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EVALUATION OF HIGH PERFORMANCE CONVERTERS UNDER LOW DOSE RATE TOTAL IONIZING DOSE (TID) TESTING FOR NASA PROGRAMS

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ABSTRACT

This paper reports the results of low dose rate (0.01-0.18 rads(Si)/sec) total ionizing dose (TID) tests performed on several types of high performance converters. The parts used in this evaluation represented devices such as a high speed flash converter, a 16-bit ADC and a voltage-to-frequency converter.

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ABSTRACT

This paper reports the results of low dose rate (0.01-0.18 rads(Si)/sec) total ionizing dose (TID) tests performed on several types of high performance converters. The parts used in this evaluation represented devices such as a high speed flash converter, a 16-bit ADC and a voltage-to-frequency converter.

Introduction

A number of NASA programs are using commercial (non-radiation-hardened) high performance converters such as 12-16 bit resolution ADCs, 10-bit flash converters, and synchronous voltage-to-frequency converters. There are no radiation tolerance guarantees provided on these parts by the manufacturers. Most of the characterization data available on these parts either from the manufacturers or independent test organizations is high dose rate. In several recent papers on enhanced low dose rates for bipolar linear devices, concerns have been expressed about the validity of high dose rate test data and its applicability to space environment, where the actual dose rates are several orders of magnitude lower. Also, these converters, during irradiation are usually subjected to limited functional testing, e.g., in a 12-bit ADC, the devices are tested for linearity (or differential nonlinearity) and missing codes only at certain transition points and not 4096 codes that an "all codes" test requires. Similarly, the flash ADCs may not be tested at the minimum guaranteed conversion rate (e.g., 3 MSPS for AD9050).

The objective of this testing on high performance converters was to use a combination of low dose rate to simulate low dose rate space environment in combination with special tests like "all codes" and "at speed" to detect any anomalous results.

Test Facilities and Procedures

The TID testing is performed using Co-60 gamma irradiator located in the Radiation Effects Facility of NASA/Goddard Space Flight Center. The radiation dose rate capabilities within the irradiator room range from 0.001 to 1.3 rads(Si)/sec, and is measured using ionization chamber probe. The test devices were irradiated using static bias. The selection of total dose radiation steps for each series of tests were based on anticipated radiation sensitivity of the parts and the predicted total dose requirements for

the program. Most commonly used irradiation steps were 2.5, 5, 10, 15, 20, 30, 50, 75 and 100 krads(Si). The dose rate for high performance converters testing varied from 0.01 to 0.18 rads(Si)/sec. During some irradiation steps and after the final exposure, the parts were annealed under bias at room temperature (25°C) for periods ranging from 96-168 hours.

The electrical measurements consisted of various DC parametric tests including supply currents (IDD), Input leakage currents (IIL, IIH), Output voltages (VOL, VOH); functional tests such as missing codes, differential nonlinearity (DNL), integral nonlinearity (INL) measurements; and special "at speed" tests.

Parts tested and Results

1. High Speed 10-bit Flash ADC

A TID evaluation was performed on Analog Devices AD9050 (10-bit flash A/D converters) to determine their radiation tolerance at a combination of low dose irradiation exposure plus special functionals including all codes and at speed test program. In order to meet the minimum guaranteed conversion rate of 3 MSPS for the AD9050, ATE frequencies of greater than 16 MHz were used. To gain more information on the missing codes, the output waveform was captured for all parts, including the control samples, after total dose steps of 20, 30 and 50 krads to evaluate the impact of any missing codes on the output waveforms. Seven devices were used as test samples, along with two control samples.

After 5 krad exposure, one device showed a missing code. During irradiations of 10, 15 and 20 krad exposure, two additional devices showed missing codes. After annealing these parts for 144 hours at 25°C, the parts showed significant recovery in missing codes and some recovery in DNL and INL. During two additional exposures of 30 and 50 krads, most of the devices exhibited significant degradation and missing codes. After annealing the parts for 168 hours at 25°C, the parts showed little or no recovery. During the final exposures of 75 and 100 krads, all parts continued to degrade in missing codes and showed no recovery during final annealing step of 168 hours at 25°C. Table I provides a summary of the test results with the mean and standard deviation values for each parameter after each irradiation exposure and annealing step. Table II provides performance details for three critical parameters: Missing codes, DNL and INL.

2. 16-bit BiCMOS A/D Converter AD976

A combination of low dose rate and special functional tests for missing codes was performed on these devices. The detailed test results will be reported in the final paper.

3. Synchronous Voltage-to-Frequency Converter AD652

A combination of low dose rate and special functional tests for missing codes was performed on these devices. The detailed test results will be reported in the final paper.

Conclusions

For many high performance converters, high dose rate radiation tolerance data provided by the manufacturer may not represent the actual device hardness. The TID evaluation of these converters performed for NASA programs has been quite useful in demonstrating the need for an integrated approach that combines low dose rate testing and special functional tests for nonlinearity and missing codes. Therefore, a careful characterization of high performance converters should be performed to verify that the parts meet the application requirements in the projected mission total dose requirements.

TABLE I : Summary of Electrical Measurements After Total Dose Exposures and Annelaing for AD9050BR /1

Test #	Parameters	Units	Spec. Lim. /2 min	Spec. Lim. /2 max	Initial mean	Initial sd	Total Dose Exposure (kRads) 5.0 mean	5.0 sd	10.0 mean	10.0 sd	15.0 mean	15.0 sd	20.0 mean	20.0 sd	Annealing /5 144 hours @25°C mean	Annealing /5 144 hours @25°C sd	Total Dose Exposure (kRads) 30.0 /6 mean	30.0 /6 sd	50.0 /7 mean	50.0 /7 sd	Annealing /5 168 hours @25°C mean	Annealing /5 168 hours @25°C sd	Total Dose Exposure (kRads) 75.0 mean	75.0 sd	100 mean	100 sd
48	Missing Codes /3 /4	P/F			P		6P/1F		4P/3F		5P/2F		4P/3F		6P/1F		1P/6F		F		F		F		F	
49	DNL	lsb		1.75	1.00	0.13	1.05	0.24	1.20	0.36	1.12	0.37	1.38	0.73	1.32	0.70	18.8	19.4	50.1	5.6	41.1	5.4	37.0	2.1	35.9	1.8
50	INL	lsb		3.00	2.41	0.33	2.45	0.32	2.66	0.73	2.51	0.32	2.94	1.10	2.94	1.06	16.8	13.6	43.0	0	41.8	3.0	41.8	3.0	42.8	9.2
1	Idd	mA		80	50	1.9	50	1.8	50	1.8	50	1.8	50	1.7	50	1.7	50	1.7	55	1.2	52	1.1	59	1.4	62	2.6
2	PD	mW		400	249	9.0	249	8.9	248	8.8	248	9.2	248	9.3	248	9.0	251	8.5	276	6.2	260	5.4	296	7.6	312	11.9
3	Encode_iil	nA	-1000	1000	-173	47	-156	22	-144	25	-168	33	-153	30	-163	33	<-2E4		<-2E4		<-2E4		<-2E4		<-2E4	
4	Encode_iih	nA	-1000	1000	39	7	32	7	33	5	31	6	32	4	29	5	34	7	50	4	92	21	54	4.2	51	5.6
5-14	Voh_5V	V	4.95		4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0
15-24	Vol_5V	mV		50	10	0.3	10	0.5	10	0.5	10	0.5	10	0.5	10	0.5	11	0.5	12	0.5	8	0.5	12	0.5	13	0.5
25-34	Voh_3V	V	2.95		2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0
35-44	Vol_3V	mV		50	13	0.5	13	0.5	13	0.5	14	0.5	14	0.5	13	0.6	13	0.9	15	0.8	15	0.5	15	0.5	15	1.0
46	Input_Resistance	kΩ	3.5	100	16.1	0.7	16.2	0.7	16.1	0.7	16.1	0.7	16.1	0.7	16.1	0.7	16.1	0.6	16.1	0.6	16.1	0.6	16.1	0.6	16.2	0.6

Notes:

1/ The mean and standard deviation values were calculated over the seven parts irradiated in this testing. The control samples remained constant throughout the testing and are not included in this table.

2/ These are manufacturer's pre-irradiation data sheet specification limits. No post-irradiation limits were provided by the manufacturer at the time the tests were performed.

3/ "P" ("F") means that all parts passed (failed) this test at this step, nPmF means that n parts passed and m parts failed this test at this step.

4/ Missing Codes is a very sensitive test and occasionally the noise associated with the ATE may lead to a missing code. The details of this test are provided in tabel 3. For more information in Missing Codes, the ouput waveforms were captured after 20, 30 and 50 kRads. The captured waveforms and their interpretations are included in Appendix 1.

5/ The interim annealing step was added due to significant degradation in the parts at this level. The addition of this interim annealing step better simulates the space environment's lower dose rate for very sensitive devices. This may allow parts to show satisfactory performance at higher doses or indicate that the part can not be used beyond the previous dose level.

6/ All parts from this point read -20,000nA, the minimum value the the test equimpment can measure for Encode_iil.

7/ At 50 kRads, SN 54 output pin DB5 produced anomalous readings for several tests. The mean and standard deviation are calculated without this part for this step only.

Radiation sensitive parameter: Missing Codes, DNL, INL Encode_Iil, Voh, Vol.

TABLE II : Performance of Critical Parameters for Each Part after Total Dose Expsoures and Annealing 1/ 2/ 3/

SN	Parameter	Units	Initial	Total Ionizing Dose (kRads) 5	10	15	20	Anneal 144 hrs	TID (kRads) 30	50	Anneal 168 hrs	TID (kRads) 75	100	Anneal 168 hrs
250	Missing Codes	address	P	P	P	P	P	P	P	P		P	P	P
	DNL	lsb	0.98	0.98	0.98	0.98	0.98	0.98	0.96	0.98		0.96	0.98	0.96
	INL	lsb	2.08	2.18	* 2.07	2.04	2.04	2.01	2.08	2.00		2.01	2.11	2.18
50	Missing Codes	address	P	P	P	P	P	P	P	P		P	P	P
	DNL	lsb	0.96	0.98	0.96	0.98	0.98	0.96	0.96	0.98		0.94	0.96	0.98
	INL	lsb	2.48	2.53	2.40	2.22	2.47	2.47	2.29	2.47		2.56	2.38	2.00
51	Missing Codes	address	P	P	45 F	P	45 F	45 F	1 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.98	0.94	1.97 F	0.98	3.00 F	2.98 F	56.8 F	51.7 F	42.2 F	34.5 F		35.3 F
	INL	lsb	2.73	2.70	4.38 F	2.91	5.56 F	5.38 F	43.0 F	43.0 F	43.0 F	43.0 F		76.6 F
52	Missing Codes	address	P	P	P	P	P	P	1 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.94	0.96	0.92	0.96	0.96	0.98	7.42 F	37.2 F	34.7 F	35.5 F	37.8 F	40.4 F
	INL	lsb	2.39	2.44	2.54	2.39	2.54	2.49	11.3 F	43.0 F	43.0 F	43.0 F	34.1 F	91.4 F
53	Missing Codes	address	P	P	P	P	P	P	P	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.98	0.98	0.98	0.98	0.98	0.98	0.94	50.2 F	45.5 F	38.5 F	36.7 F	35.1 F
	INL	lsb	2.15	2.18	2.25	2.19	2.36	2.26	1.98	43.0 F	43.0 F	43.0 F	33.0 F	58.2 F
54	Missing Codes	address	P	519 F	519 F	519 F	909 F	P	1 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.98	1.00	1.00	1.00	1.00	0.98	34.7 F	49.7 F	42.0 F	37.5 F	38.4 F	36.2 F
	INL	lsb	1.89	1.86	1.98	1.96	2.02	1.98	26.3 F	43.0 F	43.0 F	34.3 F	33.0 F	61.6 F
55	Missing Codes	address	P	P	P	P	P	P	45 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.87	0.87	0.87	0.89	0.89	0.92	5.03 F	51.4 F	31.4 F	34.2 F	34.0 F	13.9 F
	INL	lsb	2.47	2.57	2.57	2.63	2.56	2.53	6.69 F	43.0 F	34.4 F	43.0 F	54.4 F	58.3 F
56	Missing Codes	address	231 F											
	DNL	lsb	1.00											
	INL	lsb	3.28 F											
57	Missing Codes	address	P	P	845 F	845 F	845 F	P	45 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	1.32	1.64	1.24	2.02 F	1.83 F	1.41	24.3 F	55.7 F	46.8 F	40.3 F	34.6 F	35.5 F
	INL	lsb	2.26	2.52	2.42	2.61	2.54	2.68	22.8 F	43.0 F	43.0 F	43.0 F	48.8 F	67.7 F
58	Missing Codes	address	P	P	P	P	P	P	45 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.98	0.98	1.41	0.98	0.98	0.96	2.59 F	54.5 F	45.4 F	38.3 F	34.1 F	1.00
	INL	lsb	2.97	2.89	2.50	2.90	3.03 F	3.26 F	5.23 F	43.0 F	43.0 F	43.0 F	51.4 F	57.1 F

Notes:

1. SN's 250 and 50 are control samples
2. P (F) means the part passed (failed) this test at this level. The number for MC is the code block. The number for DNL and INL is in lsb.
3. SN 56 failed initially and was removed from further tseting.

TABLE I : Summary of Electrical Measurements After Total Dose Exposures and Annelaing for AD9050BR /1

Test #	Parameters	Units	Spec. Lim. /2 min	Spec. Lim. /2 max	Initial mean	Initial sd	Total Dose Exposure (kRads) 5.0 mean	5.0 sd	10.0 mean	10.0 sd	15.0 mean	15.0 sd	20.0 mean	20.0 sd	Annealing /5 144 hours @25°C mean	Annealing /5 144 hours @25°C sd	Total Dose Exposure (kRads) 30.0 /6 mean	30.0 /6 sd	50.0 /7 mean	50.0 /7 sd	Annealing /5 168 hours @25°C mean	Annealing /5 168 hours @25°C sd	Total Dose Exposure (kRads) 75.0 mean	75.0 sd	100 mean	100 sd
48	Missing Codes /3 /4	P/F			P		6P/1F		4P/3F		5P/2F		4P/3F		6P/1F		1P/6F		F		F		F		F	
49	DNL	lsb		1.75	1.00	0.13	1.05	0.24	1.20	0.36	1.12	0.37	1.38	0.73	1.32	0.70	18.8	19.4	50.1	5.6	41.1	5.4	37.0	2.1	35.9	1.8
50	INL	lsb		3.00	2.41	0.33	2.45	0.32	2.66	0.73	2.51	0.32	2.94	1.10	2.94	1.06	16.8	13.6	43.0	0	41.8	3.0	41.8	3.0	42.5	9.2
1	Idd	mA		80	50	1.9	50	1.8	50	1.8	50	1.8	50	1.7	50	1.7	50	1.7	55	1.2	52	1.1	59	1.4	62	2.6
2	PD	mW		400	249	9.0	249	8.9	248	8.8	248	9.2	248	9.3	248	9.0	251	8.5	276	6.2	260	5.4	296	7.6	312	11.9
3	Encode_Iil	nA	-1000	1000	-173	47	-156	22	-144	25	-168	33	-153	30	-163	33	<-2E4		<-2E4		<-2E4		<-2E4		<-2E4	
4	Encode_Iih	nA	-1000	1000	39	7	32	7	33	5	31	6	32	4	29	5	34	7	50	4	92	21	54	4.2	51	5.6
5-14	Voh_5V	V	4.95		4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0	4.99	0
15-24	Vol_5V	mV		50	10	0.3	10	0.5	10	0.5	10	0.5	10	0.5	10	0.5	11	0.5	12	0.5	8	0.5	12	0.5	13	0.5
25-34	Voh_3V	V	2.95		2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0	2.97	0
35-44	Vol_3V	mV		50	13	0.5	13	0.5	13	0.5	14	0.5	14	0.5	13	0.6	13	0.9	15	0.8	15	0.5	15	0.5	15	1.0
46	Input_Resistance	kΩ	3.5	100	16.1	0.7	16.2	0.7	16.1	0.7	16.1	0.7	16.1	0.7	16.1	0.7	16.1	0.6	16.1	0.6	16.1	0.6	16.1	0.6	16.2	0.6

Notes:

1/ The mean and standard deviation values were calculated over the seven parts irradiated in this testing. The control samples remained constant throughout the testing and are not included in this table.

2/ These are manufacturer's pre-irradiation data sheet specification limits. No post-irradiation limits were provided by the manufacturer at the time the tests were performed.

3/ "P" ("F") means that all parts passed (failed) this test at this step, nPmF means that n parts passed and m parts failed this test at this step.

4/ Missing Codes is a very sensitive test and occasionally the noise associated with the ATE may lead to a missing code. The details of this test are provided in tabel 3. For more information in Missing Codes, the ouput waveforms were captured after 20, 30 and 50 kRads. The captured waveforms and their interpretations are included in Appendix 1.

5/ The interim annealing step was added due to significant degradation in the parts at this level. The addition of this interim annealing step better simulates the space environment's lower dose rate for very sensitive devices. This may allow parts to show satisfactory performance at higher doses or indicate that the part can not be used beyond the previous dose level.

6/ All parts from this point read -20,000nA, the minimum value the the test equimpment can measure for Encode_iil.

7/ At 50 kRads, SN 54 output pin DB5 produced anomalous readings for several tests. The mean and standard deviation are calculated without this part for this step only.

Radiation sensitive parameter: Missing Codes, DNL, INL Encode_Iil, Voh, Vol.

TABLE II : Performance of Critical Parameters for Each Part after Total Dose Expsoures and Annealing 1/ 2/ 3/

SN	Parameter	Units	Initial	Total Ionizing Dose (kRads) 5	10	15	20	Anneal 144 hrs	TID (kRads) 30	50	Anneal 168 hrs	TID (kRads) 75	100	Anneal 168 hrs
250	Missing Codes	address	P	P	P	P	P	P	P	P		P	P	P
	DNL	lsb	0.98	0.98	0.98	0.98	0.98	0.98	0.96	0.98		0.96	0.98	0.96
	INL	lsb	2.08	2.18	2.07	2.04	2.04	2.01	2.08	2.00		2.01	2.11	2.18
50	Missing Codes	address	P	P	P	P	P	P	P	P		P	P	P
	DNL	lsb	0.96	0.98	0.96	0.98	0.98	0.96	0.96	0.98		0.94	0.96	0.98
	INL	lsb	2.48	2.53	2.40	2.22	2.47	2.47	2.29	2.47		2.56	2.38	2.00
51	Missing Codes	address	P	P	45 F	P	45 F	45 F	1 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.98	0.94	1.97 F	0.98	3.00 F	2.98 F	56.8 F	51.7 F	42.2 F	34.5 F		35.3 F
	INL	lsb	2.73	2.70	4.38 F	2.91	5.56 F	5.38 F	43.0 F	43.0 F	43.0 F	43.0 F		76.6 F
52	Missing Codes	address	P	P	P	P	P	P	1 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.94	0.96	0.92	0.96	0.96	0.98	7.42 F	37.2 F	34.7 F	35.5 F	37.8 F	40.4 F
	INL	lsb	2.39	2.44	2.54	2.39	2.54	2.49	11.3 F	43.0 F	43.0 F	43.0 F	34.1 F	91.4 F
53	Missing Codes	address	P	P	P	P	P	P	P	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.98	0.98	0.98	0.98	0.98	0.98	0.94	50.2 F	45.5 F	38.5 F	36.7 F	35.1 F
	INL	lsb	2.15	2.18	2.25	2.19	2.36	2.26	1.98	43.0 F	43.0 F	43.0 F	33.0 F	58.2 F
54	Missing Codes	address	P	519 F	519 F	519 F	909 F	P	1 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.98	1.00	1.00	1.00	1.00	0.98	34.7 F	49.7 F	42.0 F	37.5 F	38.4 F	36.2 F
	INL	lsb	1.89	1.86	1.98	1.96	2.02	1.98	26.3 F	43.0 F	43.0 F	34.3 F	33.0 F	61.6 F
55	Missing Codes	address	P	P	P	P	P	P	45 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.87	0.87	0.87	0.89	0.89	0.92	5.03 F	51.4 F	31.4 F	34.2 F	34.0 F	13.9 F
	INL	lsb	2.47	2.57	2.57	2.63	2.56	2.53	6.69 F	43.0 F	34.4 F	43.0 F	54.4 F	58.3 F
56	Missing Codes	address	231 F											
	DNL	lsb	1.00	✗										
	INL	lsb	3.28 F											
57	Missing Codes	address	P	P	845 F	845 F	845 F	P	45 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	1.32	1.64	1.24	2.02 F	1.83 F	1.41	24.3 F	55.7 F	46.8 F	40.3 F	34.6 F	35.5 F
	INL	lsb	2.26	2.52	2.42	2.61	2.54	2.68	22.8 F	43.0 F	43.0 F	43.0 F	48.8 F	67.7 F
58	Missing Codes	address	P	P	P	P	P	P	45 F	1 F	1 F	1 F	1 F	1 F
	DNL	lsb	0.98	0.98	1.41	0.98	0.98	0.96	2.59 F	54.5 F	45.4 F	38.3 F	34.1 F	1.00
	INL	lsb	2.97	2.89	2.50	2.90	3.03 F	3.26 F	5.23 F	43.0 F	43.0 F	43.0 F	51.4 F	57.1 F

Notes:

1. SN's 250 and 50 are control samples
2. P (F) means the part passed (failed) this test at this level. The number for MC is the code block. The number for DNL and INL is in lsb.
3. SN 56 failed initially and was removed from further tseting.

What does this mean? "blank"?