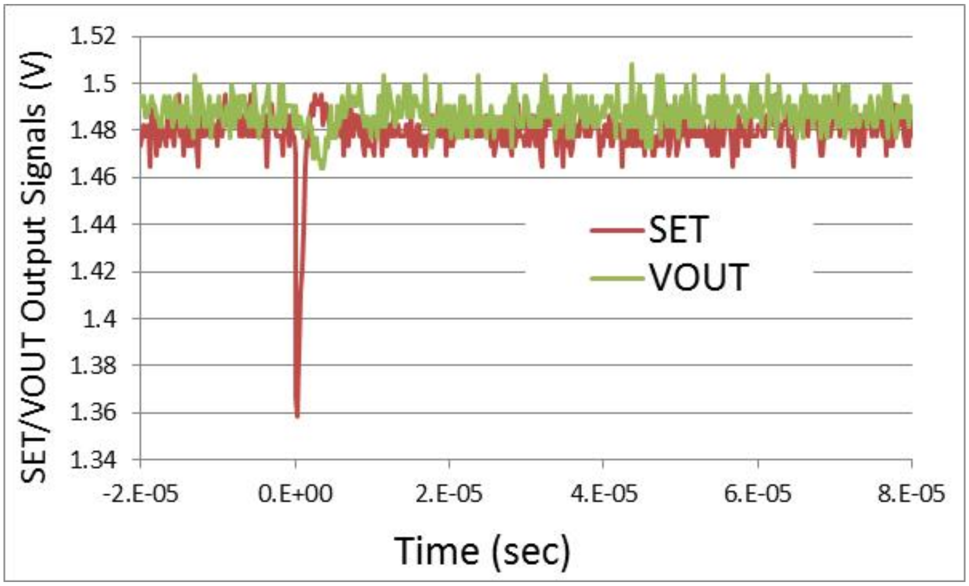

Fig. 9: Sharp Negative Transient Pulse on the SET signal vs. Beam Time
Run 14, Waveform 3

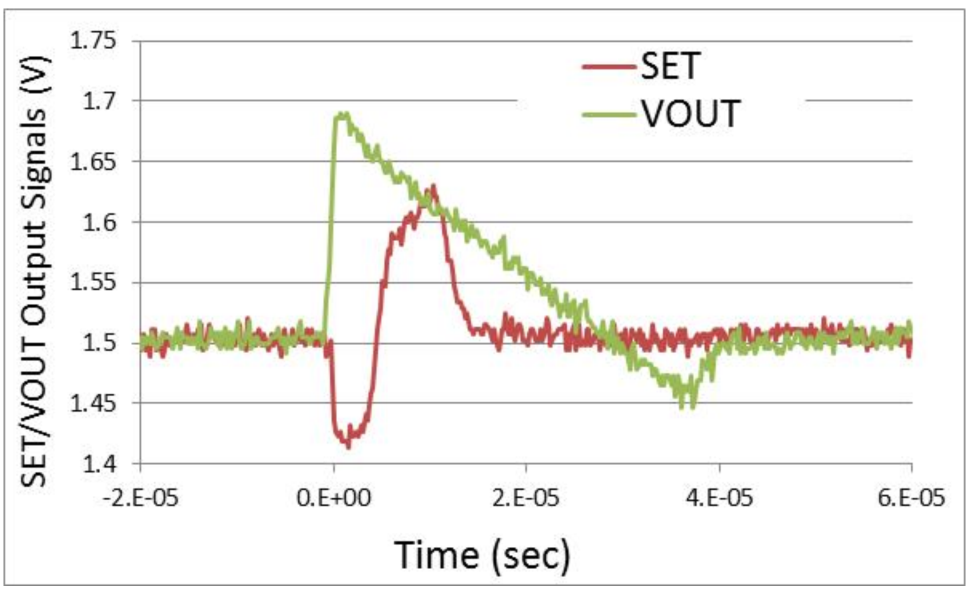

Fig. 10: Negative followed by Positive Transient Pulse on the SET signal vs. Beam Time
Run 98, Waveform 84

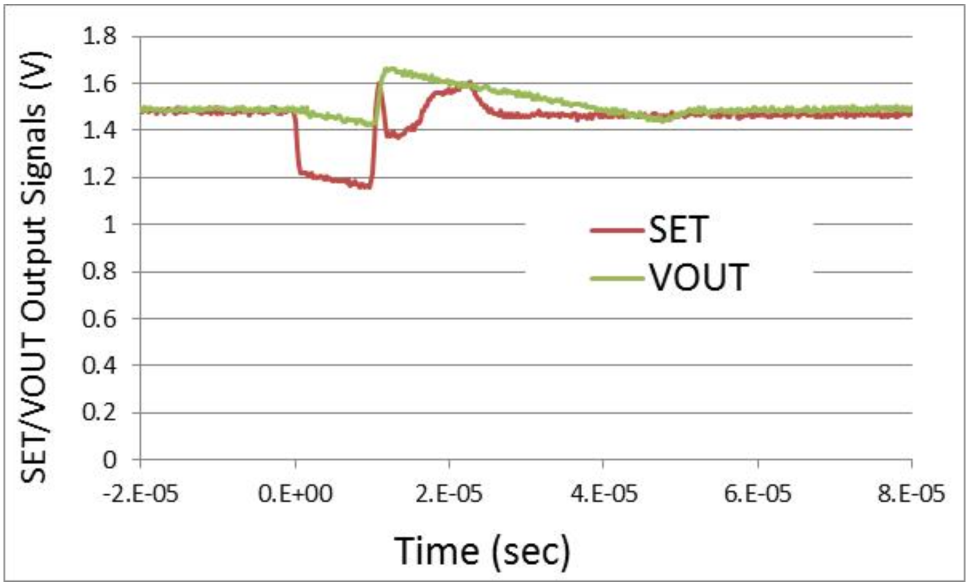

Fig. 11: Negative and Positive Transient Pulse on the SET signal vs. Beam Time
Run 14, Waveform 102

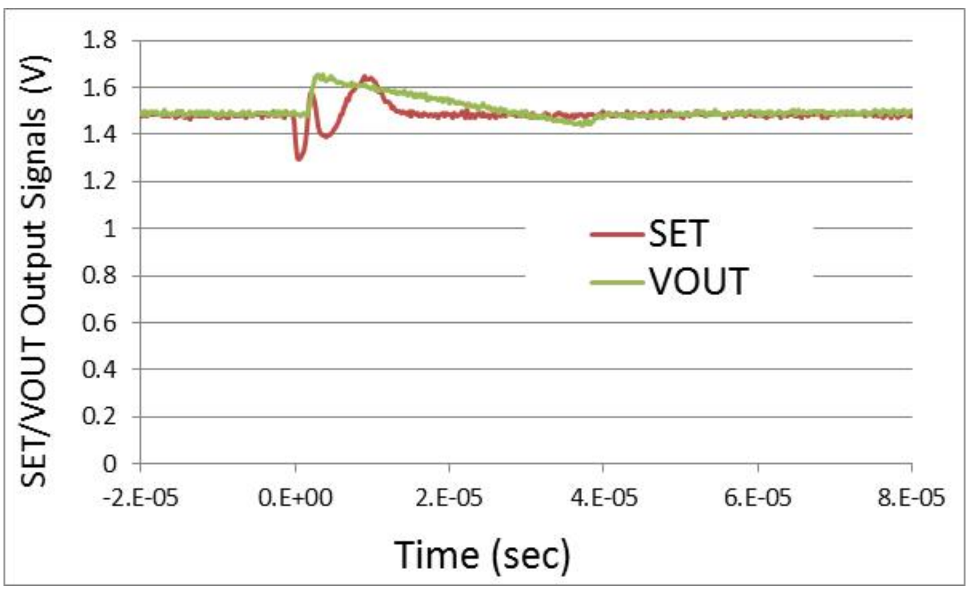

Fig. 12: Negative and Positive Transient Pulse on the SET signal vs. Beam Time
Run 14, Waveform 4

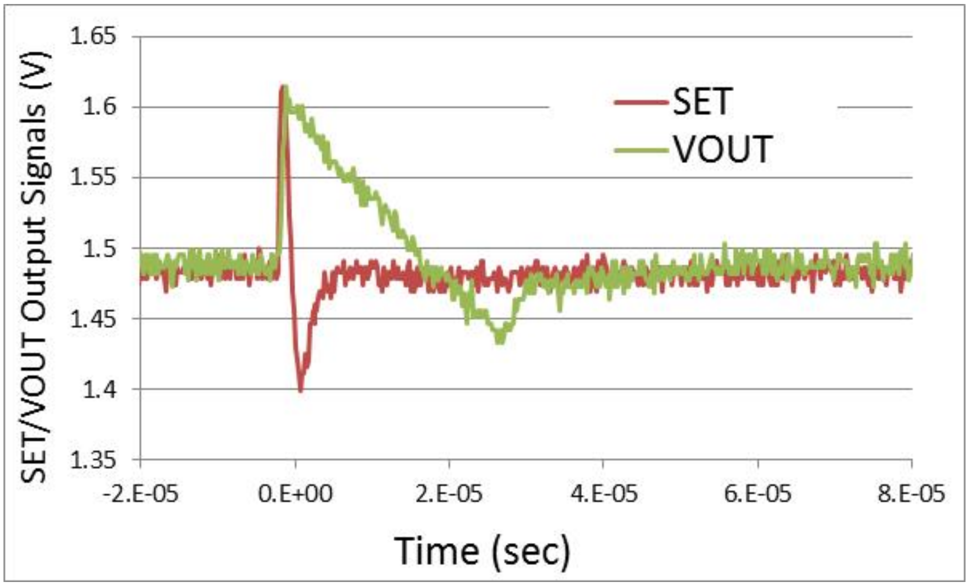

Fig. 13: Positive Pulse followed by Negative Transient Pulse on the SET signal vs. Beam Time
Run 14, Waveform 6

Finally, Figs. 14 and 15 show the cumulative distributions with the SET amplitudes and widths, respectively. Fig. 16 shows the SET amplitudes versus the SET pulse-widths. Note that wider pulse-widths are reported in Figs. 15 and 16 because of settle-time that is needed for the output signal but the actual SET pulse as shown in Fig. 9 to 13 did not exceed 44us.

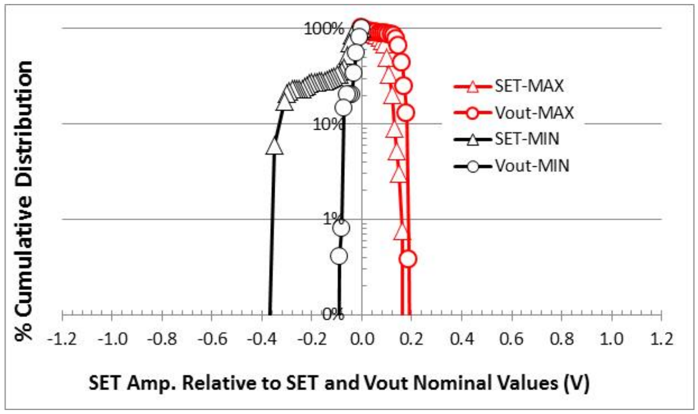

Fig. 14: % Cumulative Distributions vs. SET Pulse-Amplitudes
Runs#14, and 98, Vin=3.3V; Vout=1.5V; Iout=0.1A; Room Temp.; Xenon Ions with LET=58.78 MeV.cm^2/mg

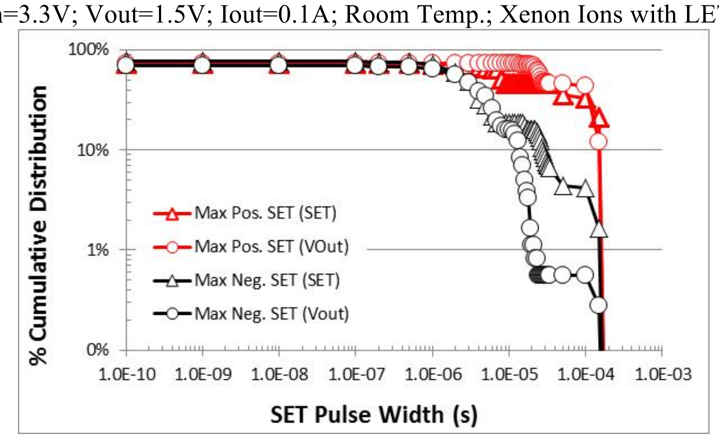

Fig. 15: % Cumulative Distributions vs. SET Pulse-Widths
Runs#14, and 98, Vin=3.3V; Vout=1.5V; Iout=0.1A; Room Temp.; Xenon Ions with LET=58.78 MeV.cm^2/mg

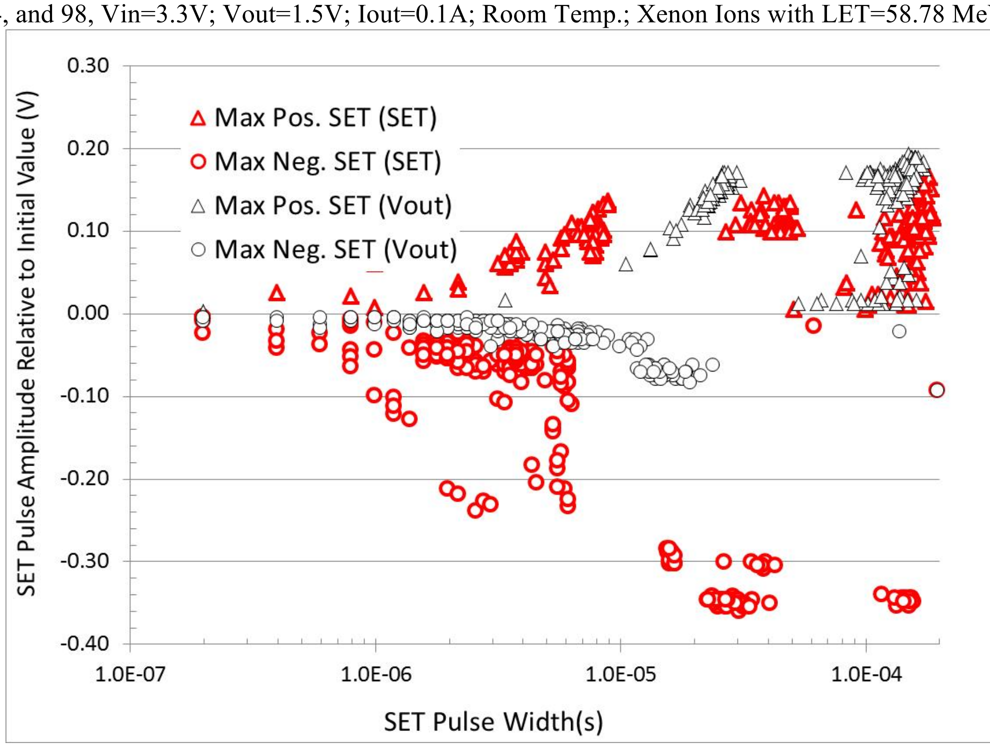

Fig. 16: % SET Pulse-Amplitudes vs. SET Pulse-Widths
Runs#14, and 98, Vin=3.3V; Vout=1.5V; Iout=0.1A; Room Temp.; Xenon Ions with LET=58.78 MeV.cm^2/mg

1) *Input Voltage Supply and Output Load Current Effects On the SET Pulse-Amplitudes, Pulse Widths and Cross-Sections*

Fig. 17 shows the SET cross-sections at different input biases and the fitting Weibull curves that customers can use to determine the RH3083MK orbital error rates in their space flight designs. In Table 4 are provided the Weibull parameters for their calculations, as demonstrated in Eq. a. Note that if SET pulse amplitudes within 10% of the output signal can be tolerated, then the resulting orbital error-rates will be greatly reduced as 90% of these SETs amplitudes were less than 10%.

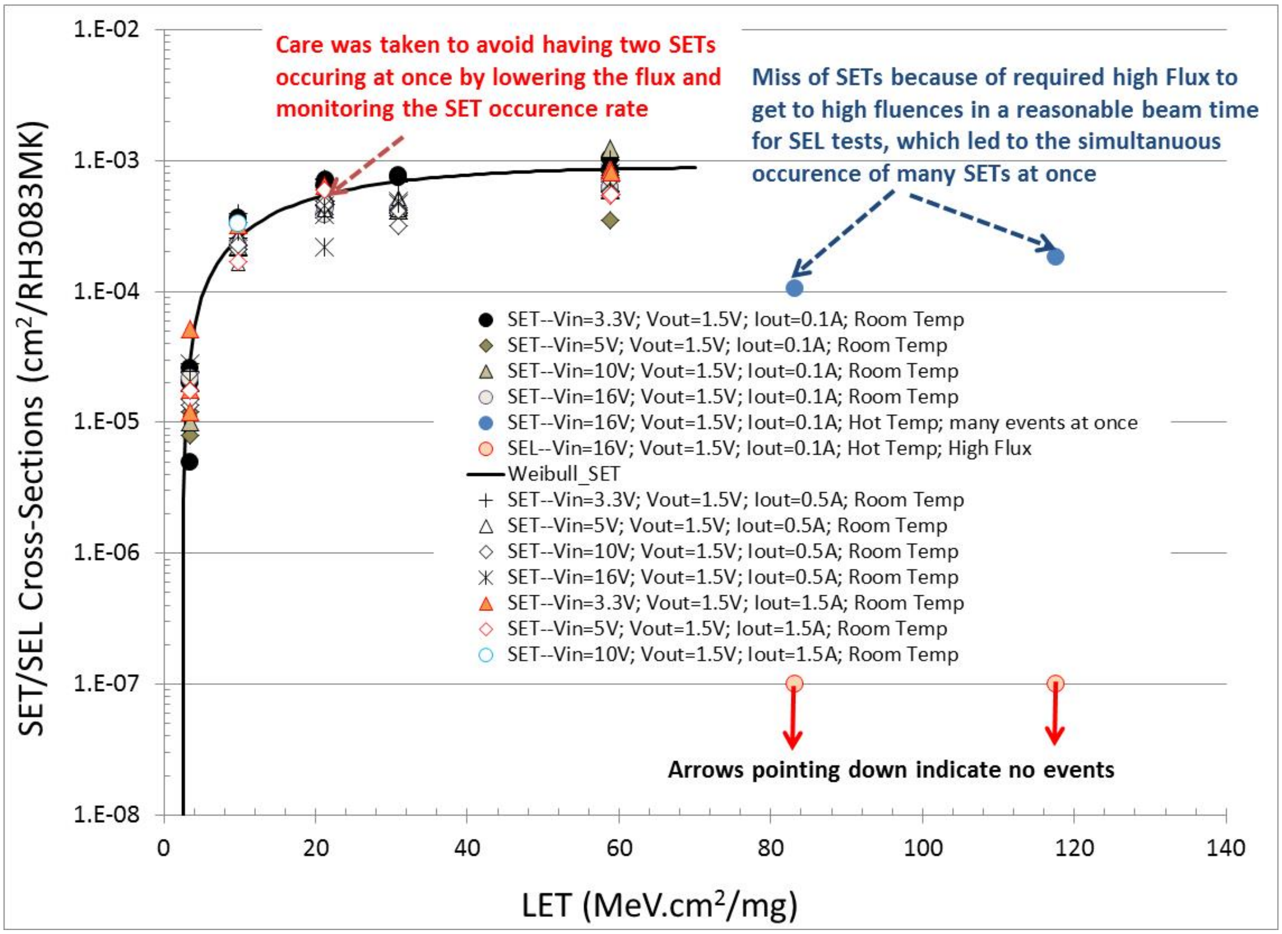

Fig. 17: Measured SET and SEL Cross-Sections vs. LET, showing:

1) the RH3083MK immunity to Destructive Events including SELs
2) the non-dependence of SET Cross-Sections on the input to output differential voltage

Table 4: Weibull Parameters Used for the RH3083MK SEE Cross-Section and the Calculation of the Error Rates

L_0	W	S	σ_0
(MeV / mg-cm^2)	(MeV / mg-cm^2)		(cm^2)
2.4	20	1	9E-4

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

2) SEL Immunity at Hot (100°C) (at 16V Input Voltage)

The SEL tests were run at input voltage equal to 16V, output voltage of 1.5V and load current of 100 mA. At high temperature (100°C) at the DUT case, the test results (red circles in Fig. 19) showed immunity to SELs up to an LET of 117.5 MeV.cm^2/mg. SET cross-sections at hot are shown in blue circles and are smaller at high LETs because of the high used flux needed to accumulate the high fluence required for SEL tests, which led to wider SETs but smaller number of them due to accumulation of few transients at once.

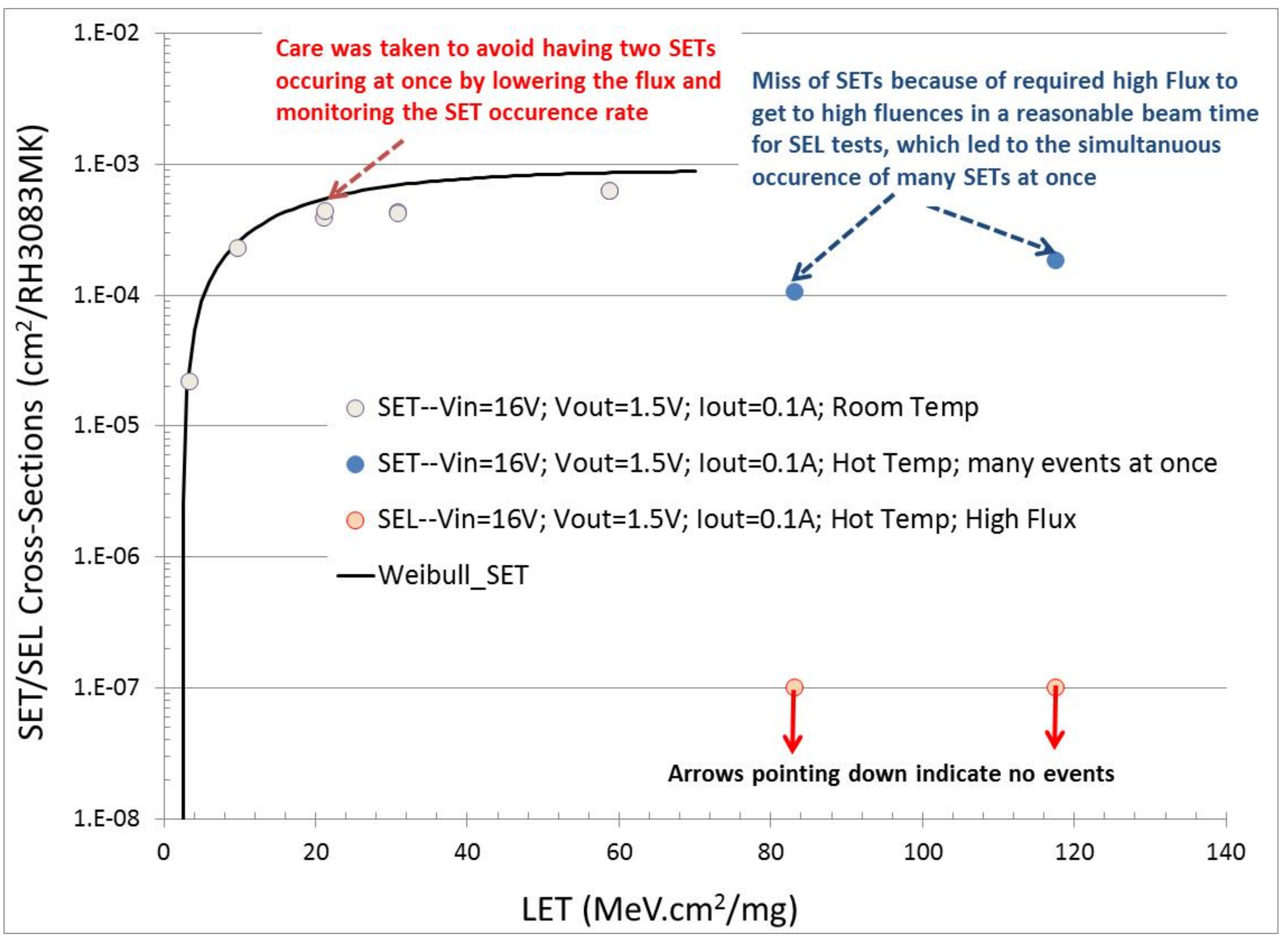

Fig. 18: Measured SEL Cross-Sections vs. LET, showing the RH3083MK immunity to Destructive Events and SELs Arrows pointing down are indication of no observed SETs up to that fluence at tested LET

In summary, under heavy-ion irradiations, and at the various input bias conditions (Table 3), the RH3083MK showed sensitivities only to SETs. The measured SET sensitive saturation cross-section is about 9E-4 cm^2, about 1.8% of the total die's cross-section, while the SET threshold LET was about 3 $MeV.cm^2/mg$. Note that although the RH3083MK die cross-section is 2.25 times the RH3080MK die cross-section, the SET sensitive cross-section is very similar to the RH3080MK [3], as they share very similar reference circuitry.

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

Run	DUT	Tb (Vacuum)	Vin	**Total Eff. Fluence**	**Average Flux**	**Maximum Flux**	**Ion**	**Effective LET**	**Angle**	TID (Run)	TID (Cum.)	SET	SET Cross-Section	Comments
#	#	Degrees	(V)	**p/cm2**	**p/sec/cm2**	**p/sec/cm2**		**MeV.cm2/mg**	**degrees**	rads(Si)	rads(Si)	#	MeV.cm^2/mg	
10	57	24	10	9.78E+04	1.19E+03	1.32E+03	Xe	58.78	0	9.20E+01	9.20E+01	120	1.23E-03	
11	57	24	10	2.01E+05	1.23E+03	1.39E+03	Xe	58.78	0	1.89E+02	2.81E+02	183	9.10E-04	
12	57	24	5	2.01E+05	1.04E+03	1.32E+03	Xe	58.78	0	1.89E+02	4.70E+02	71	3.53E-04	
13	57	24	5	2.01E+05	1.18E+03	1.31E+03	Xe	58.78	0	1.89E+02	6.59E+02	117	5.82E-04	
14	57	24	3.3	1.15E+05	1.16E+03	1.28E+03	Xe	58.78	0	1.08E+02	7.67E+02	119	1.03E-03	
15	57	24	16	2.00E+05	1.18E+03	1.36E+03	Xe	58.78	0	1.88E+02	9.55E+02	125	6.25E-04	
16	57	24	16	6.40E+04	1.93E+03	2.06E+03	Kr	30.97	4.9	3.17E+01	9.87E+02		0.00E+00	
17	57	24	16	2.02E+05	1.99E+03	2.14E+03	Kr	30.97	4.9	1.00E+02	1.09E+03	84	4.16E-04	
18	57	24	10	3.02E+05	1.97E+03	2.12E+03	Kr	30.97	4.9	1.50E+02	1.24E+03	127	4.21E-04	
19	57	24	10	3.01E+05	1.93E+03	2.13E+03	Kr	30.97	4.9	1.49E+02	1.39E+03	134	4.45E-04	
20	57	24.5	10	3.02E+05	2.26E+03	2.59E+03	Kr	30.97	4.9	1.50E+02	1.54E+03	155	5.13E-04	
21	57	24.5	5	3.02E+05	2.35E+03	2.54E+03	Kr	30.97	4.9	1.50E+02	1.69E+03	120	3.97E-04	
22	57	24.5	3.3	3.01E+05	2.30E+03	2.50E+03	Kr	30.97	4.9	1.49E+02	1.83E+03	232	7.71E-04	
23	57	24.5	3.3	3.01E+05	1.82E+03	2.16E+03	Cu	21.25	4.9	1.02E+02	1.94E+03	214	7.11E-04	
24	57	24.5	5	3.02E+05	1.81E+03	2.03E+03	Cu	21.25	4.9	1.03E+02	2.04E+03	148	4.90E-04	
25	57	24.5	10	3.01E+05	1.77E+03	2.23E+03	Cu	21.25	4.9	1.02E+02	2.14E+03	162	5.38E-04	
26	57	27	16	3.01E+05	1.74E+03	2.10E+03	Cu	21.25	4.9	1.02E+02	2.24E+03	132	4.39E-04	
27	57	27	16	1.34E+04	4.31E+03	4.20E+03	Ar	9.78	4.9	2.10E+00	2.25E+03	84	6.27E-03	Short Run (3.11sec)
28	57	27	10	3.03E+05	4.07E+03	8.56E+03	Ar	9.78	4.9	4.74E+01	2.29E+03	67	2.21E-04	
29	57	27	5	4.03E+05	3.85E+03	8.14E+03	Ar	9.78	4.9	6.31E+01	2.36E+03	90	2.23E-04	
30	57	27	3.3	4.03E+05	3.83E+03	7.84E+03	Ar	9.78	4.9	6.31E+01	2.42E+03	146	3.62E-04	
31	57	27	3.3	9.99E+05	6.43E+03	6.69E+03	Ne	3.5	4.9	5.59E+01	2.48E+03	26	2.60E-05	
32	57	27	5	2.00E+06	1.17E+04	1.20E+04	Ne	3.5	4.9	1.12E+02	2.59E+03	16	8.00E-06	
33	57	27	10	4.00E+06	2.24E+04	2.42E+04	Ne	3.5	4.9	2.24E+02	2.81E+03	40	1.00E-05	
34	57	24.5	10	6.95E+05	2.22E+04	2.28E+04	Ne	3.5	4.9	3.89E+01	2.85E+03	14	2.01E-05	
35	57	27	16	3.99E+06	2.25E+04	2.46E+04	Ne	3.5	4.9	2.23E+02	3.07E+03	87	2.18E-05	
36	57	39.5	16	4.01E+06	2.26E+04	2.34E+04	Ne	3.49	0	2.24E+02	3.30E+03	82	2.04E-05	
37	57	39.5	10	4.01E+06	3.00E+03	2.35E+04	Ne	3.49	0	2.24E+02	3.52E+03	60	1.50E-05	
38	57	27	5	1.26E+06	2.27E+04	2.34E+04	Ne	3.49	0	7.04E+01	3.59E+03			Invalid Run
39	57	27	5	4.01E+06	2.27E+04	2.43E+04	Ne	3.49	0	2.24E+02	3.82E+03	59	1.47E-05	
40	57	27	3.3	4.01E+06	2.31E+04	2.46E+04	Ne	3.49	0	2.24E+02	4.04E+03	99	2.47E-05	
41	57	24.5	3.3	6.96E+05	1.30E+04	2.47E+04	Ar	9.74	0	1.08E+02	4.15E+03	179	2.57E-04	
42	57	26.25	5	4.04E+05	1.13E+04	1.16E+04	Ar	9.74	0	6.30E+01	4.21E+03	66	1.63E-04	
43	57	29.5	10	4.03E+05	8.77E+03	1.45E+04	Ar	9.74	0	6.28E+01	4.27E+03	85	2.11E-04	
44	57	34.5	16	5.05E+05	8.35E+02	9.16E+03	Cu	21.17	0	1.71E+02	4.45E+03	110	2.18E-04	
45	57	49.5	16	5.02E+05	3.27E+03	3.79E+03	Cu	21.17	0	1.70E+02	4.62E+03	196	3.90E-04	
46	57	42.75	10	5.01E+05	1.97E+03	3.37E+03	Cu	21.17	0	1.70E+02	4.79E+03	231	4.61E-04	
47	57	34.5	5	5.01E+05	1.90E+03	2.13E+03	Cu	21.17	0	1.70E+02	4.95E+03	211	4.21E-04	
48	57	32	3.3	5.01E+05	1.88E+03	2.11E+03	Cu	21.17	0	1.70E+02	5.12E+03	354	7.07E-04	
49	57	29.5	3.3	2.01E+05	2.25E+03	2.42E+03	Kr	30.86	0	9.92E+01	5.22E+03	139	6.92E-04	
50	57	29.5	5	2.01E+05	2.29E+03	2.45E+03	Kr	30.86	0	9.92E+01	5.32E+03	84	4.18E-04	
51	57	35.5	10	3.01E+05	6.04E+03	2.21E+04	Kr	30.86	0	1.49E+02	5.47E+03	96	3.19E-04	
52	57	49.5	16	2.00E+05	1.17E+03	1.98E+03	Kr	30.86	0	9.88E+01	5.57E+03	95	4.75E-04	
53	57	57	16	2.00E+05	8.41E+02	1.06E+03	Xe	58.78	0	1.88E+02	5.76E+03	160	8.00E-04	
54	57	57	16	2.00E+05	8.56E+02	9.66E+02	Xe	58.78	0	1.88E+02	5.95E+03	175	8.75E-04	
55	57	57	10	1.16E+04	8.39E+02	9.05E+02	Xe	58.78	0	1.09E+01	5.96E+03			Invalid Run
56	57	49.5	10	2.00E+05	8.53E+02	9.73E+02	Xe	58.78	0	1.88E+02	6.15E+03	114	5.70E-04	
57	57	39.5	5	2.00E+05	8.50E+02	1.00E+03	Xe	58.78	0	1.88E+02	6.33E+03	115	5.75E-04	
58	57	37	3.3	2.77E+03	8.83E+02	9.76E+02	Xe	58.78	0	2.61E+00	6.34E+03	181	6.53E-02	Short Run (3.11sec)
59	54	29.75	3.3	2.00E+05	8.78E+02	1.00E+03	Xe	58.78	0	1.88E+02	1.88E+02	169	8.45E-04	
60	54	39.5	5	2.00E+05	8.24E+02	9.79E+02	Xe	58.78	0	1.88E+02	3.76E+02	109	5.45E-04	
61	54	49.5	10	1.42E+05	8.41E+02	9.47E+02	Xe	58.78	0	1.34E+02	5.10E+02	109	7.68E-04	thermal shutdown
62	54	49.5	10	7.53E+04	8.70E+02	1.00E+03	Xe	58.93	4.1	7.10E+01	5.81E+02	110	1.46E-03	thermal shutdown
63	54	49.5	16	7.46E+04	8.82E+02	1.01E+03	Xe	58.93	4.1	7.03E+01	6.51E+02	10	1.34E-04	thermal shutdown + current limit; cannot have max current
64	54	49.5	10	5.22E+03	9.00E+02	1.06E+03	Xe	58.93	4.1	4.92E+00	6.56E+02	127	2.43E-02	thermal shutdown
65	54	37	5	2.00E+05	1.78E+03	1.95E+03	Xe	58.93	4.1	1.89E+02	8.45E+02	111	5.55E-04	
66	54	49.5	3.3	2.00E+05	1.78E+03	1.94E+03	Xe	58.93	4.1	1.89E+02	1.03E+03	165	8.25E-04	
67	54	49.5	3.3	2.00E+05	2.43E+03	2.61E+03	Cu	21.22	4.1	6.79E+01	1.10E+03	129	6.45E-04	
68	54	34.5	5	2.02E+05	2.45E+03	2.61E+03	Cu	21.22	4.1	6.86E+01	1.17E+03	120	5.94E-04	

69	54	49.5	10	2.01E+05	2.48E+03	2.67E+03	Cu	21.22	4.1	6.82E+01	1.24E+03	182	9.05E-04	thermal shutdown
70	54	49.5	10	4.02E+05	6.21E+03	2.09E+04	Ar	9.76	4.1	6.28E+01	1.30E+03	133	3.31E-04	thermal shutdown
71	54	34.5	5	4.02E+05	5.24E+03	5.60E+03	Ar	9.76	4.1	6.28E+01	1.37E+03	68	1.69E-04	
72	54	37	3.3	5.02E+05	5.27E+03	5.55E+03	Ar	9.76	4.1	7.84E+01	1.44E+03	164	3.27E-04	
73	54	49.5	3.3	5.01E+05	4.52E+03	6.40E+03	Ne	3.5	4.1	2.81E+01	1.47E+03	26	5.19E-05	
74	54	49.5	3.3	1.00E+06	1.12E+04	1.16E+04	Ne	3.5	4.1	5.60E+01	1.53E+03	12	1.20E-05	
75	54	49.5	3.3	1.00E+06	1.11E+04	1.16E+04	Ne	3.5	4.1	5.60E+01	1.58E+03	18	1.80E-05	
76	54	34.5	5	2.00E+06	1.51E+04	2.26E+04	Ne	3.5	4.1	1.12E+02	1.70E+03	35	1.75E-05	
77	54	49.5	10	1.80E+06	2.21E+04	2.27E+04	Ne	3.5	4.1	1.01E+02	1.80E+03	236	1.31E-04	thermal shutdown
78	54	44.5	16	2.00E+06	1.13E+04	1.20E+04	Ne	3.5	4.1	1.12E+02	1.91E+03	56	2.80E-05	
79	54	39.5	10	2.01E+06	1.14E+04	1.20E+04	Ne	3.49	0	1.12E+02	2.02E+03	27	1.34E-05	
80	54	27	5	2.01E+06	1.15E+04	1.20E+04	Ne	3.49	0	1.12E+02	2.13E+03	25	1.24E-05	
81	54	24.5	3.3	2.01E+06	1.15E+04	1.19E+04	Ne	3.49	0	1.12E+02	2.25E+03	56	2.79E-05	
82	54	44.5	3.3	3.02E+05	4.20E+03	6.66E+03	Ar	9.74	0	4.71E+01	2.29E+03	120	3.97E-04	
83	54	39.5	5	4.01E+05	3.23E+03	6.73E+03	Ar	9.74	0	6.25E+01	2.36E+03	107	2.67E-04	
84	54	32	10	4.01E+05	3.66E+03	3.96E+03	Ar	9.74	0	6.25E+01	2.42E+03	91	2.27E-04	
85	54	42	16	4.02E+05	3.58E+03	6.04E+03	Ar	9.74	0	6.26E+01	2.48E+03	115	2.86E-04	
86	54	47	16	2.71E+05	1.38E+03	1.76E+03	Cu	21.17	0	9.18E+01	2.57E+03	124	4.58E-04	
87	54	34.5	10	2.01E+05	1.44E+03	1.60E+03	Cu	21.17	0	6.81E+01	2.64E+03	98	4.88E-04	
88	54	27	5	2.01E+05	1.39E+03	1.57E+03	Cu	21.17	0	6.81E+01	2.71E+03	86	4.28E-04	
89	54	24.25	3.3	2.01E+05	1.43E+03	1.58E+03	Cu	21.17	0	6.81E+01	2.78E+03	145	7.21E-04	
90	54	24.25	3.3	2.01E+05	1.00E+03	4.47E+03	Kr	30.86	0	9.92E+01	2.88E+03	139	6.92E-04	
91	54	26.75	5	2.00E+05	9.42E+02	1.07E+03	Kr	30.86	0	9.88E+01	2.97E+03	102	5.10E-04	
92	54	39.25	10	2.00E+05	9.35E+02	1.08E+03	Kr	30.86	0	9.88E+01	3.07E+03	83	4.15E-04	
93	54	49.5	16	2.00E+05	9.12E+02	1.04E+03	Kr	30.86	0	9.88E+01	3.17E+03	98	4.90E-04	
94	54	44.5	16	2.01E+05	1.42E+03	1.56E+03	Xe	58.78	0	1.89E+02	3.36E+03	122	6.07E-04	
95	54	37	10	2.01E+05	1.45E+03	1.59E+03	Xe	58.78	0	1.89E+02	3.55E+03	117	5.82E-04	
96	54	29.5	5	2.00E+05	1.44E+03	1.58E+03	Xe	58.78	0	1.88E+02	3.74E+03	119	5.95E-04	
97	54	24.5	3.3	2.00E+05	1.38E+03	1.51E+03	Xe	58.78	0	1.88E+02	3.93E+03	202	1.01E-03	
98	54	22	3.3	2.00E+05	1.39E+03	5.47E+03	Xe	58.78	0	1.88E+02	4.11E+03	169	8.45E-04	
99	54	22	5	2.00E+05	8.44E+02	9.97E+02	Xe	58.78	0	1.88E+02	4.30E+03	163	8.15E-04	
100	54	22	10	2.01E+05	8.81E+02	9.91E+02	Xe	58.78	0	1.89E+02	4.49E+03	121	6.02E-04	
101	54	25.5	16	2.00E+05	8.74E+02	9.94E+02	Xe	58.78	0	1.88E+02	4.68E+03	125	6.25E-04	
102	54	25.75	16	2.00E+05	4.54E+02	2.00E+03	Kr	30.88	2.3	9.88E+01	4.78E+03	85	4.25E-04	
103	54	22	10	2.01E+05	1.42E+03	1.57E+03	Kr	30.88	2.3	9.93E+01	4.88E+03	84	4.18E-04	
104	54	22	5	2.00E+05	1.44E+03	1.58E+03	Kr	30.88	2.3	9.88E+01	4.98E+03	79	3.95E-04	
105	54	19.5	3.3	2.01E+05	1.42E+03	1.57E+03	Kr	30.88	2.3	9.93E+01	5.08E+03	148	7.36E-04	
106	54	19.5	3.3	2.00E+05	1.09E+03	1.22E+03	Cu	21.19	2.3	6.78E+01	5.14E+03	129	6.45E-04	
107	54	19.5	5	2.00E+05	1.09E+03	1.21E+03	Cu	21.19	2.3	6.78E+01	5.21E+03	91	4.55E-04	
108	54	22	10	2.00E+05	1.09E+03	1.23E+03	Cu	21.19	2.3	6.78E+01	5.28E+03	85	4.25E-04	
109	54	25.75	16	2.00E+05	1.11E+03	1.23E+03	Cu	21.19	2.3	6.78E+01	5.35E+03	78	3.90E-04	
110	54	25.75	16	2.01E+05	2.00E+03	2.83E+03	Ar	9.75	2.3	3.14E+01	5.38E+03	46	2.29E-04	
111	54	22	10	2.01E+05	2.59E+03	4.93E+03	Ar	9.75	2.3	3.14E+01	5.41E+03	44	2.19E-04	
112	54	22	5	2.01E+05	2.73E+03	5.43E+03	Ar	9.75	2.3	3.14E+01	5.44E+03	42	2.09E-04	
113	54	19.5	3.3	2.01E+05	2.62E+03	2.83E+03	Ar	9.75	2.3	3.14E+01	5.47E+03	68	3.38E-04	
114	54	25.75	3.3	2.02E+05	5.36E+03	8.68E+03	Ne	3.49	2.3	1.13E+01	5.48E+03	1	4.95E-06	
115	54	22	3.3	2.01E+06	2.73E+04	3.16E+04	Ne	3.49	2.3	1.12E+02	5.60E+03	42	2.09E-05	
116	54	22	3.3	1.00E+06	4.13E+03	4.35E+03	Ne	3.49	2.3	5.58E+01	5.65E+03	20	2.00E-05	
117	54	19.5	5	1.00E+06	4.09E+03	4.31E+03	Ne	3.49	2.3	5.58E+01	5.71E+03	12	1.20E-05	
118	54	97	16	1.67E+05	1.05E+03	1.05E+04	Xe	58.83	2.3	1.57E+02	5.87E+03	50	2.99E-04	
119	54	97	16	1.00E+07	5.59E+04	7.19E+04	Xe	83.13	45	1.33E+04	1.92E+04	1051	1.05E-04	
120	54	97	16	1.00E+07	6.79E+04	7.19E+04	Xe	117.56	60	1.88E+04	3.80E+04	1835	1.84E-04	

*Tb - the temperature sensed by the transistor on the board (as shown in Fig. 5), Tjc =3C/W

*Ion – selected withinEnergy Cocktail = 10MeV/nucleon

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[3] RH3080MK SEE Report: http://cds.linear.com/docs/en/radiation-report/SEE_Test_Report_RH3080.pdf

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