SEE Test Report V3.0
Heavy Ion SEE test of RHFL4913 from ST Microelectronics with SET mitigation circuitry

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Test Date(s): November 18, 2006 Report Date: September 19, 2007

I. Introduction

This study is a follow up to earlier heavy ion testing of RHFL4913[1] adjustable positive voltage regulator. Previous test showed high SET susceptibility. Data showed that increasing output capacitor did not change significantly SET cross-sections. Data also that a RC filter reduced SET cross-sections at high LET and that only short duration transients remained. The goal of this test was to check if additional components to the RC filter and modified circuit topology further reduced effects.

The Devices Under Test (DUT) were monitored for transient interruptions in the output signal and for destructive events induced by exposing it to a heavy ion beam at the Texas A&M Cyclotron Institute Radiation Effects Testing Facility. This test was performed in consideration for the LaRC Advanced Avionics project requirements and for the NASA Parts and Packaging Program (NEPP).

II. Devices Tested

The sample size of the testing was three devices. Two devices were exposed and one was used as a control sample. ST Microelectronics manufactured the device. The tested devices had a Lot Date Code of 0510A. The device technology was bipolar and the device was packaged in a 16 pin flat package. The devices were prepped for test by delidding and then incorporated into the target circuit assembly. DUT1-SN103 and DUT2-SN104 were tested.

III. Test Facility

Facility: Texas A&M University Cyclotron Single Event Effects Test Facility, 15 MeV/amu tune)

Flux: 7.3×10^3 to 9.7×10^4 particles/cm^2/s.

Fluence:

Most tests were run up to 2×10^7 p/cm^2 or until a sufficient (>100) number of transient events occurred.

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[1] "Heavy ion SEE test of RHFL4913 from ST Microelectronics," SEE test report V1.0, January 23, 2006.

Table 1: Ion an LET and range values at target for 0 degree incidence

Ion	LET ($MeV \cdot cm^2/mg$)	Range (μm)
Ne	2.8	262
Ar	8.7	174
Xe	53.9	102

IV. Test Conditions and Error Modes

Test Temperature: Room Temperature

Bias conditions: Bias conditions are shown below. Different test conditions are itemized in Table 2. They are representative of different application conditions.

Baseline bias condition is shown in Figure 1. It includes the same RC filter (0.1 ohm, 200 mF) than the one used in previous tests. In addition, the two mitigations suggested by ST Microelectronics, DUT manufacturer, were implanted. They consist in a 0.2 ohm resistor placed at the input before input filtering capacitors and a 1N5820 Schottky diode placed just at the DUT output. Another change from previous test was the remote feedback. A drawback of RC filtering is the voltage dropout in the serial resistor. By placing the feedback after the RC filter, the regulated output voltage remains the same whatever the output current. In previous tests we used remote programmable loads that were about 3 feet from DUT. Manufacturer suggested that the use of programmable active loads combined to the distance from DUT might have been an issue. For these tests NASA LaRC built a printed circuit boards (PCB) for each DUT. Resistive loads are mounted on the PCB. Therefore, loads are close to the DUT.

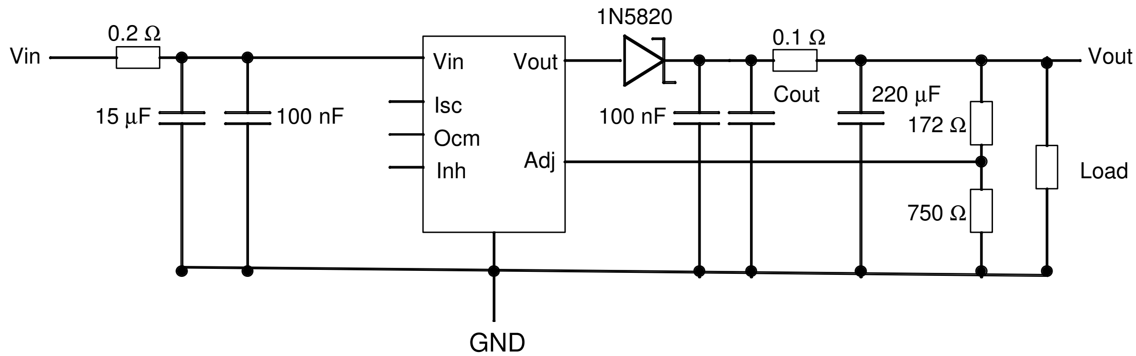

Figure 1: Baseline bias configuration, remote feedback

In the second tested configuration, shown in Figure 2, the feedback is before the filter after Schottky diode. Therefore, because of voltage dropout in filter resistor, output voltage changes with output current.

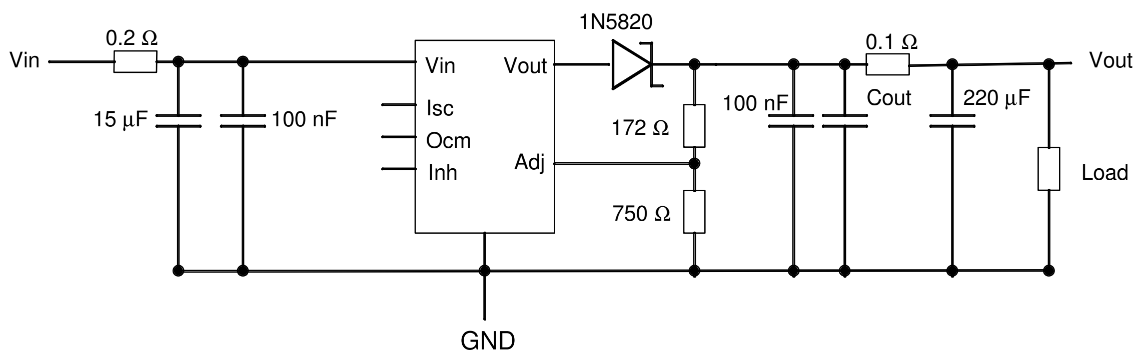

Figure 2: local feedback configuration

Test conditions are shown in Table 2.

Table 2: Test conditions

Test Configuration	Vin (V)	Vout (V)	Cout (µF)	Iout (mA)
BaseLine Remote Feedback	3.3	1.5	No output capacitor (filter only)	0 (no load)
	3.3	1.5	No output capacitor (filter only)	300
	3.3	1.5	No output capacitor (filter only)	600
	3.3	1.5	No output capacitor (filter only)	1500
	5	1.5	No output capacitor (filter only)	0 (no load)
	3.3	1.5	60	300
	3.3	1.5	60	600
	3.3	1.5	690	1500
	3.3	1.5	750	300
Local Feedback	3.3	1.5	No output capacitor (filter only)	0
	3.3	1.5	No output capacitor (filter only)	300
	3.3	1.5	No output capacitor (filter only)	600
	3.3	1.5	No output capacitor (filter only)	1500

LaRC PCB is shown in Figure 3. Configuration and load conditions are changed via jumpers.

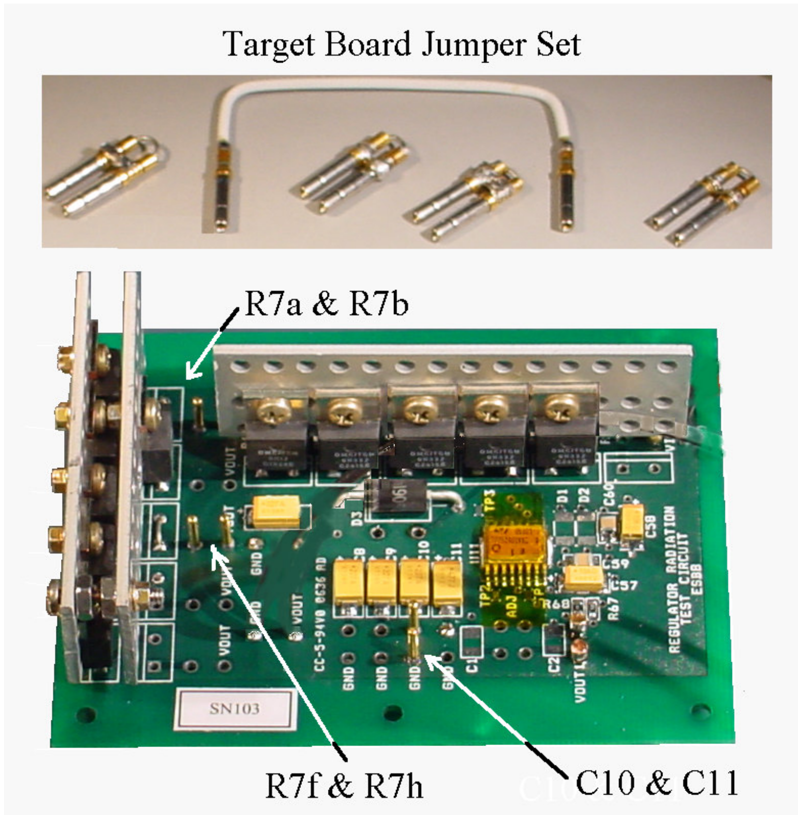

Figure 3: LaRC test board

PARAMETERS OF INTEREST: Input current, Output voltage

SEE Conditions: SEL, SEGR, SET

V. Test Methods

Test circuit, as shown in Figure 4, for the adjustable regulator contains a power supply for the input voltage and a digital scope for capturing any output anomalies.

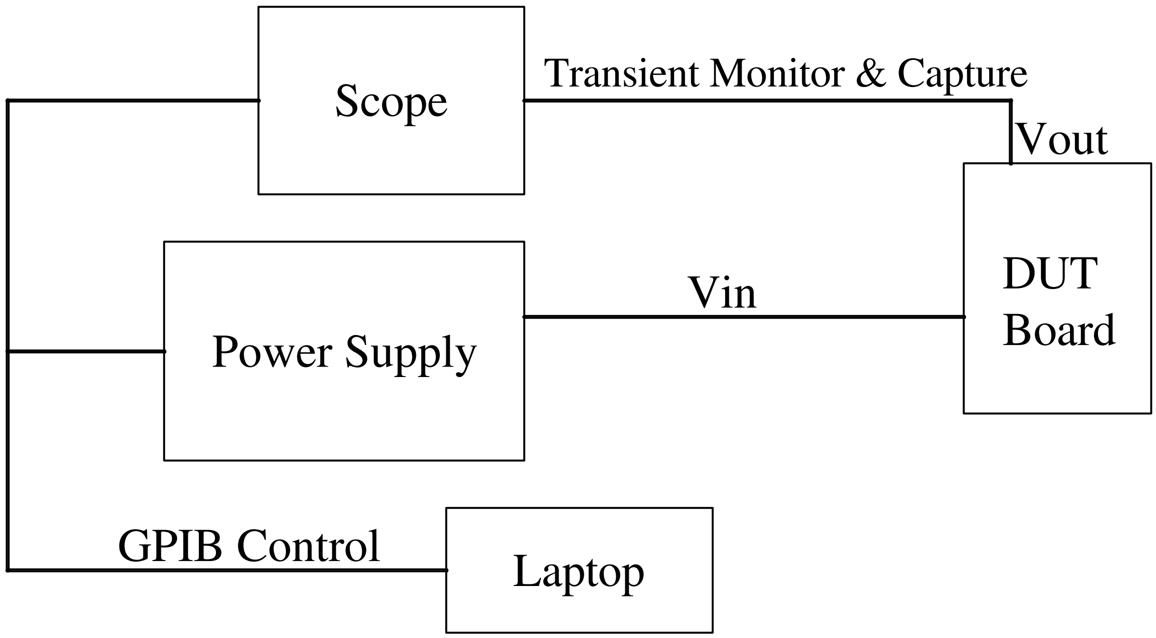

Figure 4. Overall Block Diagram for the testing of the RHFL4913.

Once the adjustable regulator received the input voltage, it produced a regulated output, which was determined by an external resistor network (see Figure 1). The digital scope triggered for both voltage dropouts and over voltage conditions at the output terminal. Trigger levels for different test conditions are shown in Table 3.

Table 3: Trigger Levels

Feedback	Iout (mA)	Vout (V)	Dropout trigger (V)	Over voltage trigger (V)
Remote	all	1.53	1.45	1.6
Local	No load	1.53	1.45	1.6
	300	1.49	1.42	1.56
	600	1.47	1.4	1.54
	1500	1.38	1.31	1.45

VI. Test Results

Detailed test results are shown in Appendix. Figure 5 shows the plot of SET cross-sections versus LET. If we compare the measured cross-sections with the one measured in the previous tests, we can see that the additional mitigations (input resistor and Schottky diode) work. Cross sections are significantly lower. With the filter, at the highest LET of 75 MeVcm^2/mg, maximum cross-section measured for a load of 300 mA was about 5E-4 cm^2/device. During these tests the maximum cross-section for a load of

300 mA is about 1E-4 cm2/device. The difference is even larger at low LET (about one order of magnitude). Another significant difference is the effect of load. During previous tests sensitivity was increasing with output current. Here it is different. Part is not sensitive to SET for low loads (no output current) and the highest load (1.5A). Sensitivity is the highest for intermediate loads (output current of 300 and 600 mA). Other salient results are:

- as observed during previous tests, increasing output capacitor reduces SET cross-sections but not significantly.
- DUT is more sensitive for 5V input voltage
- There is part-to-part variability. One part was more sensitive than the other (about a factor 2)
- DUT is more sensitive in the remote feedback configuration (about a factor 2).

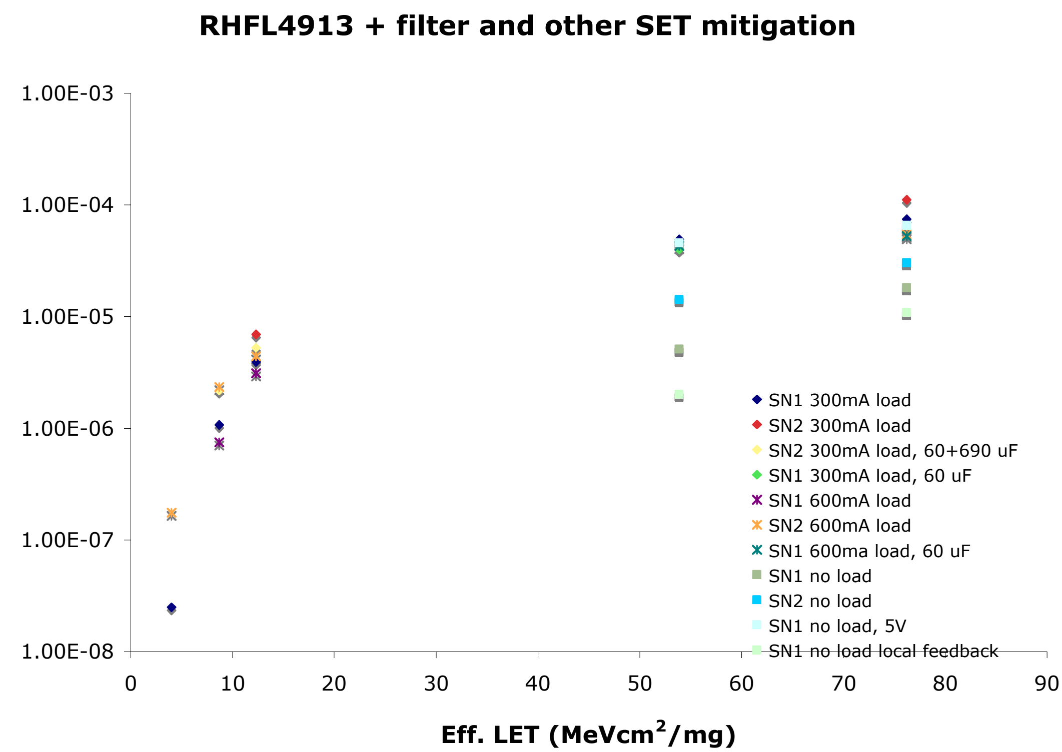

Figure 5. SET cross-sections

Figure 6 shows typical transient waveforms in the remote feedback configuration, without load at high LET. We can see that most transients are positive going pulses of small amplitude (~120 mV) and a duration of about 2 µs. A few SETs with a small amplitude as well but a very short duration (~ 20 ns) have also been observed. These short duration transients maybe positive going or bipolar.

Figure 7 shows typical SETs for the same conditions but a 5V input voltage. Waveforms are the same but their amplitude is larger.

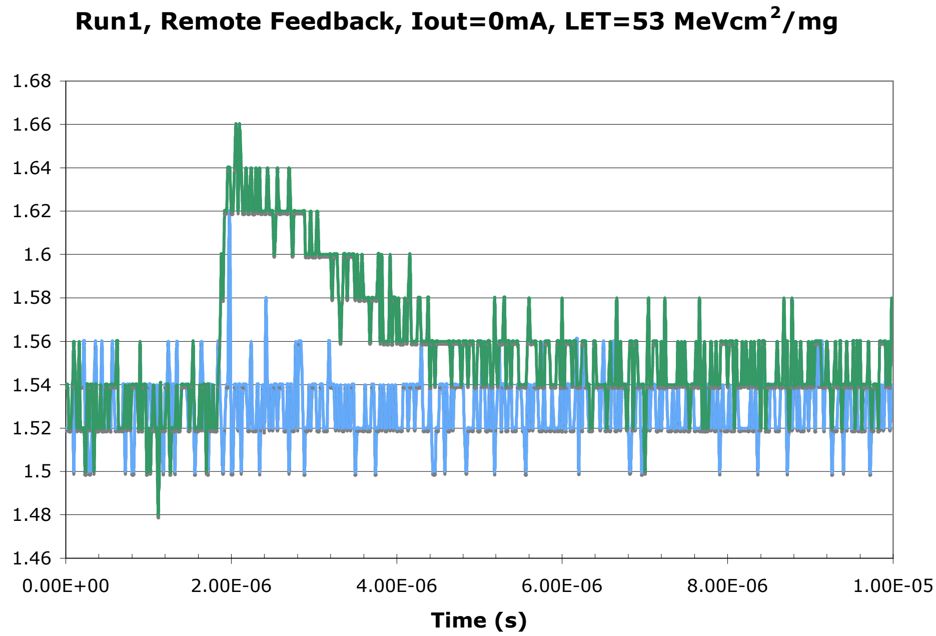

Figure 6. Typical SET waveform with remote feedback and no output current

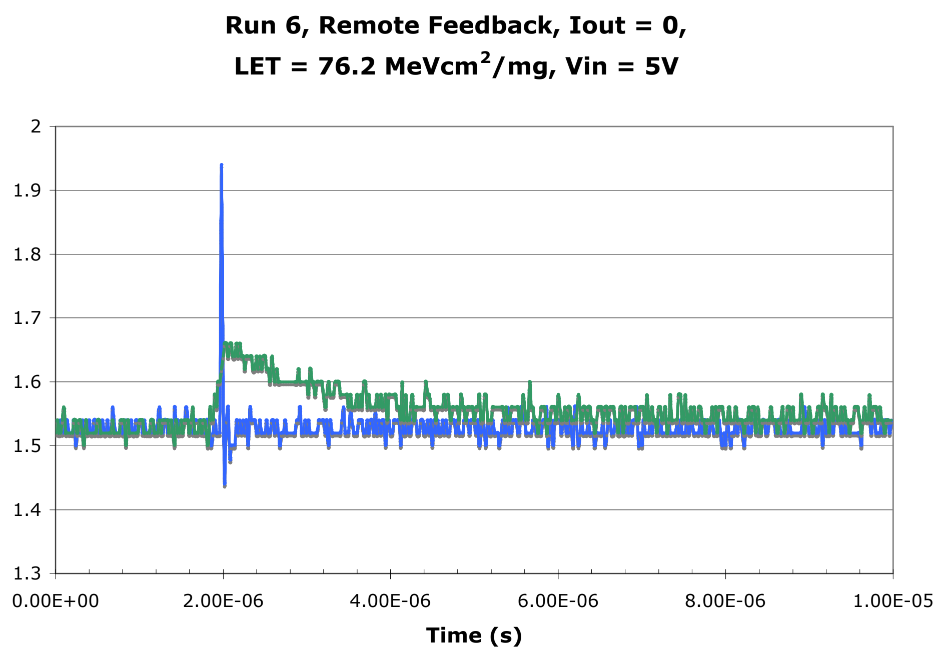

Figure 7. Typical SET waveform with remote feedback, no output current, and Vin=5V

Figure 8 shows typical SETs at high LET without load and a local feedback. We can see that with the local feedback we don't have any more long duration SETs.

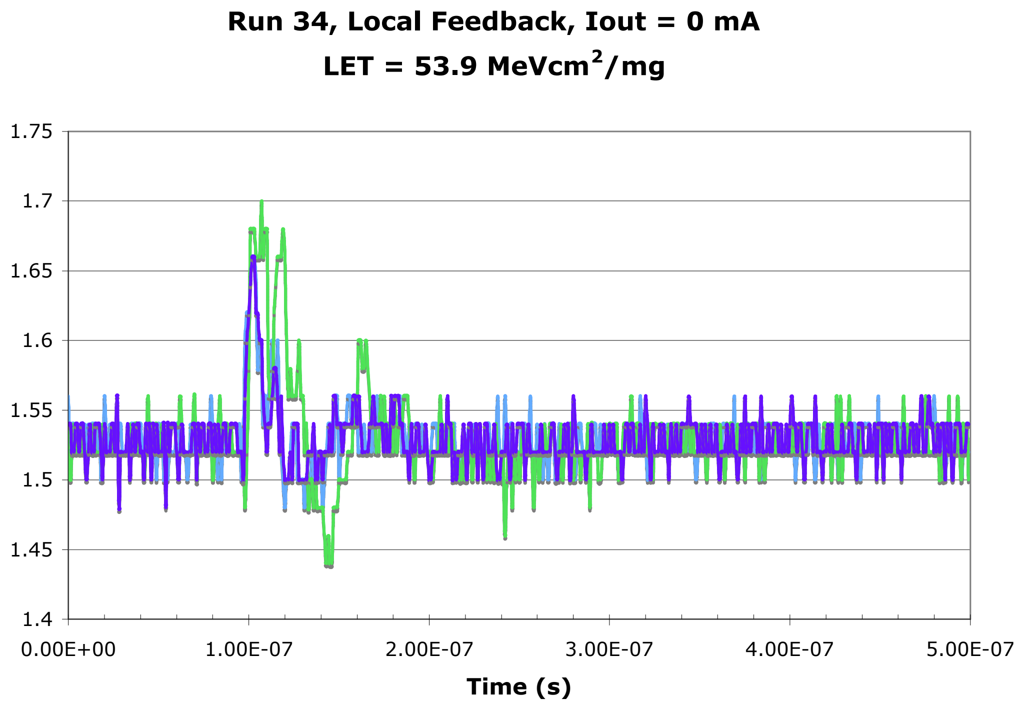

Figure 8: Typical SETs, local feedback, Iout = 0 mA, at high LET

Figure 9 shows typical SETs obtained at low LET with the remote feedback and an output current of 300 mA. All transients are bipolar and have small amplitude and short duration. At high LET we also see the small amplitude SET with long duration as shown in Figure 10.

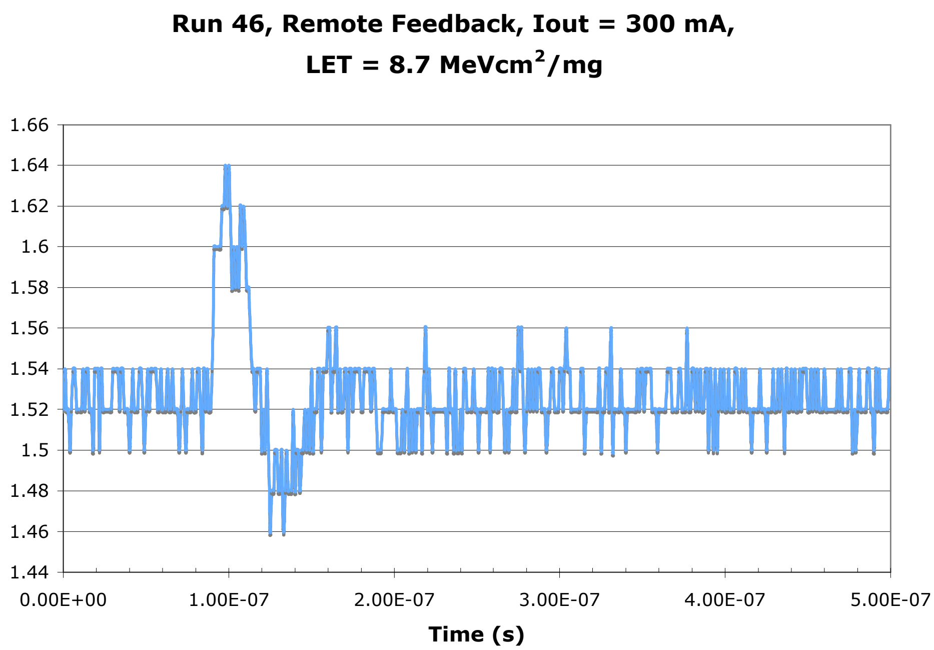

Figure 9: Typical SETs, remote feedback, Iout = 300 mA, LET = 8.7 MeVcm^2/mg

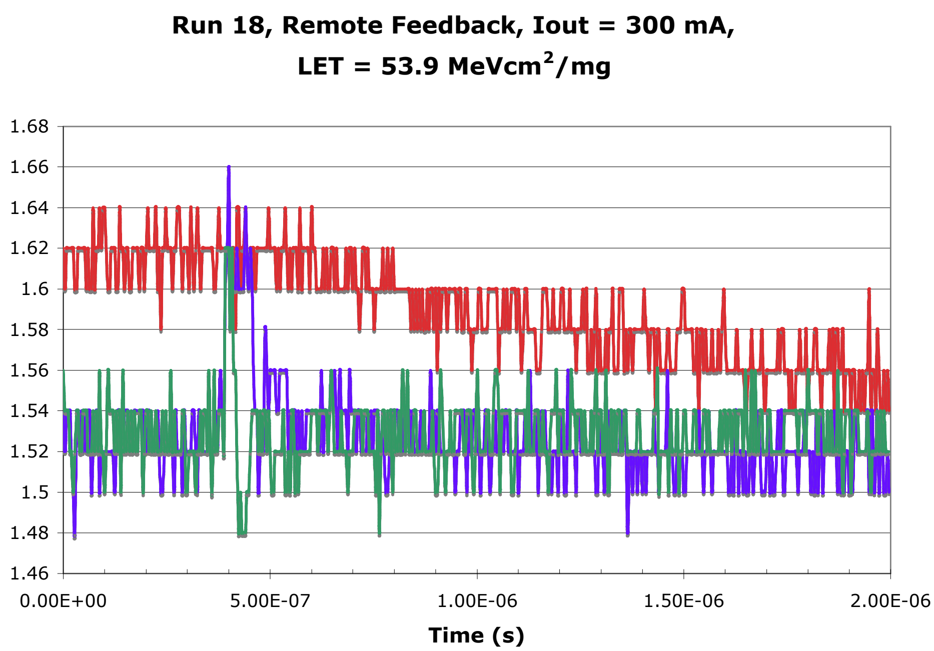

Figure 10: Typical SETs, remote feedback, Iout = 300 mA, LET = 53.9 MeVcm^2/mg

If we add additional output capacitors, long duration SETs are filtered as shown in Figure 11.

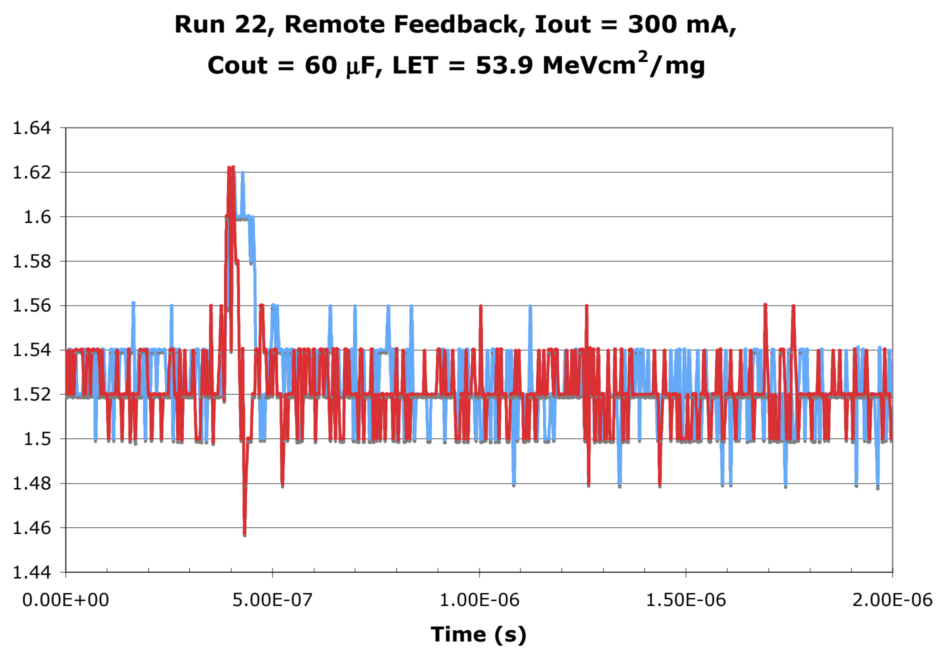

Figure 11: Typical SETs, remote feedback, Iout = 300 mA, Cout = 60 µF, LET = 53.9 $MeVcm^2/mg$

With an output current of 600 mA, some transient have a small amplitude long duration negative going component as shown in Figure 12.

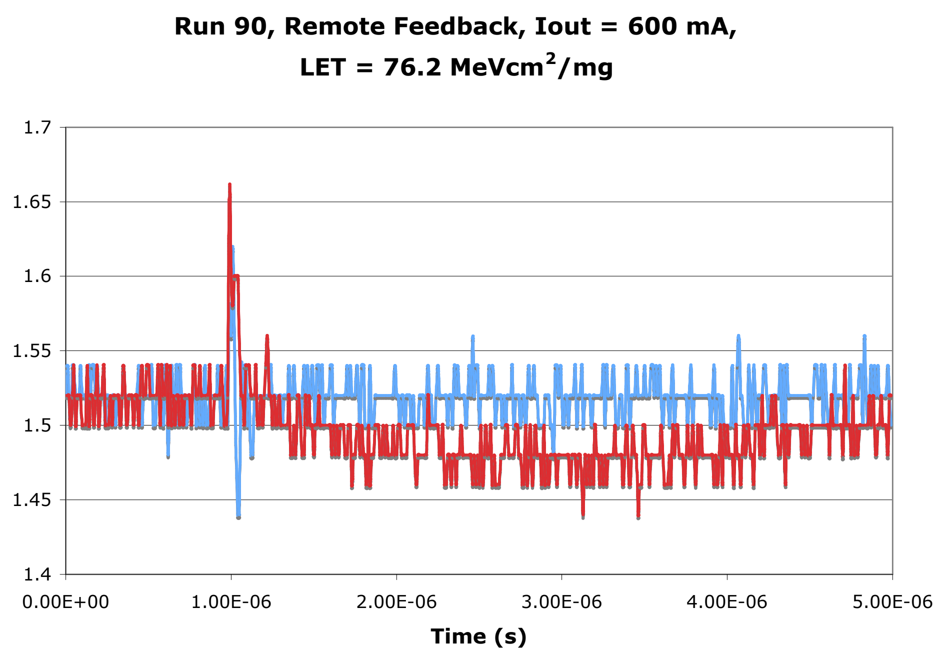

Figure 12: Typical SETs, remote feedback, Iout = 600 mA, LET = 76.2 $MeVcm^2/mg$

With an additional capacitor, only small amplitude short duration SETs remain as it is shown in Figure 13.

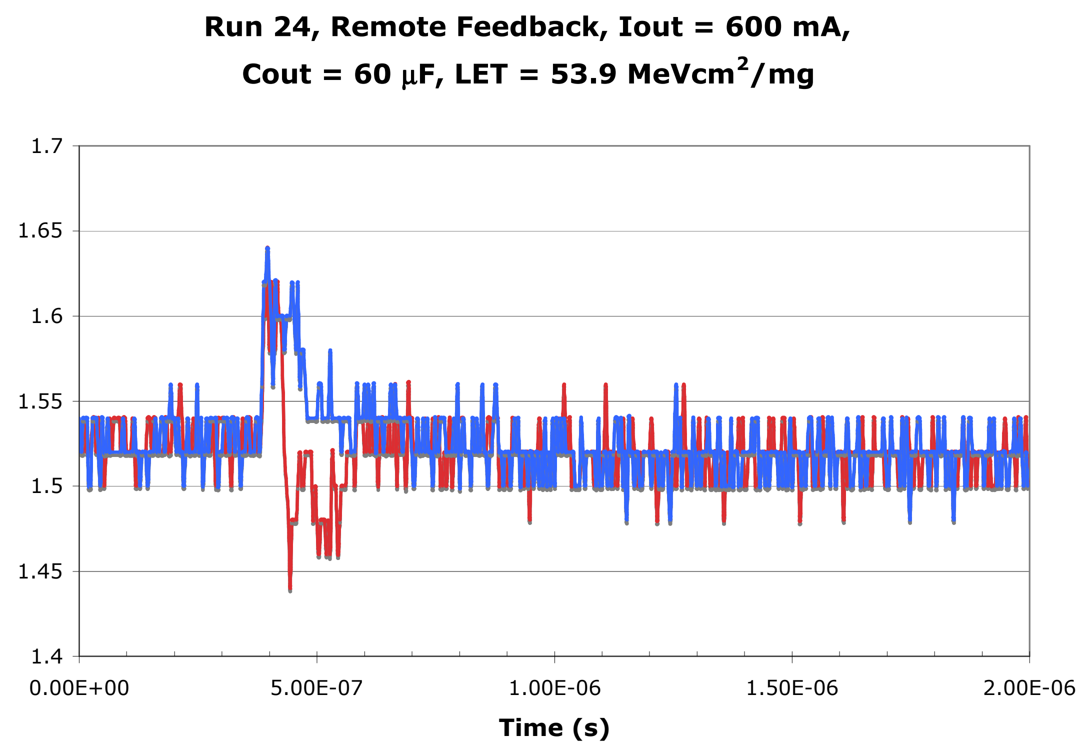

Figure 13: Typical SETs, remote feedback, Iout = 600 mA, Cout = 60 µF, LET = 53.9 meVcm^2/mg

VII. CONCLUSIONS

Previous tests have shown that RHFL4913 is very sensitive to heavy ion induced SETs. However, most SETs can be mitigated with a RC filter, an output capacitor, an input resistor, and a schottky diode. With these mitigations, SET sensitivity is significantly reduced and all remaining SETs have a small amplitude (< 100 mV) and a short duration (< 20 ns).

Appendix: Detailed test results

RUN #	Type	Test Configuration	DUT #	Vout (V)	Vin (V)	Iout (mA)	Cout (uF)	Icc (mA)	SET	Ion	Energy (MeV)	(MeVcm²/mg)	tilt	eff LET (MeVcm²/mg)	eff. Fluence (#/cm²)	SEL	X sec SET (cm²/dev)
1	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	87	Xe	1291	53.9	0	53.9	1.67E+07	0	5.21E-06
2	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	6	Xe	1291	53.9	0	53.9	9.99E+05	0	6.01E-06
3	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	99	Xe	1291	53.9	0	53.9	2.00E+07	0	4.95E-06
4	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	109	Xe	1291	53.9	45	76.2	5.30E+06	0	2.06E-05
5	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	109	Xe	1291	53.9	45	76.2	6.77E+06	0	1.61E-05
6	RHFL4913-0510A	Remote Feedback	1	1.5	5	no load	0	63	147	Xe	1291	53.9	45	76.2	2.02E+06	0	7.28E-05
7	RHFL4913-0510A	Remote Feedback	1	1.5	5	no load	0	63	226	Xe	1291	53.9	45	76.2	3.68E+06	0	6.14E-05
8	RHFL4913-0510A	Remote Feedback	1	1.5	5	no load	0	63	128	Xe	1291	53.9	0	53.9	2.83E+06	0	4.52E-05
9	RHFL4913-0510A	Remote Feedback	1	1.5	5	no load	0	63	182	Xe	1291	53.9	0	53.9	3.97E+06	0	4.58E-05
10	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	0	1580	0	Xe	1291	53.9	0	53.9	1.44E+07	0	0.00E+00
11	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	0	1580	0	Xe	1291	53.9	0	53.9	2.00E+07	0	0.00E+00
12	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	0	1580	0	Xe	1291	53.9	45	76.2	5.04E+06	0	0.00E+00
13	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	0	1580	0	Xe	1291	53.9	45	76.2	5.01E+06	0	0.00E+00
14	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	690	1580	0	Xe	1291	53.9	0	53.9	1.02E+07	0	0.00E+00
15	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	690	1580	0	Xe	1291	53.9	0	53.9	1.00E+07	0	0.00E+00
16	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	690	1580	0	Xe	1291	53.9	45	76.2	1.01E+07	0	0.00E+00
17	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	690	1580	0	Xe	1291	53.9	45	76.2	8.50E+00	0	0.00E+00
18	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	143	Xe	1291	53.9	0	53.9	2.63E+06	0	5.44E-05
19	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	186	Xe	1291	53.9	0	53.9	4.04E+06	0	4.60E-05
20	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	99	Xe	1291	53.9	45	76.2	1.21E+06	0	8.18E-05
21	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	128	Xe	1291	53.9	45	76.2	1.83E+06	0	6.99E-05
22	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	60	349	91	Xe	1291	53.9	0	53.9	2.14E+06	0	4.25E-05
23	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	60	349	101	Xe	1291	53.9	0	53.9	2.65E+06	0	3.81E-05
24	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	60	640	119	Xe	1291	53.9	0	53.9	2.77E+06	0	4.30E-05
25	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	60	640	120	Xe	1291	53.9	0	53.9	2.78E+06	0	4.32E-05
26	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	60	640	108	Xe	1291	53.9	45	76.2	1.98E+06	0	5.45E-05
27	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	60	640	115	Xe	1291	53.9	45	76.2	2.25E+06	0	5.11E-05
28	RHFL4913-0510A	Local Feedback	1	1.5	3.3	1500	0	1430	0	Xe	1291	53.9	0	53.9	1.00E+07	0	0.00E+00
29	RHFL4913-0510A	Local Feedback	1	1.5	3.3	1500	0	1430	0	Xe	1291	53.9	0	53.9	8.68E+06	0	0.00E+00
30	RHFL4913-0510A	Local Feedback	1	1.5	3.3	1500	0	1430	0	Xe	1291	53.9	45	76.2	6.01E+06	0	0.00E+00
31	RHFL4913-0510A	Local Feedback	1	1.5	3.3	1500	0	1430	0	Xe	1291	53.9	45	76.2	5.56E+06	0	0.00E+00
32	RHFL4913-0510A	Local Feedback	1	1.5	3.3	no load	0	42	100	Xe	1291	53.9	45	76.2	1.06E+07	0	9.43E-06
33	RHFL4913-0510A	Local Feedback	1	1.5	3.3	no load	0	42	102	Xe	1291	53.9	45	76.2	7.88E+06	0	1.29E-05
34	RHFL4913-0510A	Local Feedback	1	1.5	3.3	no load	0	42	33	Xe	1291	53.9	0	53.9	2.00E+07	0	1.65E-06
35	RHFL4913-0510A	Local Feedback	1	1.5	3.3	no load	0	42	47	Xe	1291	53.9	0	53.9	2.00E+07	0	2.35E-06
36	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	0	1580	0	Ar	496	8.7	0	8.7	1.61E+06	0	0.00E+00
39	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	1500	0	1580	0	Ar	496	8.7	0	8.7	1.22E+06	0	0.00E+00
40	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	0	Ar	496	8.7	0	8.7	1.52E+06	0	0.00E+00
41	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	0	Ar	496	8.7	0	8.7	1.08E+06	0	0.00E+00
42	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	0	Ar	496	8.7	45	12.3	1.27E+06	0	0.00E+00
43	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	no load	0	42	0	Ar	496	8.7	45	12.3	1.26E+06	0	0.00E+00
44	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	6	Ar	496	8.7	45	12.3	2.01E+06	0	2.99E-06
45	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	10	Ar	496	8.7	45	12.3	2.04E+06	0	4.90E-06
46	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	2	Ar	496	8.7	0	8.7	2.01E+06	0	9.95E-07
47	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	14	Ar	496	8.7	0	8.7	1.29E+07	0	1.09E-06
48	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	0	639	7	Ar	496	8.7	0	8.7	1.13E+07	0	6.19E-07
49	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	0	639	9	Ar	496	8.7	0	8.7	1.01E+07	0	8.91E-07
50	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	0	639	29	Ar	496	8.7	45	12.3	1.00E+07	0	2.90E-06
51	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	0	639	34	Ar	496	8.7	45	12.3	1.01E+07	0	3.37E-06
52	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	0	639	0	Ne	266	2.8	45	4.0	2.00E+07	0	0.00E+00
53	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	600	0	639	0	Ne	266	2.8	45	4.0	2.00E+07	0	0.00E+00
54	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	0	Ne	266	2.8	45	4.0	1.99E+07	0	0.00E+00
55	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	2	Ne	266	2.8	45	4.0	2.00E+07	0	1.00E-07
56	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	0	Ne	266	2.8	45	4.0	1.99E+07	0	0.00E+00
57	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	0	Ne	266	2.8	45	4.0	2.00E+07	0	0.00E+00
58	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	0	Ne	266	2.8	0	2.8	2.01E+07	0	0.00E+00
59	RHFL4913-0510A	Remote Feedback	1	1.5	3.3	300	0	349	0	Ne	266	2.8	0	2.8	1.99E+07	0	0.00E+00
60	RHFL4913-0510A	Local Feedback	2	1.5	3.3	300	0	344	0	Ne	266	2.8	0	2.8	2.00E+07	0	0.00E+00
61	RHFL4913-0510A	Local Feedback	2	1.5	3.3	300	0	344	0	Ne	266	2.8	0	2.8	2.00E+07	0	0.00E+00
62	RHFL4913-0510A	Local Feedback	2	1.5	3.3	300	0	344	0	Ne	266	2.8	45	4.0	2.00E+07	0	0.00E+00
63	RHFL4913-0510A	Local Feedback	2	1.5	3.3	300	0	344	0	Ne	266	2.8	45	4.0	1.99E+07	0	0.00E+00
64	RHFL4913-0510A	Local Feedback	2	1.5	3.3	600	0	616	3	Ne	266	2.8	45	4.0	2.01E+07	0	1.49E-07
65	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	638	3	Ne	266	2.8	45	4.0	1.99E+07	0	1.51E-07
66	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	638	1	Ne	266	2.8	45	4.0	1.99E+07	0	5.03E-08
67	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	638	0	Ne	266	2.8	0	2.8	2.00E+07	0	0.00E+00
68	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	638	0	Ne	266	2.8	0	2.8	2.00E+07	0	0.00E+00
69	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	638	20	Ar	496	8.7	0	8.7	1.09E+07	0	1.83E-06
70	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	638	29	Ar	496	8.7	0	8.7	1.00E+07	0	2.90E-06
71	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	638	26	Ar	496	8.7	45	12.3	7.05E+06	0	3.69E-06
72	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	638	31	Ar	496	8.7	45	12.3	5.86E+06	0	5.29E-06
73	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	300	750	349	14	Ar	496	8.7	0	8.7	4.97E+06	0	2.82E-06
74	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	300	750	349	6	Ar	496	8.7	0	8.7	4.23E+06	0	1.42E-06
75	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	300	750	349	16	Ar	496	8.7	45	12.3	3.65E+06	0	4.38E-06
76	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	300	750	349	15	Ar	496	8.7	45	12.3	2.24E+06	0	6.70E-06
77	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	300	0	349	15	Ar	496	8.7	45	12.3	2.01E+06	0	7.46E-06
78	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	300	0	349	13	Ar	496	8.7	45	12.3	2.01E+06	0	6.47E-06
79	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	no load	0	349	0	Ar	496	8.7	45	12.3	1.51E+06	0	0.00E+00
80	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	no load	0	349	0	Ar	496	8.7	45	12.3	1.53E+06	0	0.00E+00
81	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	no load	0	42	5	Xe	1291	53.9	0	53.9	8.93E+04	0	5.60E-05
82	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	no load	0	42	27	Xe	1291	53.9	0	53.9	2.11E+06	0	1.28E-05
83	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	no load	0	42	28	Xe	1291	53.9	0	53.9	2.01E+06	0	1.39E-05
84	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	no load	0	42	40	Xe	1291	53.9	45	76.2	1.39E+06	0	2.88E-05
85	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	no load	0	42	33	Xe	1291	53.9	45	76.2	1.02E+06	0	3.24E-05
86	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	1500	0	1570	0	Xe	1291	53.9	45	76.2	1.02E+06	0	0.00E+00
87	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	1500	0	1570	0	Xe	1291	53.9	45	76.2	1.00E+06	0	0.00E+00
88	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	300	0	348	108	Xe	1291	53.9	45	76.2	8.56E+05	0	1.26E-04
89	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	300	0	348	105	Xe	1291	53.9	45	76.2	1.06E+06	0	9.94E-05
90	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	637	53	Xe	1291	53.9	45	76.2	1.01E+06	0	5.25E-05
91	RHFL4913-0510A	Remote Feedback	2	1.5	3.3	600	0	637	57	Xe	1291	53.9	45	76.2	1.00E+06	0	5.70E-05