Heavy Ion Test Report for the MSK5063RH Switching Regulator with the RH3845 and RH411 Die

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I. Introduction

The purpose of this test is to determine the heavy ion-induced single-event effect (SEE) susceptibility for the MSK5063RH switching regulator from Anaren / MSK Products, which contains the RH3845 and RH411 die from Linear Technology Corporation, now Analog Devices Incorporated.

II. Device Under Test

The MSK5063RH is a radiation hardened step-down synchronous switching regulator. The input and output voltages have a wide range of up to 60 V and 36 V, respectively. The MSK5063RH is manufactured with the RH3845 and RH411 die from Analog Devices [1]. The RH3845 and RH411 are built on a proprietary Radhard process and qualified for total-ionizing dose (TID) per Mil-Std-883 TM 1019 [2], [3]. The MSK5063RH is packaged in a hermetically sealed 46 pin Flatpack.

Figure 1 shows a schematic diagram of the device pinout with descriptions of each pin. Table I lists the basic part and test information.
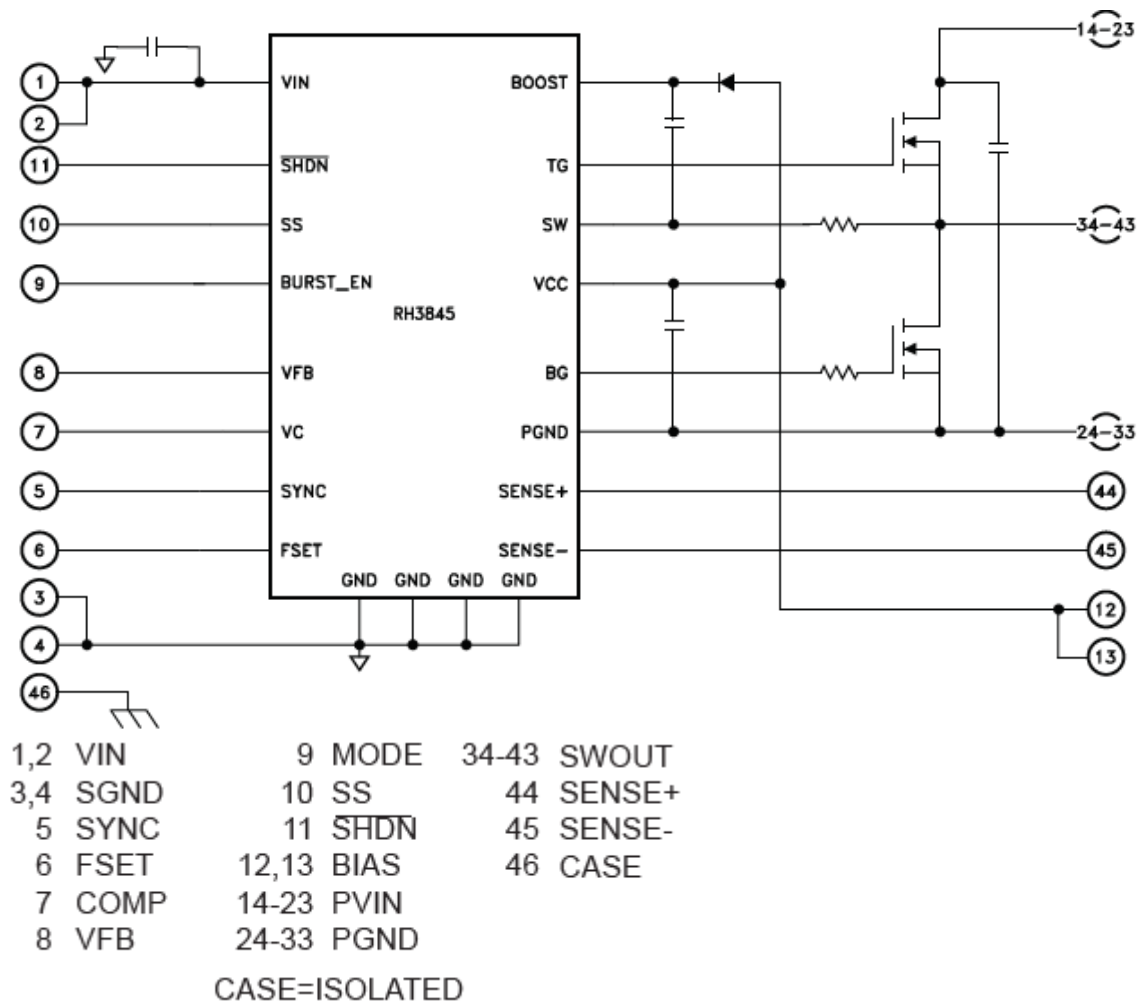

Figure 1. Schematic diagram of the pin configuration for the MSK5063RH.

Table I
Part and test information.

Parameter	Description
Part Number:	MSK5063RH
Manufacturer:	Anaren / MSK Products
Die Manufacturer:	Analog Devices Inc.
Lot Date Code (LDC):	1704
Die lot/wafer number:	RH3845MK Fabrication Lot: WP3227E.1 W#4 RH411MK Fabrication Lot: HF203036.1 W#10
Quantity Tested:	5
Part Function:	Synchronous buck regulator
Part Technology:	BIPU405 and DMOS06
Package Style:	46-pin Flatpack
Test Equipment:	DC analyzer (N6705B) with Keysight 14585A software Oscilloscope (LeCory HRO 66Zi) Load box A (Reay Labs RL1000) with RL1000 software Load box B (Reay Labs RL1000) with RL1000 software PC

III.   Test Facility

The heavy-ion testing was carried out at the Lawrence Berkeley National Laboratory (LBNL) Berkeley Accelerator Space Effects (BASE) Facility. The facility utilizes an 88-inch cyclotron to accelerate a cocktail of ions. The testing was performed in vacuum. Also, the SEE testing was performed in accordance with JESD57 test procedures [4].

Facility: Lawrence Berkeley National Laboratory
Cocktail: 10 MeV/amu
Flux: $\sim 1 \times 10^4$ ions/cm^2/sec
Fluence: Up to 1×10^6 ions/cm^2 per run
Ions: Shown in Table II

Table II
Heavy-ion specie, linear energy transfer (LET) value, range in Si, and energy.

Ion	Initial LET in air (MeV·cm^2/mg)	Range in Si (µm)	Energy (MeV)
Ne	3.5	175	216
Ar	9.7	130	400
Cu	21.2	108	659
Kr	30.9	110	886
Ag	48.2	90	1039
Xe	58.8	90	1233

IV.   Test Method

A. Test Setup

We used a custom-built test board for the heavy ion beam experiment. Figure 2 shows a schematic diagram of the test circuit. The device-under-test (DUT) was delidded to expose the RH3845 and RH411 die. Each component in the hybrid was targeted individually during the heavy ion test.

A DC analyzer, an oscilloscope, and two load boxes were located in the cave. The equipment was operated directly from the control room via USB cables. Figure 3 shows a schematic block diagram of the test setup. The figure also includes a photograph of the test board containing the DUT with a 15 V output. The rectangular outline next to the circuit shows the potential position for a second test circuit with a 3.3 V output.
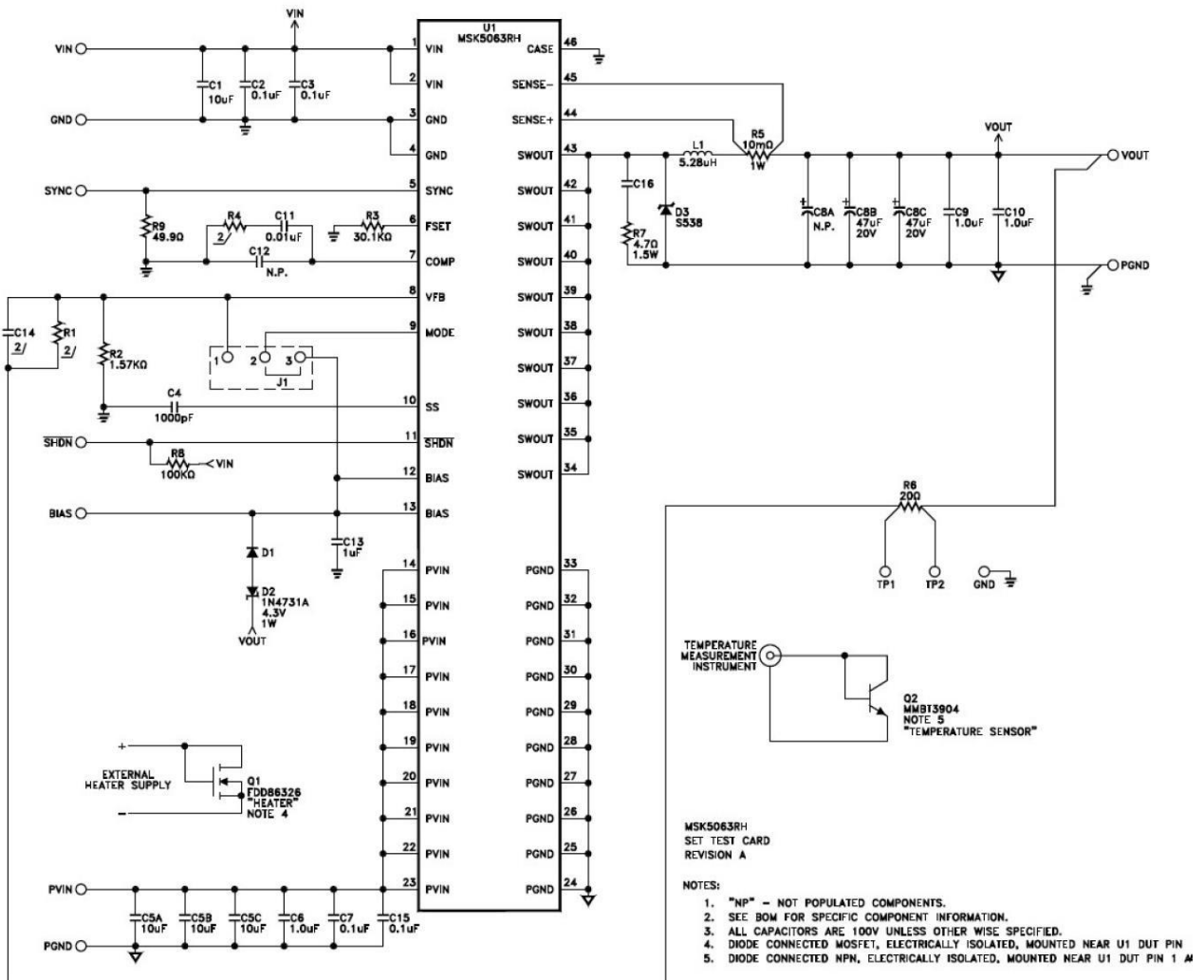

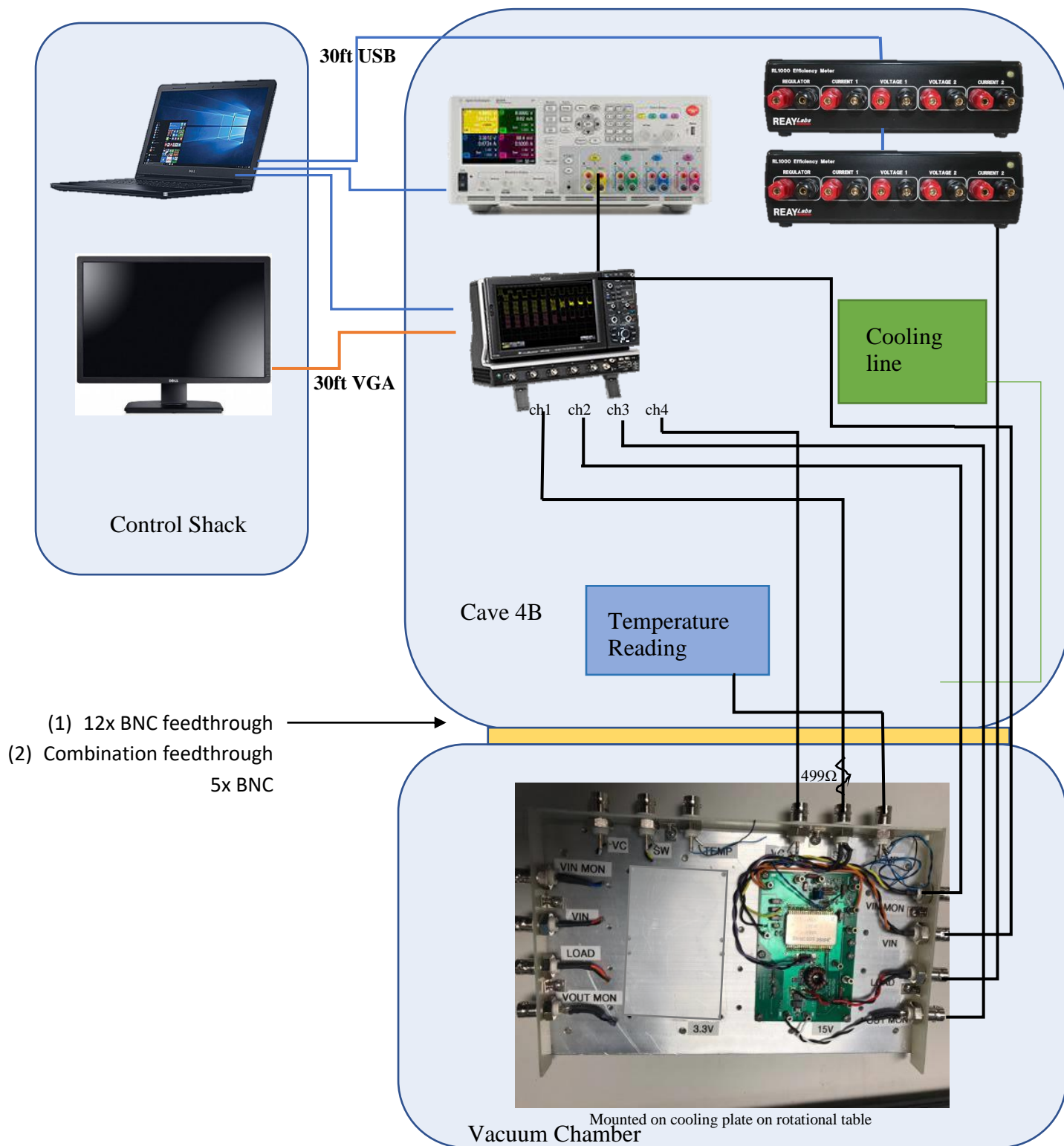Figure 2. Schematic diagram of the test circuit.

30ft USB

30ft VGA

Control Shack

RL1000 Efficiency Meter
REGULATOR   CURRENT 1   VOLTAGE 1   VOLTAGE 2   CURRENT 2
REAYLabs

RL1000 Efficiency Meter
REGULATOR   CURRENT 1   VOLTAGE 1   VOLTAGE 2   CURRENT 2
REAYLabs

Cooling
line

ch1   ch2   ch3   ch4

Cave 4B

Temperature
Reading

(1) 12x BNC feedthrough

(2) Combination feedthrough
5x BNC

499Ω

VC   SW   TEMP   VC
VIN MON
VIN MON
VIN
VIN
LOAD
LOAD
VOUT MON
OUT MON
3.3V   15V

Mounted on cooling plate on rotational table

Vacuum Chamber

Figure 3. Schematic block diagram of the test setup at LBNL. The inset photograph shows the test board. The rectangular outline shows the potential position for a second test circuit with a 3.3 V output.

Test Temperature: Ambient temperature (test performed in vacuum)
V_{in}:   10 – 50 V
PV_{in}:   10 – 51 V
Output Voltage: V_{out} = 3.3 and 15 V
Output Load: I_{out} = 1, 3, and 5 A
Angles of Incidence: 0° (normal) and 45°
Parameters: V_{out}, V_{in}, SW, and COMP pin

V.   Results

A. Single-event transient (SET)

We observed single-event transients (SET) under the evaluated test conditions. Figure 4 shows the SET amplitude vs. the pulse width at full-width-half-maximum (FWHM) for the MSK5063RH under all test conditions, including all ions/LETs, input, and output levels. The SETs are categorized by the output voltage. The figure shows that the SETs can be generally categorized into two groups – negative-going transients with pulse widths of 1 to 10 nsec and positive-going transients with pulse widths of 10 to 100 µsec. The figure also shows that most of the recorded transients for V_{out} of 15 V have relatively short duration with negative-going peaks, while either output levels can be vulnerable to the longer positive-going transients.
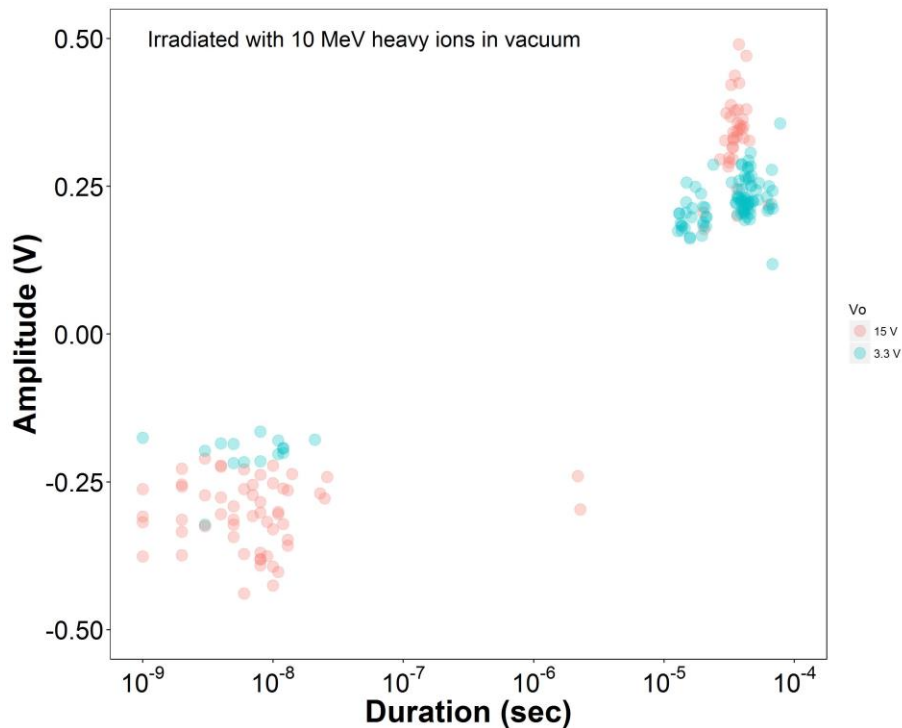

Figure 4. SET amplitude vs. duration plot for the MSK5063RH irradiated with 10 MeV/nuc heavy ions in vacuum.

B. *Destructive SEE of the RH3845 Controller*

In addition to SETs, we also observed destructive SEEs from both the RH3845 controller and the RH411 power MOSFETs. During the test, we targeted each component of the hybrid separately. For example, when evaluating the RH3845 controller, the two MOSFETs were shielded from the beam. Previous test campaigns have found destructive effects in the RH3845 [4]. The failures evidently produced physical damage and blown bond wire from the V_{in} region on the RH3845 die. In this test, we observed failures with similar characteristics as the previous tests. Figure 5 shows the minimum input voltage for which failure was observed as a function of the LET. We plot our data with data extracted from the JPL report. The voltage required to induce failure generally decreases with increasing LET. The data from this test, for cases where Vin and PV_{in} are tied together, appear to fit consistently with the JPL data. Note that the data at an effective LETs of 84.3 MeV·cm^2/mg was taken at 60° incident angle.
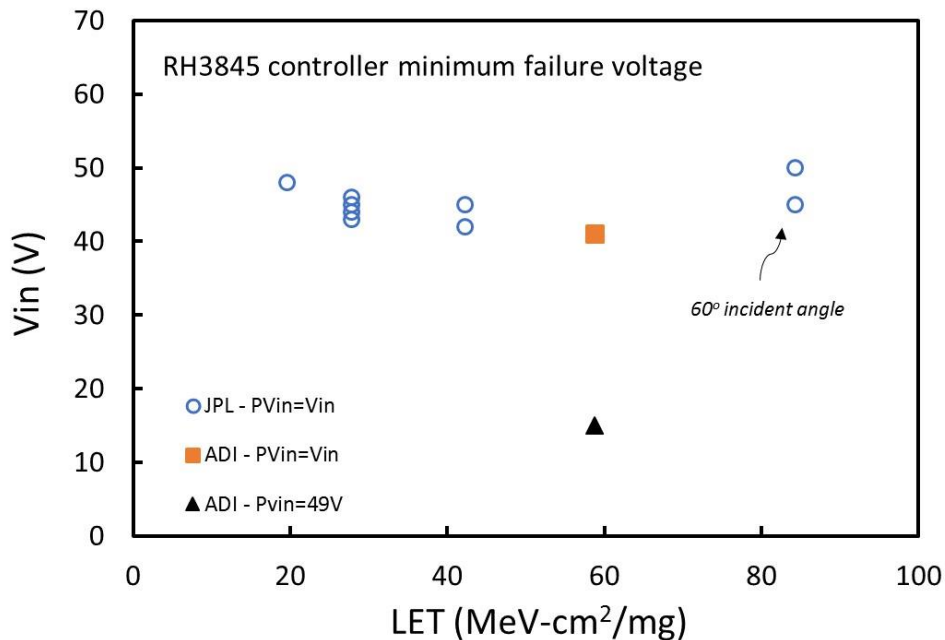

Figure 5. SET cross section as a function of LET for the MSK5063RH irradiated with 10 MeV/nuc heavy ions in vacuum.

In additional to the previously described failure mode, we also observed another failure on the RH3485 die, which resulted in physical damage from a different die location. This failure occurred with a V_{in} of 15 V and PV_{in} of 49 V. The different bias conditions and the different physical locations of destructive signature suggest different failure modes for the two event types. These results show that it is possible to have failures with different combinations of V_{in} and PV_{in}. Therefore, it is important to understand the safe-operating-area (SOA) in terms of V_{in} and PV_{in}. Figure 6 plots the failure level for V_{in} and PV_{in}, with the limited available data. It may be necessary to obtain additional data points to map out a more comprehensive SOA for applications using different V_{in} and PV_{in} values.
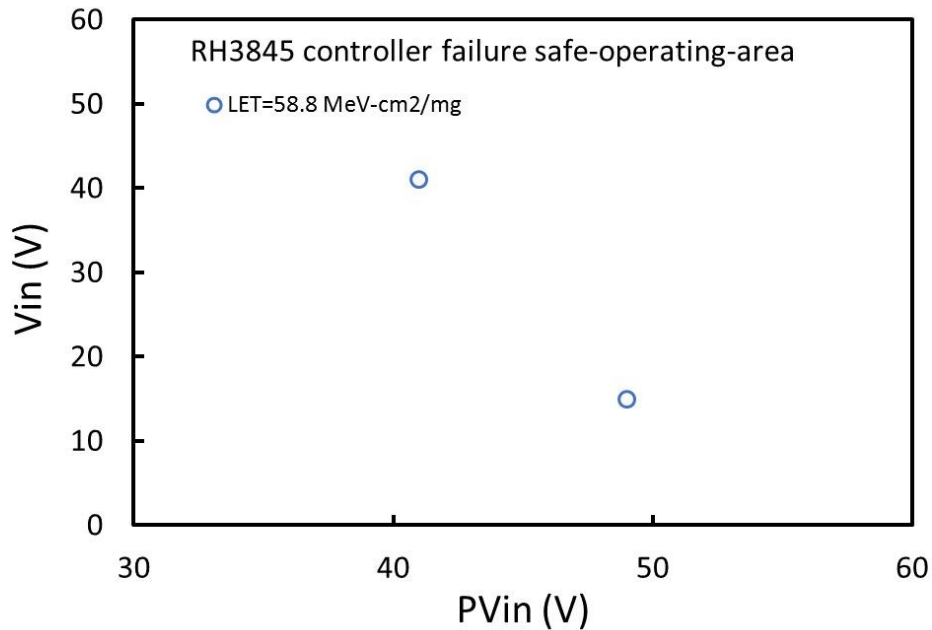
Figure 6. Minimum failure V_{in} and PV_{in} at a LET of 58.8 MeV·cm^2/mg, for the RH3845 irradiated with 10 MeV/nuc heavy ions in vacuum.

Figure 7 shows the cross section vs. LET for all failures observed on the RH3845 controller. The figure shows the three failures observed in this test, plotted using unique symbols and colors, and the JPL data. The cross section is consistent with the trend shown by the JPL data for similar bias conditions ($V_{in} = PV_{in}$). The failure with $V_{in} = 15$ V and $PV_{in} = 41$ V produced a lower cross section than that with $V_{in} = PV_{in} = 41$ V for the same LET. Also, the cross section at an effective LET of 84.3 MeV·cm^2/mg for 60° incident angle are lower than the cross section at a LET of 58.8 MeV·cm^2/mg. The bias dependence and angular dependence exhibited here are consistent with characteristics of single-event burnout (SEB) or single-event dielectric rupture (SEDR). We determined that there is no capacitor connected directly to the input pin, where many of the failures occurred. Therefore, it is probable that the failures are caused by SEB of a power BJT in the respective sensitive regions.
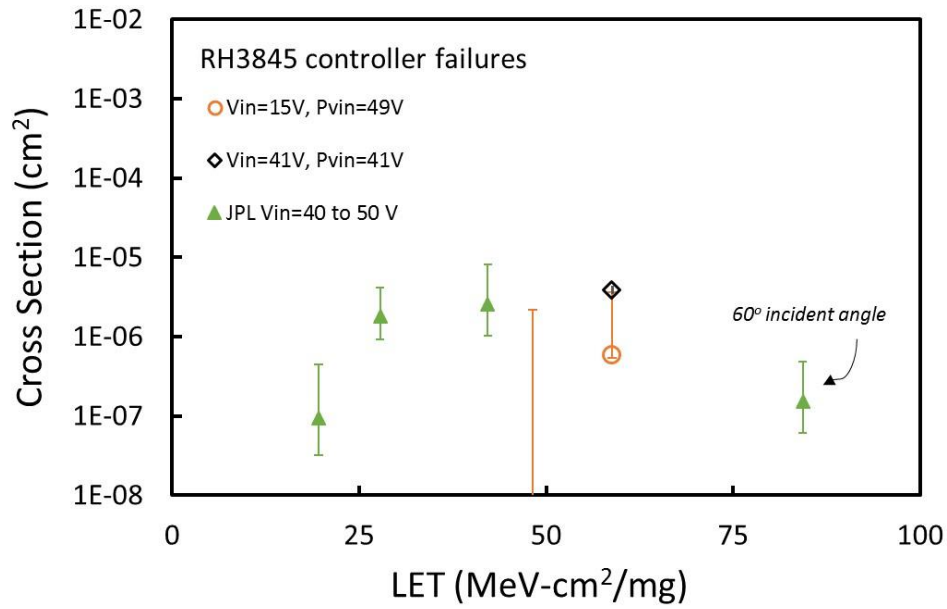
Figure 7. Destructive SEE cross section as a function of LET for the RH3845 controller in the MSK5063RH irradiated with 10 MeV/nuc heavy ions in vacuum. Error bars represent Poisson error.
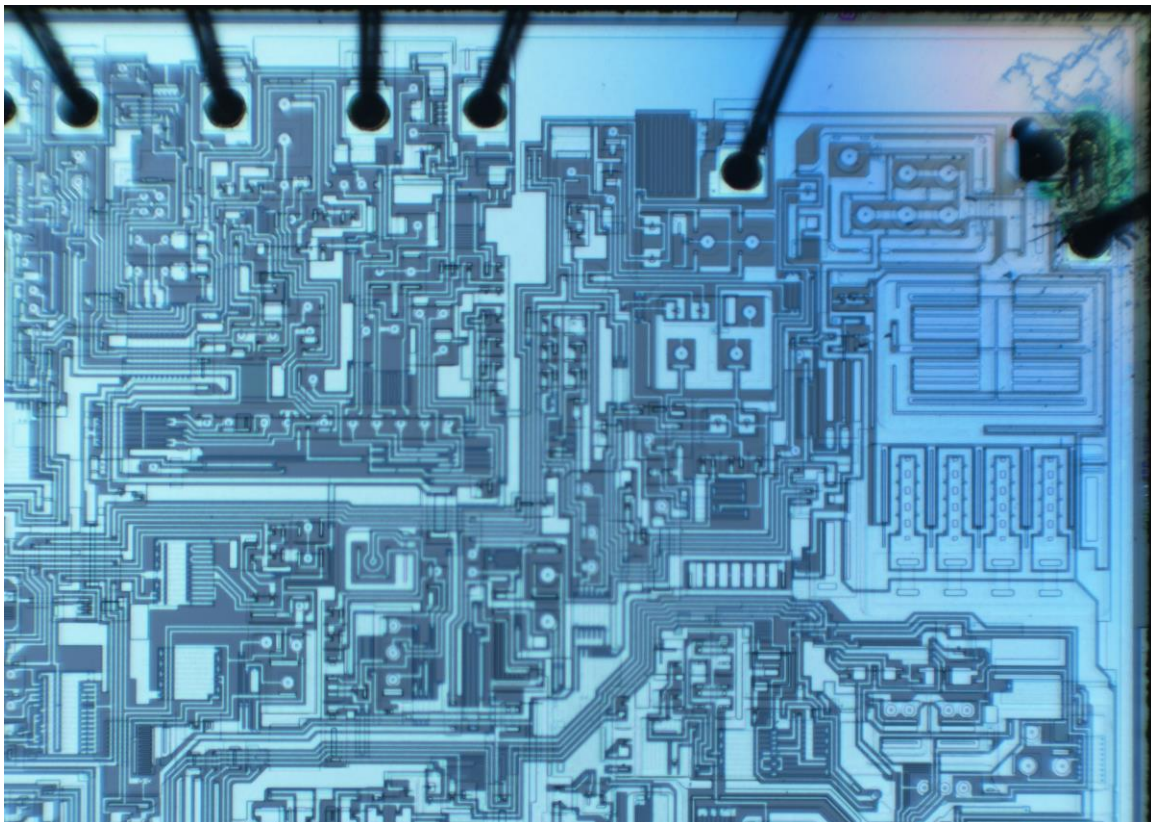

Figure 8. Microphotograph of the RH3845 die for a part that exhibited destructive SEE. The bond wire on the top right corner of the image is blown as a result of the destructive SEE.
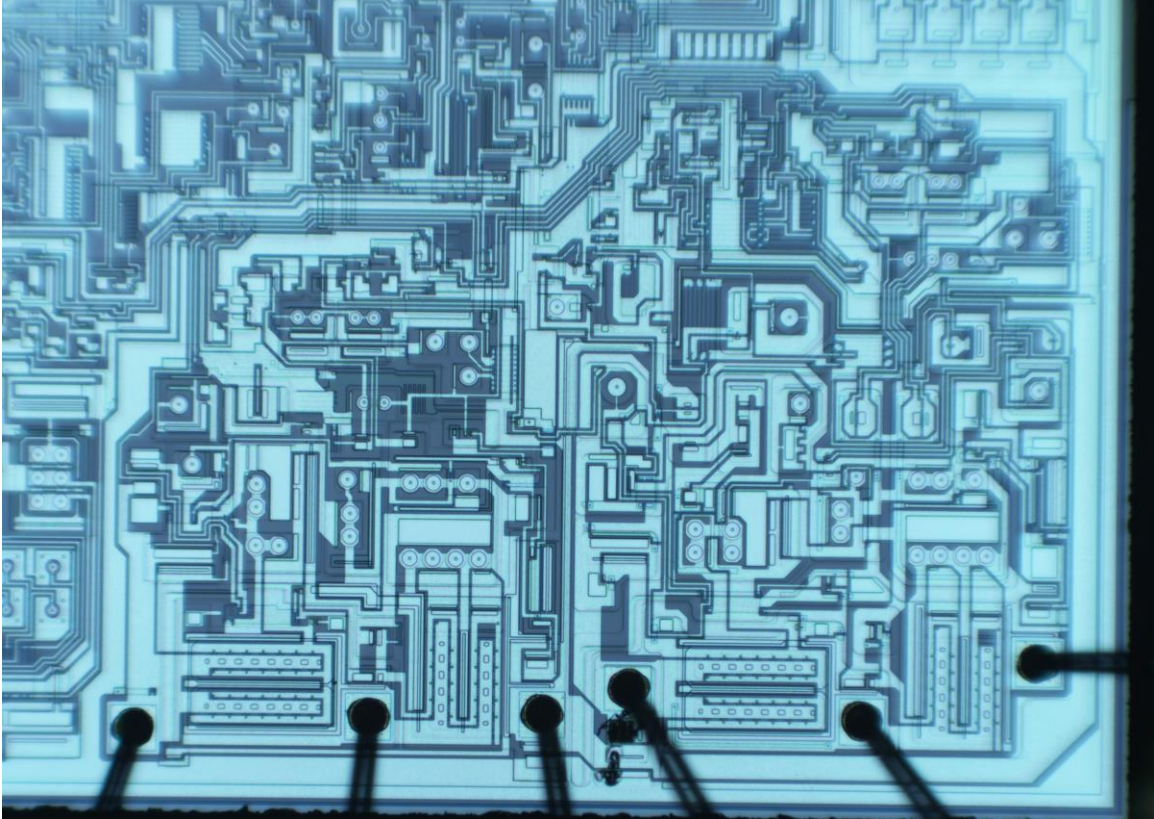
Figure 8. Microphotograph of the RH3845 die for a part that exhibited destructive SEE. The failure resulted in damage at a different part of the die than the previous blown bond wire.

C. Destructive SEE of the RH411 Power MOSFETs

In addition to the evaluation of the RH3845 controller, we also irradiated each of the RH411 power MOSFETs independently. We found destructive effects in both the top and bottom FETs. Figure 8 shows the cross section as a function of the PV_{in} voltage, which is also the drain voltage of the top MOSFET. The figure shows that the MOSFETs are vulnerable to failure with a PV_{in} of 50 V and at a LET of 58.8 MeV·cm^2/mg for the top FET and 48.2 MeV·cm^2/mg for the bottom FET. The error bars at 40 V shows the 95% confidence level upper bound.
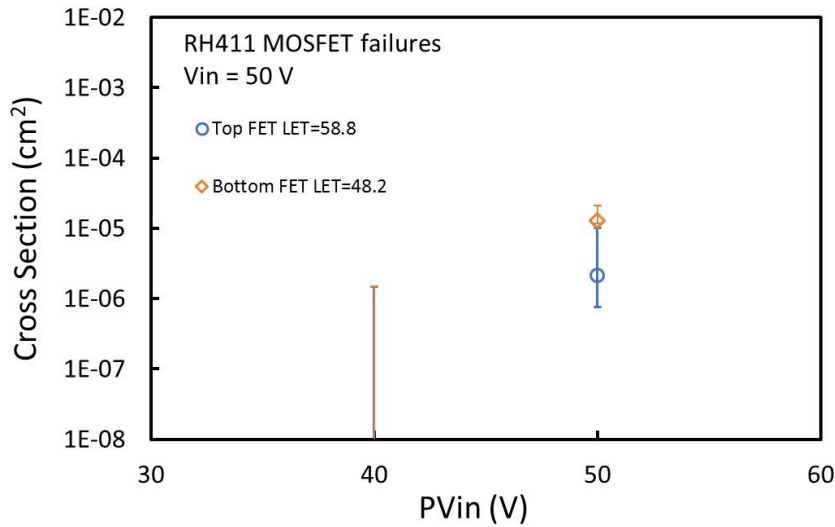
Figure 8. Destructive SEE cross section vs. PV_{in} for the RH411 MOSFETs in the MSK5063RH irradiated with 10 MeV/nuc heavy ions in vacuum.

VI.   Conclusion

We found destructive SEE in the MSK5063RH hybrid from heavy ion irradiation. The error modes include one that is consistent with previously observed failures, where the susceptibility increased with increasing input voltage. The threshold V_{in} (minimum voltage required to cause failure) is approximately 41 V for a LET of 58.8 MeV·cm^2/mg. The threshold level gradually increases for decreasing LET, with a value of ~48 V for a LET of 19.6 MeV·cm^2/mg. In addition, we observed another failure mode with V_{in} of 15 V and PV_{in} of 49 V, for a LET of 58.8 MeV·cm^2/mg. This failure resulted in damage from a different physical area on the die. Thus, the results likely suggest unique failure modes. It is advisable to evaluate the voltage dependence of the destructive effects further, if the application requires different V_{in} and PV_{in} levels.

Finally, we determined that the part is susceptible to destructive SEE from the power MOSFETs with a PV_{in} voltage threshold between 40 and 50 V, at a LET of 58.8 and 48.2 MeV·cm^2/mg for the top and bottom FETs, respectively.

VII.   Reference

[1] Anaren / MSK Products, "MSK5063RH Rad High Voltage Synchronous Switching Regulator," MSK5965RH datasheet, November, 2017. [Rev F, Apr. 2016]
[2] Analog Devices, "RH3845MK DICE Radiation Hardened High Voltage Synchronous Step-Down Controller," RH3845MK datasheet, accessed on November 6th, 2017.
[3] Analog Devices, "RHK3845MKDICE Radiation Hardened High Voltage Synchronous Step-Down Regulator Kit with Power NMOS FETs," RH3845MK datasheet, accessed on November 6th, 2017.
[4] JEDEC Government Liaison Committee, Test Procedure for the Management of Single-Event Effects in Semiconductor Devices from Heavy Ion Irradiation," JESD57, http://www.jedec.org/ standards-documents/docs/jesd-57, Dec. 1996.
[5] S. Vartanian, G. Allen, F. Irom, L. Scheick, S. Hart, N. Vanno, and L. Pearce, "Destructive single-events and latchup in radiation-hardened switching regulators," to be published in *European Conference on Radiation and Its Effects on Components and Systems Data Workshop Proceedings*, Oct. 2017.