SPACE RADIATION CHARACTERIZATION OF THE ART2800 DC/DC CONVERTER FAMILY AND 7846 POST REGULATOR*

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Abstract

This paper describes the simulations, ionizing dose, neutron and SEE exposures for the "ground-up" radiation hard design, triple output DC/DC converter tested in 10 Watt and 30 Watt configurations and, a triple output series regulator. Specifically, the testing performed was to confirm operation in earth geosynchronous space environments. Post-ionizing dose, post 1019.4 annealing data, post neutron and post SEE data are presented. The radiation evaluations on ART2815T samples demonstrated performance within specification to 1.5E6 Rads (Si), 1E13 n/cm², no SEU or SEL to LET of 83 and post 1019.4 anneal data yielding all parameters within 1% of pre irradiation values.

I. Design Versatility And Significance

Design of the ART2800 series DC/DC converters was predicated on several fundamental concepts. Principal among these was a design possessing a conservatively rated level of radiation hardness which was reproducible at a reasonable cost. Because of the design complexity as well as the significant effort and expense necessary to qualify the radiation hardness levels, it was further decided that the design should be universal; that is, it should be possible to provide a variety of voltage and power options utilizing the basic design without compromising the radiation hardness capability. Thus, any requirement for modified output voltages or power levels should be accomplished without recourse to the addition or replacement of active components sensitive to the radiation environment. This goal has been satisfied with this design as is demonstrated in the radiation characterization results herein. Thus, a user is afforded considerable latitude when specifying custom output power and voltage combinations while avoiding the time and costs associated with a new design and associated qualification. These changes typically require alterations to turns ratios on the power transformer and/or output inductor and, when dictated by derating requirements, a change in output capacitors. In some cases minor adjustments to small capacitor values are indicated to optimize loop stability. Additional versatility has been made available in a second hybrid module designed to utilize the same radiation characterized elements, which provides post regulation, additional output filtering, independent control of output groups and output sequencing. By use of this inherent versatility, uncompromised radiation performance can be assured when specifying unique DC/DC converter requirements for distinct applications.

II. Circuit Design And Simulations

Two DC/DC converters (ART2815T 30W, 7845 10w) and a 7846 series regulator were evaluated. The 7845 and 7846 operating as a system pair (Figure I) provide +15V, +8V, +4V and -5V outputs while the ART2815T provides +5V and ±15V outputs as a stand alone module. A single ended forward converter design with a coupled inductor output was chosen for the following reasons:

a. Single ended topologies are preferable in radiation intense environments. Single events can cause momentary disruptions in converter switching which are transparent in single ended designs. In push-pull topologies, these disruptions could lead to the simultaneous turn-on of both switches leading to device failure. Although dual topologies enjoy some size advantage because of improved transformer core utilization, this advantage is considered slight.

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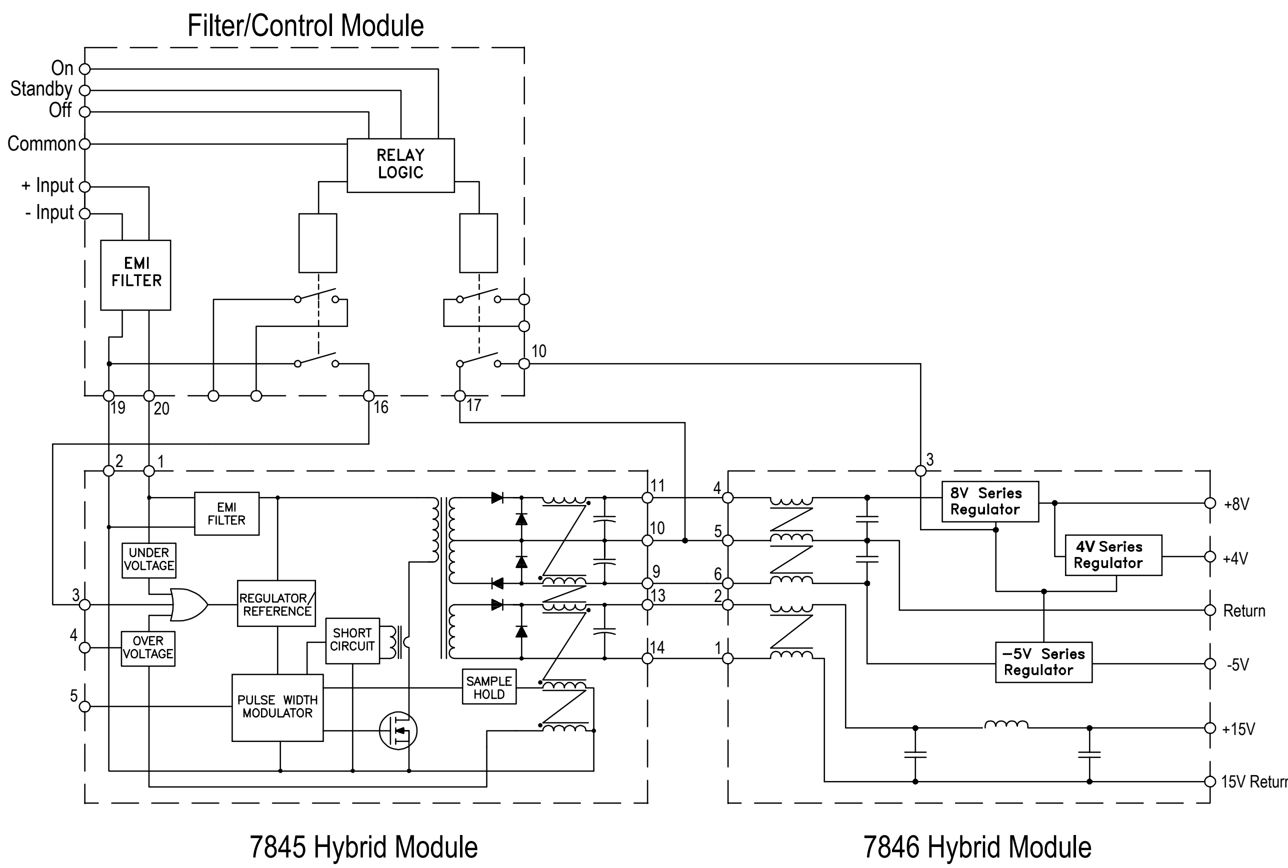
b. Single-ended forward topologies are relatively simple, requiring only a single switching device in the primary circuit. Since they are operated with reference to input common, drive for the switch is easily implemented thereby obviating the need for transformer drives or level shifting networks.

c. The coupled inductor output stage which provides good regulation on all outputs over a 10 to 1 load range was selected principally for its simplicity and low component count. This approach eliminates the need for additional regulator elements on the secondary side utilized in other feedback schemes.

These designs utilize RH-CMOS, DI bipolar, bipolar linear, power MOSFET plus bipolar transistors and diodes. Extensive TREE data exists on all the semiconductor components providing P-SPICE and RAD-SPICE inputs for worse-case analyses, trade-off studies, (other circuit designs) and circuit optimization simulations. These circuit studies were used to set optimum operating currents, thereby maximizing transistor gains for best radiation margins.

Figure I. Block Diagram of 7845 DC/DC converter and 7846 regulator in a system application. Note that a block diagram of the ART2815T converter is the same as the 7845 converter module shown.



III. Sample Description

Test samples were randomly selected from production lots of parts fabricated with material processed to meet the class K element requirements of MIL-H-38534 ("S" level equivalent). Thus, all elements are from single lots and active devices are from single wafers each of which have passed the required element evaluation processes qualifying that lot of material. By applying Method 5005.11 of MIL-STD-883D, a sample of two (2) with zero rejects is specified by Table V for Subgroup 2 (Steady-state Total Dose Irradiation's) of Group E Radiation Hardness Assurance Tests. Therefore two of each hybrid were selected for this test sequence. The following matrix identifies the distribution of test samples.

Module	Lot Code	Total Dose	Neutron	SEE
7845	9331	2		
7846	9333	2		
ART2815T	9403	1		
ART2815T	9404	1	2	
ART2815T	9327			2

IV. Test Facilities Dosimetry And Methodology

The ART2815T and 7845 converters and the 7846 regulator hybrid samples were irradiated at the Sandia Gamma Irradiation Facility in Albuquerque, New Mexico. The samples were irradiated in a biased mode at an approximate dose rate of 5,800 Rads (Si)/min. CaF_2 dosimeters were attached to each device during irradiation. The SEE evaluations were performed at Brookhaven National Laboratories in association with the Applied Physics Laboratory of Johns Hopkins University. These evaluations were performed with the samples biased in a functional mode. Neutron exposures were also performed at the Sandia facility in the SPRIII reactor using sulfur tablets and CaF_2 for dosimetry.

V. Results And Observations

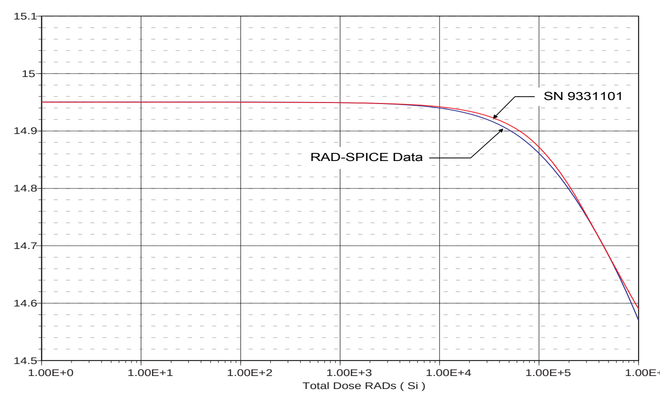
1.0 Converter Evaluations

Two examples of the ART2800 family of triple output DC/DC converters have been qualified in the ionizing dose environment to 8E5 and to 1.5E6 Rads (Si). Summaries of the pre-rad data and post annealing electrical data for significant parameters are presented in Tables I and III for the 7845 and ART2815T respectively. There were no failures to the applicable specification limits after the maximum radiation exposures for either product (i.e. 8E5 and 1.5E6 Rads (Si)). The majority of the observed changes occur at less than 3E5 Rads (Si).

1.1 7845 Observations

The 7845 converter hybrid provides three (3) output voltages: +15, +10 and -10 Volts and is optimized to provide a 10 W output. The 7845 output voltages decreased approximately 1% following 2E5 Rads (Si) compared to pre radiation values while the switching frequency increased 7 kHz or 2.9%. Additional exposure to 8E5 resulted in a further decrease in the 7845 output voltages for a total change of approximately 2% lower than pre-radiation values. Oscillator switching frequency increased 12 kHz or 5% above pre radiation values. A comparison of the 7845 +15V output voltage to the RAD-SPICE predicted values versus ionizing dose is shown in Figure II. The simulation results utilized typical pre-rad component values and then inserted degraded values for each ionizing dose level. The simulated output voltage values are within 0.3% of the observed performance. The degraded RAD-SPICE inputs were extracted from existing rad-data on the various elements. The +10V simulations were within 0.5%.

Figure II. 7845 Output Voltage Stability, Predicted vs. Actual



1.1.1 Post Ionizing Dose Annealing Results

The irradiated 7845 converter test samples were subjected to annealing at 100°C for 168 hours while under the same bias configuration as during irradiation (P_{out} = 10W, V_{in} = 35V). Those 7845 electrical parameters exhibiting the greatest change (V_{out}, Fig. III and f_{osc}, Fig. IV) annealed to within 0.5% of their pre radiation values. Complete data are presented in Table I.

Figure III. 7845 Output vs. Exposure.

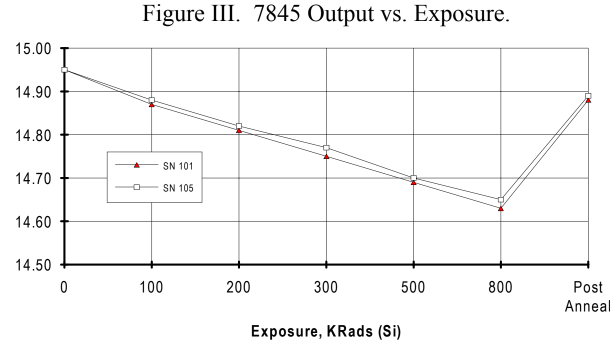
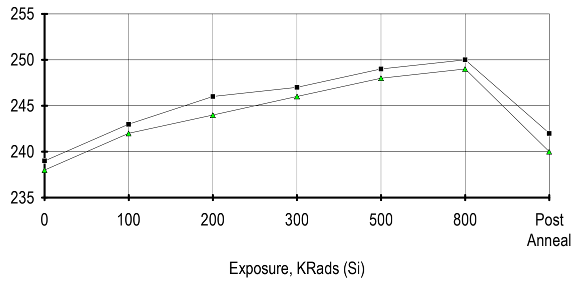


Figure IV. 7845 Frequency vs. Exposure



1.2 ART2815T Observations

The ART2815T output voltages (+5V, ±15V) decreased approximately 2.2% after 1.5E6 Rads (Si) while the oscillator frequency increased 13KHz (5.5%) compared to the pre radiation values. The other parameters exhibited minimal changes. RAD-SPICE simulations of the +5V output vs. ionizing dose yielded predicted voltages that were within 0.02V of the measured post-rad values, i.e. 0.4%.

1.2.1 Post Ionizing Dose Annealing Results

The 1.5E6 Rads (Si) irradiated ART2815T samples were subjected to a 125°C biased anneal for a period of 100 hours. Bias conditions were identical to those during radiation, i.e. P_{out} = 30W, V_{in} = 28V. The post anneal ART2815T electrical characteristics returned to within 1% of the pre-radiation values. Data are presented in Table III.

1.3 ART2815T Neutron Irradiation Results

The ART2815T samples were exposed in the Sandia SPRIII reactor in an un-biased mode (MIL-STD-883, Method 1017). The pre- and post-fluence data are summarized in Table III. There were no failures to specification min/max limits at 7E12 n/cm² or at 1E13 n/cm² (E = 1 MEV equivalent). At 3E13 n/cm², one sample would not couple to the PC controlled test system and is therefore counted as a failure. The exposures were performed on 29 June 1994 and the sample devices have not been released to confirm the failure or to determine the potential cause(s). RAD-SPICE simulation predicted in-spec operation at 2E13 n/cm². Data are presented in Table IV.

1.4 ART2815T See Results

There were NO single event latch-ups or single event upsets observed up to LET of 83 mev-cm²/mg during tests conducted at the Brookhaven National Laboratories Dual VanDeGraf generator facility on February 7-10, 1994. All of the integrated circuits used in these devices had been previously characterized for SEL and SEU, and therefore upsets and latch-ups were not anticipated. (See Figure V)

2.0 7846 Post Regulator

The function of the 7846 post regulator is to convert the ±10 volt outputs of the 7845 and to regulate them to +8, +4, and -5 volts at its output. The 7846 design utilizes the same bipolar discretes as the 7845 and the ART2815T Converters. A summary to the 7846 total ionizing dose electrical data and the post irradiation annealing electrical data are presented in Table IV. Only small parametric changes were noted with the maximum change of a 1.5% decrease in V_{out}. The worse case change in load regulation was less than 0.5%.

2.1 7846 Annealing Results

The 7846 is a bipolar hybrid which contains no MOS elements. The annealing procedures outlined in Method 1019.4 specifically address the accumulation and movement of charge in oxide layers associated with MOS devices (CMOS, power MOSFETs, etc.). It was therefore predicted that the 7846 would not exhibit major benefit from annealing process. Indeed with such small changes experienced following irradiation, there was little from which to recover. Data are presented in Table II.

VI. Conclusions

Examples of the ART2800 family of radiation hard DC/DC converters were exposed to a total ionizing dose greater than 1.5E6 Rads (Si) with additional samples exposed to 8E5 Rad (Si). In each case, the samples exhibited only very small changes in their electrical performance with no failures to applicable parametric electrical specifications. MIL-STD-883, Method 1019.4 annealing was performed with the post anneal parametric performance well within 1% of the pre-radiation performance. Correlation of the P-SPICE and RAD-SPICE simulations to the pre-rad and post rad ionizing dose parameter measurements were well with-in experimental error (< 0.5%). Additional samples were exposed to a neutron fluence of 1E13 n/cm² and to an LET > 83 without upset or latch-up.

VII. Significance

The triple output converter and triple series regulator are "universal" designs; that is, other output voltages can be attained by changing the magnetics and output filter capacitors. The semiconductor components and basic design concepts remain constant. These devices were developed as a potential family of radiation hardened converter and supplemental regulator circuits providing flexible "designed-in" hardness and capability of "S" level qualification while providing converter power densities as high as 10W/in^3 in a package of modest dimension weighing less than 140 grams.

Table I. 7845 Converter Ionizing Dose Electrical Data

Device SN 101

Exposure	Output Voltage (Volts)			Line Regulation (V)			Load Regulation (V)			Output Ripple (mV)			Input Current (mA)			Switching	Efficiency
KRads(Si)	+15	+10	-10	+15	+10	-10	+15	+10	-10	+15	+10	-10	Min Load	Inhibit	Ripple	Freq (Khz)	%
0	14.95	9.82	-9.91	-0.02	0.01	0.00	-0.29	-0.03	-0.03	15.31	11.89	7.91	63.99	2.57	17.98	239	83.20
100	14.87	9.77	-9.86	-0.02	0.02	0.01	-0.30	-0.02	-0.03	14.27	10.35	10.07	63.08	2.33	17.85	243	83.11
200	14.81	9.73	-9.83	-0.01	0.02	0.01	-0.29	-0.02	-0.03	14.14	10.27	10.06	62.70	2.31	19.42	246	83.07
300	14.75	9.69	-9.78	-0.02	0.02	0.01	-0.29	-0.02	-0.03	13.95	10.20	10.10	62.30	2.31	19.02	247	83.04
500	14.69	9.64	-9.75	-0.01	0.02	0.02	-0.30	-0.02	-0.03	13.84	10.21	10.05	61.93	2.36	18.60	249	82.99
800	14.63	9.61	-9.71	-0.01	0.02	0.01	-0.30	-0.02	-0.03	13.61	10.10	10.06	61.27	2.40	18.75	250	82.95
Pre Anneal	14.64	9.62	-9.71	-0.01	0.02	0.02	-0.29	-0.02	-0.03	14.04	10.64	9.19	61.75	2.38	18.13	251	82.97
Post Anneal	14.88	9.77	-9.87	-0.02	0.02	0.00	-0.29	-0.02	-0.03	14.52	10.49	9.49	63.07	2.30	17.00	242	83.18

Device SN 105

Exposure	Output Voltage (Volts)			Line Regulation (V)			Load Regulation (V)			Output Ripple (mV)			Input Current (mA)			Switching	Efficiency
KRads(Si)	+15	+10	-10	+15	+10	-10	+15	+10	-10	+15	+10	-10	Min Load	Inhibit	Ripple	Freq (Khz)	%
0	14.95	9.81	-9.91	-0.02	0.01	0.01	-0.31	-0.01	-0.03	15.72	11.11	8.91	63.03	2.41	21.13	238	83.56
100	14.88	9.77	-9.86	-0.02	0.01	0.01	-0.31	-0.01	-0.03	14.87	10.23	9.81	62.22	2.32	20.32	242	83.53
200	14.82	9.72	-9.82	-0.01	0.01	0.01	-0.31	-0.01	-0.03	14.66	10.31	9.79	61.82	2.35	19.56	244	83.48
300	14.77	9.69	-9.79	-0.01	0.02	0.01	-0.30	-0.01	-0.03	14.44	10.20	9.82	61.40	2.38	19.25	246	83.46
500	14.70	9.65	-9.74	-0.01	0.01	0.02	-0.30	-0.01	-0.03	14.38	10.21	9.79	61.01	2.35	18.86	248	83.43
800	14.65	9.61	-9.71	-0.01	0.02	0.01	-0.30	-0.01	-0.03	14.36	9.96	9.81	60.58	2.25	18.88	249	83.39
Pre Anneal	14.65	9.61	-9.71	-0.01	0.02	0.02	-0.30	-0.01	-0.03	14.56	10.66	8.71	60.96	2.41	18.48	250	83.38
Post Anneal	14.89	9.78	-9.87	-0.02	0.01	0.01	-0.30	-0.02	-0.03	15.14	10.36	9.14	62.21	2.36	21.03	240	83.59

Device SN 103 Control

	Output Voltage (Volts)			Line Regulation (V)			Load Regulation (V)			Output Ripple (mV)			Input Current (mA)			Switching	Efficiency
Test	+15	+10	-10	+15	+10	-10	+15	+10	-10	+15	+10	-10	Min Load	Inhibit	Ripple	Freq (Khz)	%
Pre-Rad	14.95	9.81	-9.92	-0.01	0.00	0.02	-0.31	-0.01	-0.04	15.66	11.75	8.15	64.44	2.65	21.12	239	83.17
Post-Rad	14.94	9.81	-9.92	-0.01	0.01	0.01	-0.31	-0.01	-0.03	14.70	10.25	9.62	63.84	2.31	21.08	239	83.23
Pre Anneal	14.95	9.81	-9.92	-0.02	0.01	0.02	-0.31	-0.01	-0.04	15.21	10.90	8.72	64.31	2.36	21.46	239	83.22
Post Anneal	14.95	9.81	-9.92	-0.02	0.01	0.02	-0.31	-0.01	-0.04	15.29	10.95	8.84	64.04	2.17	21.62	239	83.30

Table II. 7846 Regulator Ionizing Dose Electrical Data

Device SN 119

Exposure	Output Voltage (Volts)			Line Regulation (mV)			Load Regulation (mV)			Output Noise (mV)			Efficiency
KRads(Si)	+8	+4	-5	+8	+4	-5	+8	+4	-5	+8	+4	-5	%
0	8.01	4.02	-5.01	4.01	2.10	8.50	5.97	30.53	19.86	0.56	0.54	0.58	55.27
100	7.92	3.98	-5.05	4.40	2.24	4.85	4.82	26.59	18.70	0.48	0.49	0.48	55.24
200	7.90	3.97	-5.06	4.23	2.09	4.93	6.02	26.74	19.56	0.50	0.48	0.49	55.23
300	7.89	3.97	-5.06	4.38	2.15	5.27	7.39	27.16	20.13	0.58	0.56	0.57	55.19
500	7.88	3.97	-5.06	4.47	2.09	6.38	8.97	27.60	21.23	0.53	0.51	0.53	55.14
800	7.88	3.97	-5.06	4.41	1.87	7.08	10.17	27.61	21.67	0.53	0.49	0.51	55.14
Pre Anneal	7.88	3.97	-5.06	5.31	2.13	6.81	10.07	27.64	21.57	0.59	0.58	0.59	55.19
Post Anneal	7.98	4.01	-5.02	4.27	2.17	7.49	7.07	30.18	19.98	0.78	0.79	0.78	55.23

Device SN 120

Exposure	Output Voltage (Volts)			Line Regulation (mV)			Load Regulation (mV)			Output Noise (mV)			Efficiency
KRads(Si)	+8	+4	-5	+8	+4	-5	+8	+4	-5	+8	+4	-5	%
0	8.01	4.02	-5.02	2.67	1.70	7.64	5.97	30.17	19.84	0.56	0.54	0.57	55.28
100	7.93	3.98	-5.06	2.62	1.31	4.14	5.57	26.73	18.69	0.49	0.48	0.49	55.27
200	7.91	3.97	-5.07	2.86	1.50	4.32	6.66	26.83	19.36	0.51	0.49	0.51	55.31
300	7.89	3.97	-5.07	3.16	1.43	4.83	7.77	26.89	20.23	0.55	0.54	0.56	55.19
500	7.89	3.96	-5.07	3.20	2.44	5.95	9.36	27.71	21.70	0.56	0.53	0.54	55.18
800	7.88	3.96	-5.07	3.37	2.45	6.80	10.68	28.68	22.20	0.53	0.51	0.53	55.13
Pre Anneal	7.88	3.96	-5.06	4.04	1.81	6.92	10.52	27.86	22.06	0.58	0.59	0.58	55.11
Post Anneal	7.98	4.01	-5.02	2.83	1.56	6.92	6.92	29.93	19.98	0.78	0.79	0.78	55.34

Device SN 118 Control

	Output Voltage (Volts)			Line Regulation (mV)			Load Regulation (mV)			Output Noise (mV)			Efficiency
Test	+8	+4	-5	+8	+4	-5	+8	+4	-5	+8	+4	-5	%
Pre-Rad	8.01	4.02	-5.02	3.11	1.80	7.63	5.86	30.61	19.97	0.55	0.53	0.57	5.32
Post-Rad	8.01	4.02	-5.02	2.84	1.61	7.78	5.81	30.41	19.86	0.53	0.51	0.53	55.34
Pre Anneal	8.01	4.02	-5.01	3.00	1.69	7.34	5.62	29.97	19.65	0.59	0.60	0.59	55.35
Post Anneal	8.01	4.02	-5.01	2.96	1.55	6.63	5.77	30.23	19.32	0.70	0.72	0.75	55.24

Table III. ART2815T Converter Ionizing Dose Electrical Data

Device SN 4101

Exp	Vout (Volts)			Line Reg (V)			Load Reg (V)			Out Ripple (mV)			I in (mA)			Freq	Eff
KRads(Si)	+5	+15	-15	+5	+15	-15	+5	+15	-15	+5	+15	-15	RLmin	Inhibit	Ripple	(Khz)	%
0	5.00	14.78	-14.77	0.03	-0.04	-0.06	-0.21	0.02	-0.04	59.04	19.81	23.28	154	2.40	96	237	81.44
300	4.94	14.58	-14.58	0.03	-0.03	0.04	-0.24	0.02	-0.03	51.59	18.81	21.33	151	2.50	89	246	80.41
545	4.89	14.54	-14.54	0.04	-0.03	0.03	-0.22	0.01	-0.03	56.90	19.81	22.89	152	2.58	98	249	80.83
910	4.90	14.50	-14.49	0.03	-0.03	0.04	-0.22	0.02	-0.03	54.85	18.95	22.11	151	2.64	102	249	80.42
1200	4.90	14.49	-14.48	0.03	-0.02	0.03	-0.23	0.02	-0.04	54.03	18.55	22.03	151	2.61	100	249	80.36
1550	4.89	14.47	-14.46	0.03	-0.02	0.03	-0.23	0.01	-0.03	52.96	17.97	21.31	150	2.67	103	250	80.22
Post Ann'l	4.98	14.82	-14.65	0.02	-0.06	0.04	-0.22	0.02	-0.04	59.59	22.24	27.88	153	2.41	100	239	81.53

Device SN 3103

Exp	Vout (Volts)			Line Reg (V)			Load Reg (V)			Out Ripple (mV)			I in (mA)			Freq	Eff
KRads(Si)	+5	+15	-15	+5	+15	-15	+5	+15	-15	+5	+15	-15	RLmin	Inhibit	Ripple	(Khz)	%
0	5.01	14.88	-14.85	0.01	-0.07	0.03	-0.27	0.01	-0.01	31.85	23.15	15.98	156	2.83	102	236	81.34
390	4.94	14.71	-14.67	0.02	-0.07	0.05	-0.27	0.02	-0.02	30.86	22.40	15.15	154	2.93	102	244	80.80
550	4.93	14.68	-14.63	0.02	-0.06	0.06	-0.27	0.02	-0.02	31.11	22.99	14.98	154	2.89	100	246	80.86
800	4.91	14.60	-14.57	0.02	-0.05	0.04	-0.27	0.02	-0.02	30.17	22.28	15.20	152	2.87	105	247	80.47
1200	4.91	14.60	-14.56	0.02	-0.05	0.04	-0.28	0.02	-0.02	29.54	21.33	14.61	152	2.99	101	246	80.22
1400	4.90	14.57	-14.54	0.02	-0.04	0.04	-0.28	0.01	-0.02	29.40	21.58	14.58	151	2.97	102	246	80.09
1530	4.90	14.57	-14.52	0.02	-0.05	0.04	-0.28	0.02	-0.02	29.89	21.75	14.47	152	2.99	102	247	80.23
Post Ann'l	4.98	14.89	-14.70	0.02	-0.10	0.04	-0.27	0.04	-0.04	31.45	25.88	19.73	155	2.84	102	238	81.02

Device SN 7107* Control

	Vout (Volts)			Line Reg (V)			Load Reg (V)			Out Ripple (mV)			I in (mA)			Freq	Eff
Exposure	+5	+15	-15	+5	+15	-15	+5	+15	-15	+5	+15	-15	RLmin	Inhibit	Ripple	(Khz)	%
0*	4.99	14.80	14.77	0.01	-0.07	0.07	-0.24	0.02	-0.01	17.03	27.86	21.89	152	2.13	102	231	82.80
500*	4.99	14.79	14.76	0.01	-0.08	0.08	-0.24	0.01	-0.01	16.62	27.35	21.35	152	2.14	102	231	82.75
800	5.01	14.82	14.76	0.03	-0.06	0.05	-0.25	0.03	-0.01	40.16	31.43	19.53	156	2.72	93	236	81.30
1500	5.01	14.81	14.78	0.03	-0.06	0.06	-0.25	0.03	-0.01	40.89	32.55	19.76	156	2.88	96	236	81.44
Post Ann'l	5.01	14.82	14.77	0.03	-0.06	0.05	-0.25	0.03	-0.02	40.87	33.99	20.43	156	2.74	99	236	81.60

* Note: Following the 800KRad exposure, electrical problems were experienced with Control Unit #7107. At that point a second Control Unit, #3101, was substituted for this and subsequent control test runs. Data shown are representative of all control runs taken at every exposure.

Table IV. ART2815T Neutron Irradiation Electrical Data

Device SN 4103

Exp	Vout (Volts)			Line Reg (V)			Load Reg (V)			Out Ripple (mV)			I in (mA)			Freq	Eff
	+5	+15	-15	+5	+15	-15	+5	+15	-15	+5	+15	-15	RL min	Inhibit	Ripple	(Khz)	%
0	5.01	14.85	-14.84	0.01	-0.08	0.08	-0.21	0.03	-0.03	44.2	19.8	23.1	158	2.01	101	232	81.02
7.00E+12	4.98	14.77	-14.77	0.01	-0.09	0.08	-0.22	0.02	-0.02	43.3	19.0	22.5	158	2.54	97	239	80.63
1.00E+13	4.97	14.75	14.75	0.02	-0.08	0.08	-0.22	0.03	-0.03	42.9	18.6	22.3	156	1.33	98	241	80.64
3.00E+13	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——	——

Device SN 4106

Exp	Vout (Volts)			Line Reg (V)			Load Reg (V)			Out Ripple (mV)			I in (mA)			Freq	Eff
	+5	+15	-15	+5	+15	-15	+5	+15	-15	+5	+15	-15	RL min	Inhibit	Ripple	(Khz)	%
0	5.01	14.86	-14.84	0.02	-0.06	0.07	-0.24	0.01	-0.02	33.7	21.2	20.2	156	2.64	94	236	81.49
7.00E+12	4.99	14.80	-14.78	0.02	-0.06	0.07	-0.24	0.01	-0.02	36.6	20.9	19.8	155	2.73	93	243	81.26
1.00E+13	4.98	14.77	-14.75	0.02	-0.06	0.06	-0.23	0.01	-0.01	36.5	19.7	19.8	155	2.59	90	245	81.15
3.00E+13	4.93	14.65	-14.62	0.02	-0.05	0.05	-0.24	0.02	-0.01	35.9	19.5	18.8	153	2.75	80	257	80.76

Device SN 7107 Control

Exp	Vout (Volts)			Line Reg (V)			Load Reg (V)			Out Ripple (mV)			I in (mA)			Freq	Eff
	+5	+15	-15	+5	+15	-15	+5	+15	-15	+5	+15	-15	RL min	Inhibit	Ripple	(Khz)	%
0	4.99	14.81	-14.78	0.01	-0.07	0.08	-0.24	0.02	-0.01	16.5	28.8	23.1	153	2.19	103	231	82.96
7.00E+12	4.99	14.80	-14.78	0.01	-0.08	0.08	-0.24	0.01	-0.01	16.3	28.3	22.3	153	2.24	103	231	82.89
1.00E+13	4.99	14.80	-14.77	0.01	-0.07	0.08	-0.24	0.02	-0.01	16.0	27.0	21.5	151	0.73	104	231	82.87
3.00E+13	4.99	14.79	-14.77	0.01	-0.07	0.07	-0.24	0.01	-0.01	17.6	27.5	21.6	152	2.10	104	231	82.79

Figure V. ART2815T SEE Data