Test Report V1.0
Single Event Effects Heavy Ion Testing of the of the International Rectifier AFL2828SX/CH DC/DC Converter

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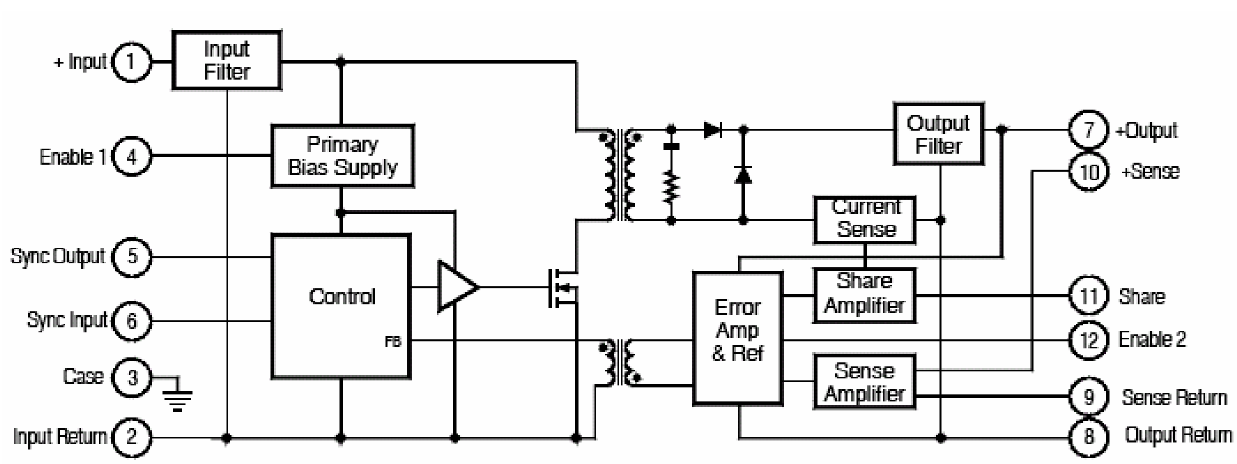
I. Introduction

This study was undertaken to determine the single event destructive latchup/burnout/gate rupture (SEL/B/GR) and transient susceptibility (SET), of the AFL 2828 DC/DC converter. The device was monitored for SETs on the output signal of the device and for destructive events induced by exposing parts to a heavy ion beam at the Texas A&M University Cyclotron Single Event Effects Test Facility. The AFL2828 DC/DC converters feature high power density with no derating, over the full military temperature range. They provide a single output voltage (at 28 volts) operating with nominal +28V inputs at an output power of approximately 112 Watts. This series incorporates International Rectifier's proprietary magnetic pulse feedback technology providing optimized dynamic line and load regulation response. This feedback system samples the output voltage at the pulse width modulator fixed clock frequency, nominally 550 kHz. Under-voltage lockout, primary and secondary referenced inhibit, soft-start and load fault protection are all provided.

Figure 1: Block Diagram of AFL 2828 DC/DC Converter



II. Devices Tested

The DC/DC Converters were designed and fabricated by International Rectifier. All devices were characterized prior to exposure. There was only enough time to test two of the three devices (plus one control device) from the 0533 Lot Date Code (LDC).

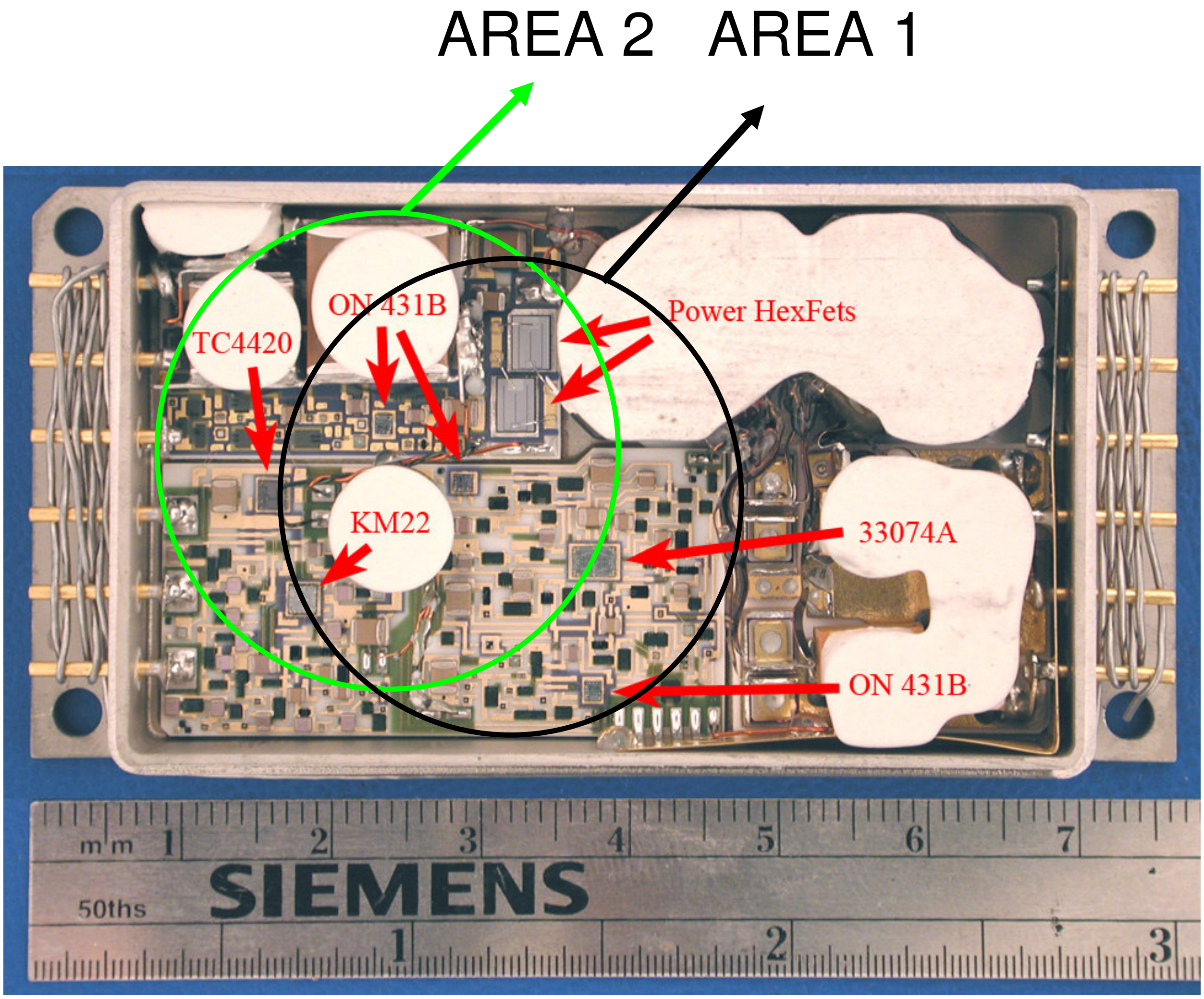
Complete package markings for the devices are**:**

International IOR Rectifier Made in USA 52467
8947 AFL2828SX/ch
DC/DC converter 28V output/112W s/n 0448101 d/c 0533

The device technology is composed of a combination of several die encased in a 12 pin hybrid package. The devices were prepped for test by Chris Greenwell, NASA GSFC, by delidding.

See **Figure 2** for locations of the two irradiated areas as well as the die layout.

Figure 2 - AFL 2828 Die Layout and Beam Irradiation Areas



III. Test Facility and Conditions

Facility: Texas A&M University Cyclotron Single Event Effects Test Facility (TAMU) with 15 MeV/amu tune
Flux: 1×10^3 to 2×10^4 particles/cm^2/s
Fluence: 1×10^5 to 5.6×10^6 particles/cm^2
Angles: 0° only, but tested at two locations on DUT
Temperature: Room temperature (25°±6°C)
Test Voltage: 28 Volts nominal
Test Loading: 10, 25, 60, 80% of V_{out} (100% = 4A)
Test Input Voltage: 20 V and 35 V (range is 16-40 V)

Ions used	LET (MeVcm^2/mg)
Kr	25.4
Xe	47.3

Test was begun with Krypton and went to Xeon ions for destructive SEE test. The test then continued with two additional samples were for SET, looking for threshold LET.

IV. Test Methods

A single DUT was mounted on a board and attached as shown in the diagram in **Figure 3.** Temperature was monitored via a sense wire attached to DUT.

Incorporation of a 100μF capacitor at the input terminals was recommended by I.R. as compensation for the dynamic effects of the parasitic resistance of the input cable reacting with the complex impedance of the converter input. It also provided an energy reservoir for transient input current requirements.

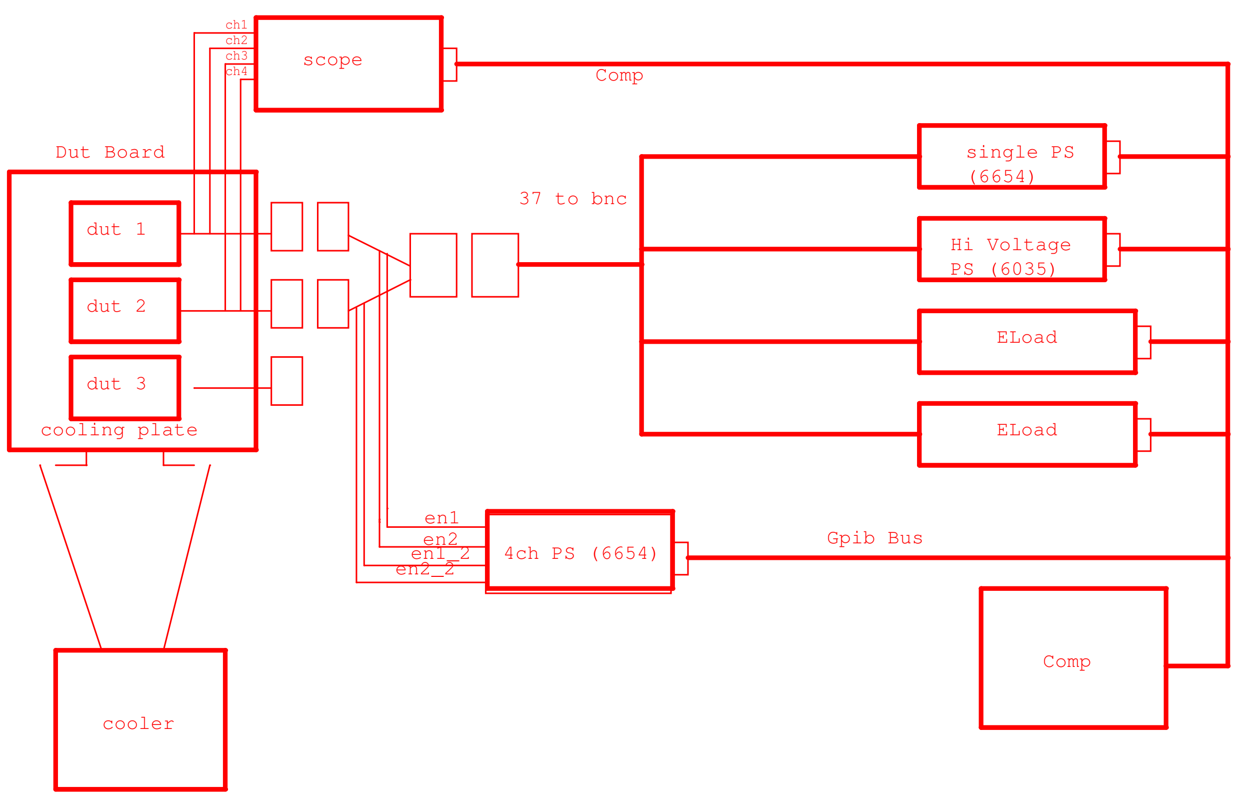


Figure 3 - AFL 2828 Test Setup Block Diagram (typical setup – AFL test utilized a single DUT)

The following is a list of major equipment used for this test:

Laptop Computer running LabVIEW
HP 6626 4-channel Power Supply
HP 6060B Electronic Load
Tektronix TDS3034b Digital Oscilloscope

V. Test Requirements

1. Perform Single Event Destructive test by exposing DUTs to at least 10^7 ions/cm^2 while monitoring the output. All testing is to be done at room temperature (25°C ±6°).
2. SET testing is to be done while monitoring the device output for dropouts and transients. Sufficient ion fluence is to be used to collect a statistically significant data set for each event type or 10^7 ions/cm^2 is reached. Errors may manifest themselves as poor spectral purity. Transient effects will cause the output voltage to deviate from its normal DC level and to return.
   Minimum SET size for capture is ±500 mV triggering.
3. Before and after LabVIEW traces are to be taken to monitor for changes in device performance.

VI. Test Procedure

Destructive test on one device only

1. Locate active components in two locations on DUT. Start at first location with Kr ion. Parameters to monitor during heavy ion irradiation include temperature of DUT, Input Current, Output Voltage, Output Loading, SETs, and functionality.

2. For each irradiation, verify that DUT is running at room temperature before part is exposed. Use both positive and negative triggering.

3. Vary loading between 10, 25, 60, and 80% of V_{out} (programmed)

4. Switch to second location on DUT and repeat **1-3**.

5. Change to heavier ion Xe if no functional failure and repeat **1-4**

6. Repeat with heavier ions until part fails or maximum LET reached.

SET Testing on two remaining devices

7. Repeat **1-4** above to find threshold LET.
8. Take scope pictures or LabVIEW captures when transients are triggered ±500 mV. Be able to measure pulse amplitude and pulse width. Toggle inhibits to verify their functionality. Repeat **1-4** above with incrementally lighter ions, Ar and Ne. (NO TIME)

End of test.

Take pictures of test setup before breaking down equipment.

Test	Test Conditions	Min	Max	Units
OUTPUT VOLTAGE REGULATION	No Load, 50% Load, 100% Load	-70	70	mV
OUTPUT RIPPLE VOLTAGE	VIN = 16, 28, 40 Volts, 100% Load, BW = 10MHz		100	mVpp
INPUT CURRENT	VIN = 28 Volts		80	mA
No Load	IOUT = 0		100	mA
Inhibit 1	Pin 4 Shorted to Pin 2		5	mA
Inhibit 2	Pin 12 Shorted to Pin 8		50	mA
INPUT RIPPLE CURRENT	VIN = 28 Volts, 100% Load, BW = 10MHz		60	mApp
EFFICIENCY	VIN = 28 Volts, 100% Load	81		%
ENABLE INPUTS (Inhibit Function)				
Converter Off	Logical Low on Pin 4 or Pin 12		0.8	V
Sink Current			100	µA
Converter On	Logical High on Pin 4 and Pin 12 - Note 9		50	V
Sink Current			100	µA
SWITCHING FREQUENCY		500	600	kHz
SYNCHRONIZATION INPUT		500	700	KHz
Frequency Range		2	10	V
Pulse Amplitude, Hi		-0.5	0.8	V
Pulse Amplitude, Lo			100	ns
Pulse Rise Time		20	80	%
Pulse Duty Cycle				
LOAD TRANSIENT RESPONSE				
Amplitude	Load Step 50%⇔ 100%	-1200	1200	mV
Recovery			200	µs
Amplitude	Load Step 10%⇔ 50%	-1200	1200	mV
Recovery			400	µs
LINE TRANSIENT RESPONSE				
Amplitude	VIN Step = 16⇔ 40 Volts	-500	500	mV
Recovery			500	µs
TURN-ON CHARACTERISTICS	VIN = 16, 28, 40 Volts. Enable 1, 2 on. (Pins 4, 12 high or open)			
Overshoot			250	mV
Delay		0	10	ms

Figure 4 - I.R. AFL 2828 Data Sheet Specifications

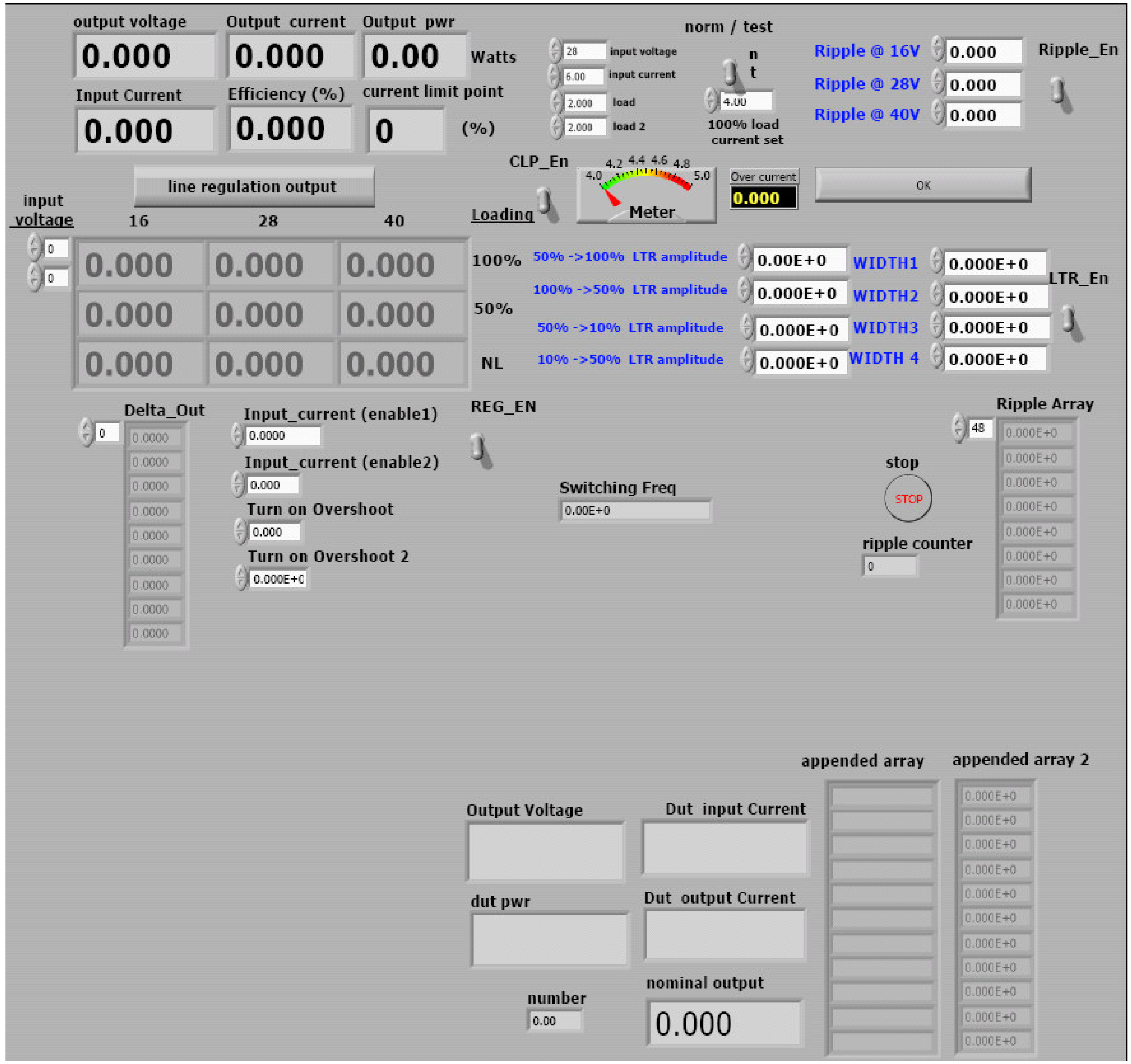


Figure 5 - AFL 2828 LabVIEW Test Program

VII. Results

No destructive single events were observed during this test. Please note that testing was only performed at room temperature and with normal beam incidence to the DUT (no angles, beam perpendicular to die plane). Below is the test log of each run showing setup (Vin, Load), Ion and beam info and SETs observed during each run.

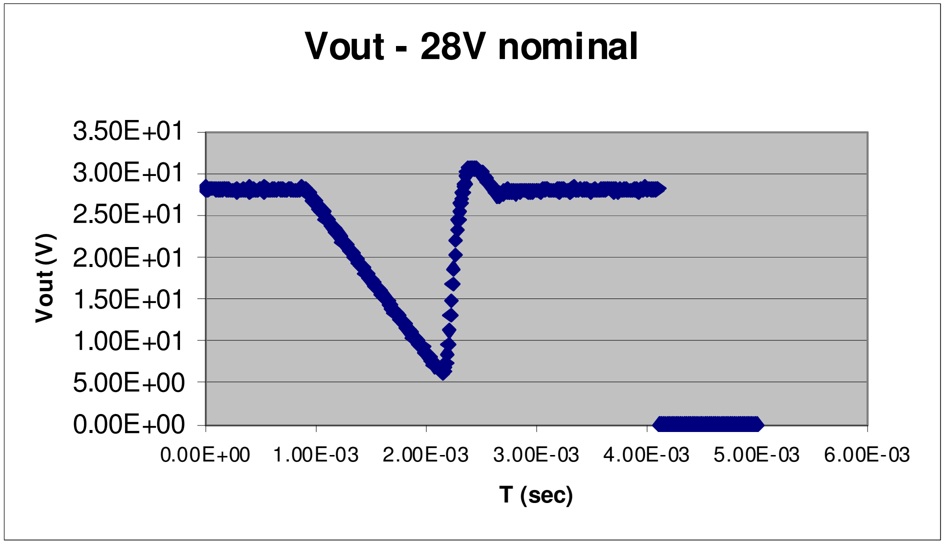
Run	DUT#	Area	Vin	Load	Iout	Icc	Ion-energy	LET	Angle	Effective LET	Flux	Eff Fluence	SET	Captured	sig_SET
1	0723002B	1	20	10%	400mA	785mA	Xe-1329	53.5	0	53.50	5.00E+04	3.96E+05	240	61	6.06E-04
2	0723002B	1	20	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	5.08E+05	567	414	1.12E-03
3	0723002B	1	20	10%	400mA		Xe-1329	53.5	0	53.50	1.00E+03	1.70E+05	204	200	1.20E-03
4	0723002B	1	20	25%	1A		Xe-1329	53.5	0	53.50	1.00E+03	1.79E+05	241	236	1.35E-03
5	0723002B	1	20	60%	2.4A		Xe-1329	53.5	0	53.50	1.00E+03	1.67E+05	221	215	1.32E-03
6	0723002B	1	20	80%	3.2A	5.56A	Xe-1329	53.5	0	53.50	1.00E+03	3.18E+05	405	393	1.27E-03
7	0723002B	1	35	80%	3.2A	3.06A	Xe-1329	53.5	0	53.50	1.00E+03	1.88E+05	222	214	1.18E-03
8	0723002B	1	20	80%	3.2A	5.56A	Xe-1329	53.5	0	53.50	1.00E+03	5.48E+04	65	64	1.19E-03
9	0723002B	1	35	60%	2.4A	2.3A	Xe-1329	53.5	0	53.50	1.00E+03	1.69E+05	209	205	1.24E-03
10	0723002B	1	35	25%	1A	1.02A	Xe-1329	53.5	0	53.50	1.00E+03	1.67E+05	200	196	1.20E-03
11	0723002B	1	35	10%	400mA	490mA	Xe-1329	53.5	0	53.50	1.00E+03	1.54E+05	207	199	1.34E-03
12	0723002B	2	20	10%	400mA	785mA	Xe-1329	53.5	0	53.50	1.00E+03	6.12E+05	108	107	1.76E-04
13	0723002B	2	20	25%	1A	1.7A	Xe-1329	53.5	0	53.50	1.00E+03	3.09E+05	51	51	1.65E-04
14	0723002B	2	20	60%	2.4A	4.07A	Xe-1329	53.5	0	53.50	5.00E+03	1.00E+06	417	385	4.17E-04
15	0723002B	2	20	80%	3.2A	5.57A	Xe-1329	53.5	0	53.50	5.00E+03	6.04E+05	211	200	3.49E-04
16	0723002B	2	35	80%	3.2A	3.06A	Xe-1329	53.5	0	53.50	5.00E+03	7.83E+05	204	196	2.61E-04
17	0723002B	2	35	60%	2.4A		Xe-1329	53.5	0	53.50	5.00E+03	7.58E+05	202	190	2.66E-04
18	0723002B	2	35	25%	1A		Xe-1329	53.5	0	53.50	5.00E+03	9.21E+05	100	98	1.09E-04
19	0723002B	2	35	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	1.60E+01	76	76	4.75E+00
20	0723005B	1	20	10%	400mA	785mA	Xe-1329	53.5	0	53.50	2.00E+03	4.17E+05	211	208	5.06E-04
21	0723005B	1	20	25%	1A		Xe-1329	53.5	0	53.50	2.00E+03	4.33E+05	100	100	2.31E-04
22	0723005B	1	20	60%	2.4A		Xe-1329	53.5	0	53.50	1.00E+03	1.38E+05	0		0.00E+00
23	0723005B	1	20	80%	3.2A		Xe-1329	53.5	0	53.50	2.00E+03	5.84E+05	207	201	3.54E-04
24	0723005B	1	35	80%	3.2A		Xe-1329	53.5	0	53.50	2.00E+03	2.18E+05	17	17	7.80E-05
25	0723005B	1	35	60%	2.4A		Xe-1329	53.5	0	53.50	5.00E+03	1.01E+06	32	32	3.17E-05
26	0723005B	1	35	25%	1A		Xe-1329	53.5	0	53.50	5.00E+03	4.23E+05	243	219	5.74E-04
27	0723005B	1	35	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	5.77E+05	411	346	7.12E-04
28	0723005B	2	20	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	1.16E+06	212	204	1.83E-04
29	0723005B	2	20	25%	1A		Xe-1329	53.5	0	53.50	5.00E+03	9.84E+05	209	201	2.12E-04
30	0723005B	2	20	60%	2.4A		Xe-1329	53.5	0	53.50	5.00E+03	4.59E+05	216	204	4.71E-04
31	0723005B	2	20	80%	3.2A		Xe-1329	53.5	0	53.50	5.00E+03	5.21E+05	211	203	4.05E-04
32	0723005B	2	35	80%	3.2A		Xe-1329	53.5	0	53.50	5.00E+03	5.92E+05	228	218	3.85E-04
33	0723005B	2	35	60%	2.4A		Xe-1329	53.5	0	53.50	5.00E+03	4.37E+05	118	112	2.70E-04
34	0723005B	2	35	25%	1A		Xe-1329	53.5	0	53.50	5.00E+03	4.04E+05	109	102	2.70E-04
35	0723005B	2	35	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	3.11E+05	115	108	3.70E-04
36	0723005B	2	20	80%	3.2A		Kr-933	29.1	0	29.10	2.00E+04	2.67E+06	204	197	7.64E-05
37	0723005B	2	20	60%	2.4A		Kr-933	29.1	0	29.10	2.00E+04	3.45E+06	208	198	6.03E-05

Table 1: SET Test Results (Part 1 of 2)

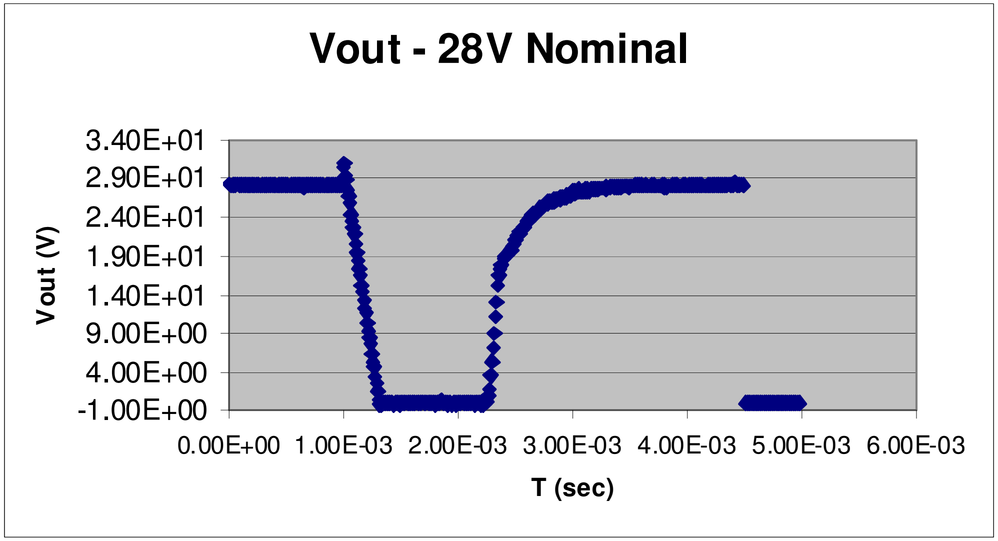
Run	DUT#	Area	Vin	Load	Iout	Icc	Ion-energy	LET	Angle	Effective LET	Flux	Eff Fluence	SET	Captured	sig_SET
1	0723002B	1	20	10%	400mA	785mA	Xe-1329	53.5	0	53.50	5.00E+04	3.96E+05	240	61	6.06E-04
2	0723002B	1	20	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	5.08E+05	567	414	1.12E-03
3	0723002B	1	20	10%	400mA		Xe-1329	53.5	0	53.50	1.00E+03	1.70E+05	204	200	1.20E-03
4	0723002B	1	20	25%	1A		Xe-1329	53.5	0	53.50	1.00E+03	1.79E+05	241	236	1.35E-03
5	0723002B	1	20	60%	2.4A		Xe-1329	53.5	0	53.50	1.00E+03	1.67E+05	221	215	1.32E-03
6	0723002B	1	20	80%	3.2A	5.56A	Xe-1329	53.5	0	53.50	1.00E+03	3.18E+05	405	393	1.27E-03
7	0723002B	1	35	80%	3.2A	3.06A	Xe-1329	53.5	0	53.50	1.00E+03	1.88E+05	222	214	1.18E-03
8	0723002B	1	20	80%	3.2A	5.56A	Xe-1329	53.5	0	53.50	1.00E+03	5.48E+04	65	64	1.19E-03
9	0723002B	1	35	60%	2.4A	2.3A	Xe-1329	53.5	0	53.50	1.00E+03	1.69E+05	209	205	1.24E-03
10	0723002B	1	35	25%	1A	1.02A	Xe-1329	53.5	0	53.50	1.00E+03	1.67E+05	200	196	1.20E-03
11	0723002B	1	35	10%	400mA	490mA	Xe-1329	53.5	0	53.50	1.00E+03	1.54E+05	207	199	1.34E-03
12	0723002B	2	20	10%	400mA	785mA	Xe-1329	53.5	0	53.50	1.00E+03	6.12E+05	108	107	1.76E-04
13	0723002B	2	20	25%	1A	1.7A	Xe-1329	53.5	0	53.50	1.00E+03	3.09E+05	51	51	1.65E-04
14	0723002B	2	20	60%	2.4A	4.07A	Xe-1329	53.5	0	53.50	5.00E+03	1.00E+06	417	385	4.17E-04
15	0723002B	2	20	80%	3.2A	5.57A	Xe-1329	53.5	0	53.50	5.00E+03	6.04E+05	211	200	3.49E-04
16	0723002B	2	35	80%	3.2A	3.06A	Xe-1329	53.5	0	53.50	5.00E+03	7.83E+05	204	196	2.61E-04
17	0723002B	2	35	60%	2.4A		Xe-1329	53.5	0	53.50	5.00E+03	7.58E+05	202	190	2.66E-04
18	0723002B	2	35	25%	1A		Xe-1329	53.5	0	53.50	5.00E+03	9.21E+05	100	98	1.09E-04
19	0723002B	2	35	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	1.60E+01	76	76	4.75E+00
20	0723005B	1	20	10%	400mA	785mA	Xe-1329	53.5	0	53.50	2.00E+03	4.17E+05	211	208	5.06E-04
21	0723005B	1	20	25%	1A		Xe-1329	53.5	0	53.50	2.00E+03	4.33E+05	100	100	2.31E-04
22	0723005B	1	20	60%	2.4A		Xe-1329	53.5	0	53.50	1.00E+03	1.38E+05	0		0.00E+00
23	0723005B	1	20	80%	3.2A		Xe-1329	53.5	0	53.50	2.00E+03	5.84E+05	207	201	3.54E-04
24	0723005B	1	35	80%	3.2A		Xe-1329	53.5	0	53.50	2.00E+03	2.18E+05	17	17	7.80E-05
25	0723005B	1	35	60%	2.4A		Xe-1329	53.5	0	53.50	5.00E+03	1.01E+06	32	32	3.17E-05
26	0723005B	1	35	25%	1A		Xe-1329	53.5	0	53.50	5.00E+03	4.23E+05	243	219	5.74E-04
27	0723005B	1	35	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	5.77E+05	411	346	7.12E-04
28	0723005B	2	20	10%	400mA		Xe-1329	53.5	0	53.50	5.00E+03	1.16E+06	212	204	1.83E-04
29	0723005B	2	20	25%	1A		Xe-1329	53.5	0	53.50	5.00E+03	9.84E+05	209	201	2.12E-04
30	0723005B	2	20	60%	2.4A		Xe-1329	53.5	0	53.50	5.00E+03	4.59E+05	216	204	4.71E-04
31	0723005B	2	20	80%	3.2A		Xe-1329	53.5	0	53.50	5.00E+03	5.21E+05	211	203	4.05E-04
32	0723005B	2	35	80%	3.2A		Xe-1329	53.5	0	53.50	5.00E+03	5.92E+05	228	218	3.85E-04
33	0723005B	2	35	60%	2.4A		Xe-1329	53.5	0	53.50	5.00E+03	4.37E+05	118	112	2.70E-04

Table 1: SET Test Results (Part 2 of 2)

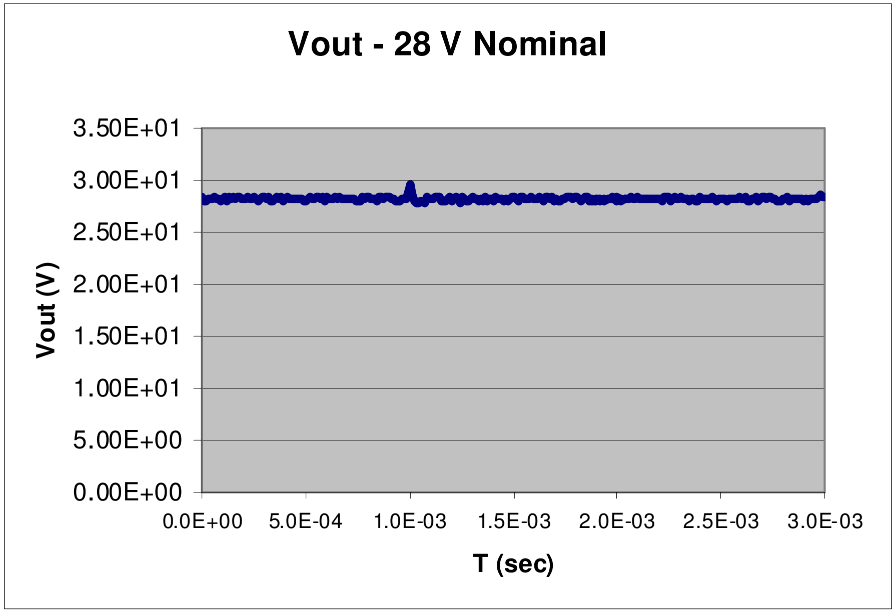
Typical SETs are shown below representing the three shapes of SETs observed



Test Conditions: DUT 0723002B
Area 2
Vin 20V
Load 10%
LET 53.5 $MeV*cm^2*mg^{-1}$



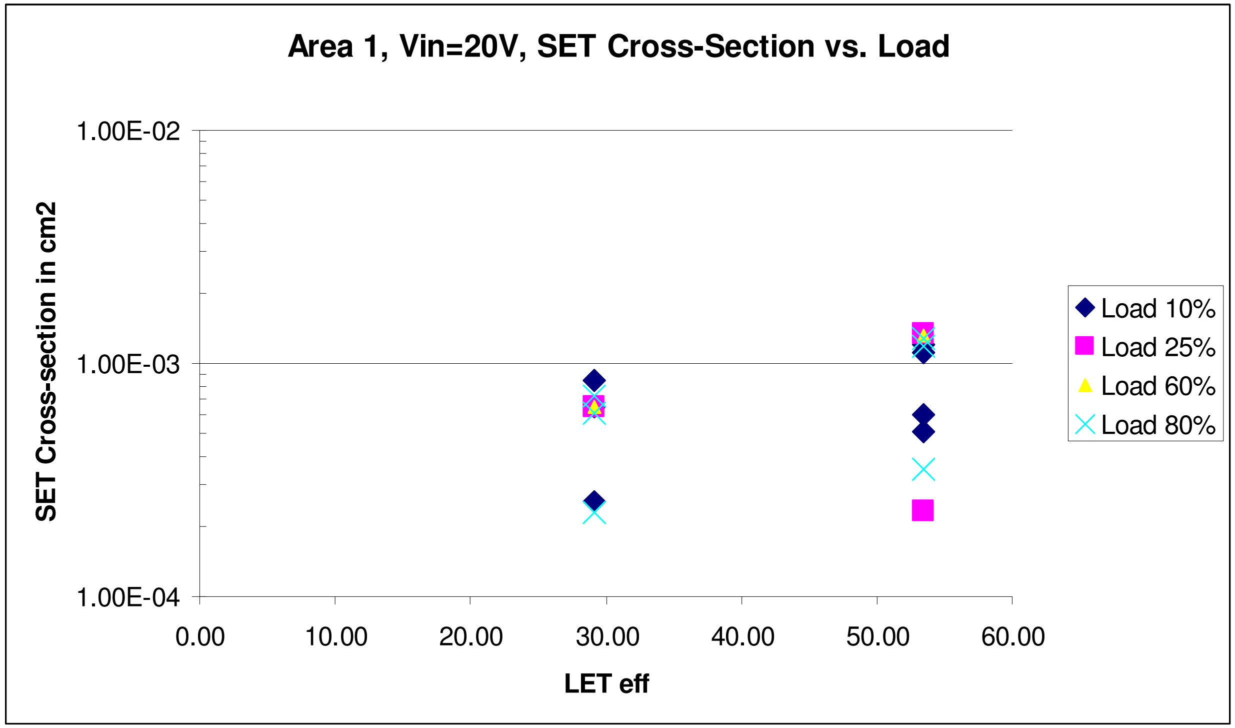
Test Conditions: DUT 0723002B
Area 1
Vin 20V
Load 60%
LET 53.5 $MeV*cm^2*mg^{-1}$

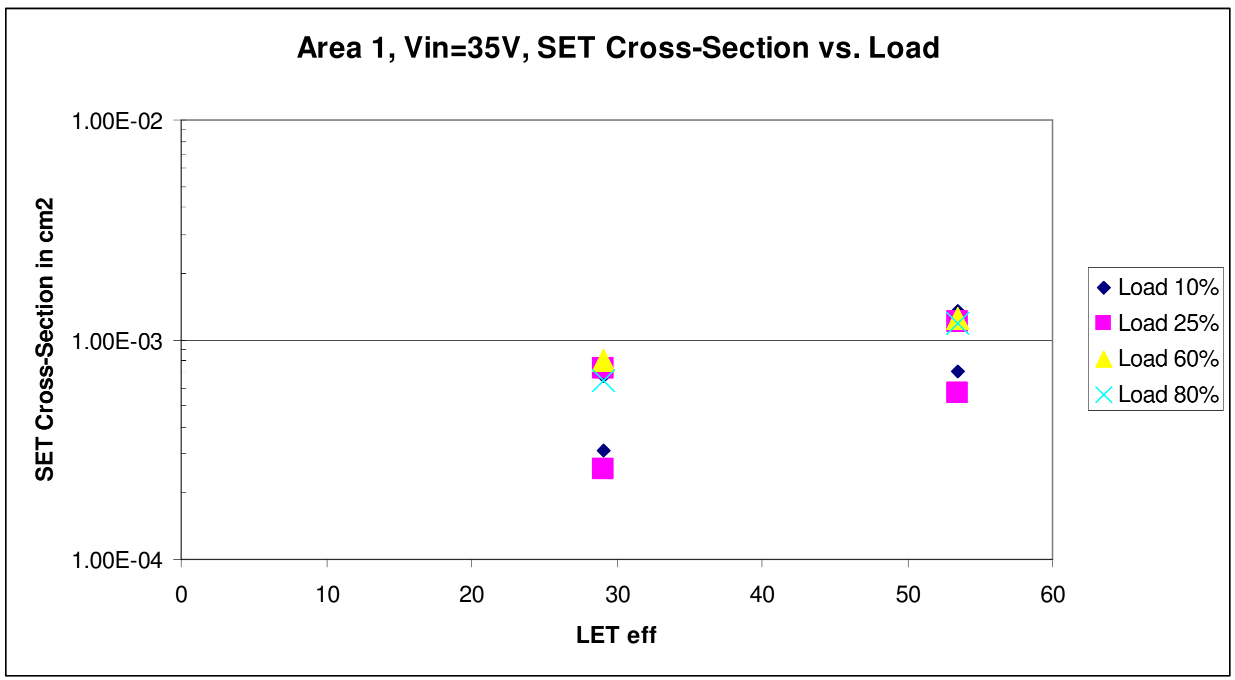


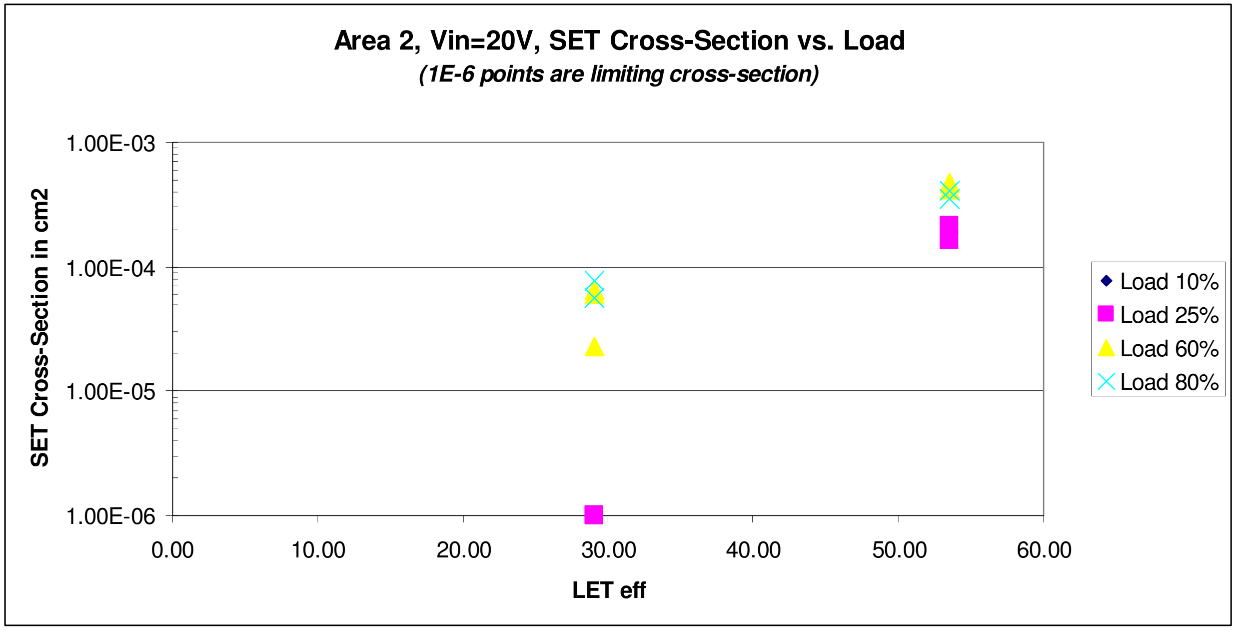
dut 2

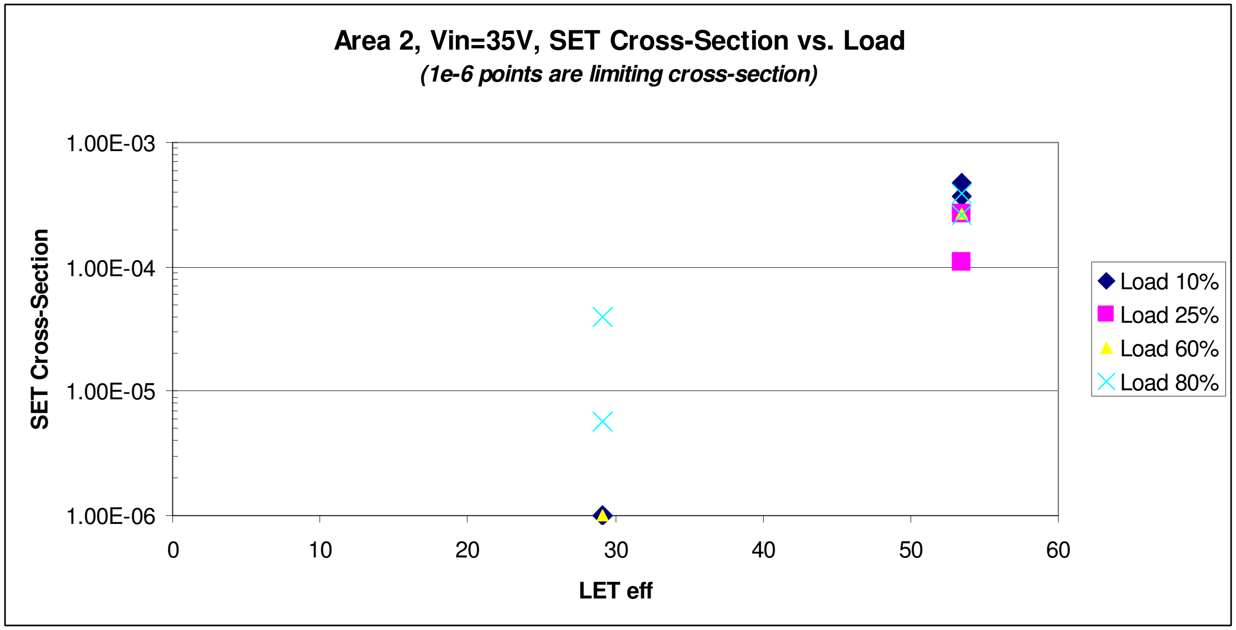
Test Conditions: DUT 0723002B
Area 1
Vin 20V
Load 60%
LET 53.5 MeV*cm^{2}*mg^{-1}

The graphs below illustrate the SETs as a function of Vin and Load. For simplicity, data from the two DUT samples were graphed together.


Area 1, Vin=20V, SET Cross-Section vs. Load
SET Cross-section in cm2
1.00E-02
1.00E-03
1.00E-04
0.00
10.00
20.00
30.00
40.00
50.00
60.00
LET eff
Load 10%
Load 25%
Load 60%
Load 80%


Area 1, Vin=35V, SET Cross-Section vs. Load
SET Cross-Section in cm2
1.00E-02
1.00E-03
1.00E-04
0
10
20
30
40
50
60
LET eff
Load 10%
Load 25%
Load 60%
Load 80%





VIII. Discussion of Results

Two device samples were tested using two parts with two ions (Xe and Kr) due to the usual beam time constraints. No destructive events were noted.

This DC-DC converter is sensitive to SET. Input voltage appears to play a role in SET sensitivity, possibly due to the fact that the part works in different modes if input voltage is higher or lower than output voltage. With Vin=20V, larger SETs were noted with the output voltage going down to 0V, and SET duration of ~1.5 ms. Load does not appear as significant for SET shape except for the lowest load of 400 mA. With a 400 mA output current, SET size is smaller (a few volts amplitude). In addition to large SETs, smaller SETs were also observed. With an input voltage of Vin=35V, only smaller SETs were noted. To hit all active die, two irradiation areas were used per DUT. When irradiating the second area, no large SETs were observed. Note due to setup constraints, the position of areas 1 and 2 were different in each of the DUTs. Hence, slightly differing results were noted between the two samples. With further analysis, identification of sensitive component within this hybrid could be determined via more testing.

Please note that the overall SET cross-section is not simply Area 1 + Area 2, since there may have been some components within the hybrid irradiated during both exposures. However, while there is the possibility of SETs occurring from cosmic rays in space, the risk does not appear high and event rates are likely tractable for many missions.