National Aeronautics and Space Administration

AD620SQ/883B
Total Ionizing Dose Radiation Lot Acceptance Report for RESTORE-LEO

Test Date(s): 7/28, 7/31, 8/1, 8/2, 8/3, 8/4, 8/7, 8/8, 8/9, 8/15, 8/21, 8/28, 8/29, 8/30, 9/1, 9/6 of 2017
Test Report Date: 9/18/17

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1. Summary

A Radiation Lot Acceptance Test was performed on the AD620SQ/883B, Lot 1708D, in accordance with MIL-STD-883, Method 1019, Condition D. Using a ^{60}Co source 4 biased parts and 4 unbiased parts were irradiated at 10 mrad/s (0.036 krad/hr) in intervals of approximately 1 krad from 3-10 krads, and ones of 5 krads from 10-25 krads, where it was annealed while unbiased at 25°C, for 2 days, and then, subsequently, annealed while biased at 25°C, for another 7 days (See Tables 6-9).

Initially, all parts passed all electrical tests, except for the Gain Error at Gain = 1—the data sheet gave a Gain Error (1) of 0.1%, but numbers were slightly above that. However it is reasonable to assume that the error comes from the Gain Error testing equipment (a Keithley 4200), as slight changes can adjust this measurement; this is supported by the fact that the Gain Error (1) for the control samples initially decreased with the rest of the samples' one (see Figure 6 in Appendix). In any case, after 25 krads of irradiation, and annealing, quite a few specs never degraded past their limits: Slew Rate, $\mathrm{V_{offset}}$, and Swing. However, note that part 8 degraded to non-functionality at 25 krads–that is, it's output values for different differential input voltages weren't even close to the expected ones, and its frequency response wasn't stable during observation on an oscilloscope (for Slew Rate testing) either—but 47 hours of unbiased annealing brought part 8 back to functionality.

Concerning the specs that did degrade to failure, the first spec, $\mathrm{I_{io}}$, increased past limits after the 3.290 krads test, then the $+\mathrm{I_b}$ did so after 5.411 krads, and the $-\mathrm{I_b}$, $\mathrm{PSRR_1}$, and $\mathrm{PSRR_{10}}$ did so after 8.536 krads (see Figures 8 & 9 in Appendix). Additionally, the Gain Error (1) rose after around 10.195 krads and the Gain Error (10) oscillated below and above spec limits throughout measurements, but because of the noise present (in both, but in different ways), it's hard to make a specific dose estimate (see Figures 6 & 7 in Appendix). Some details follow in Table 1:

	Pos Bias Current	Neg Bias Current	Input Offset Current	PSRR (Gain = 1)	PSRR (Gain = 10)
Spread (krad)	4.818 – 7.367	7.108 – 14.080	2.611 – 8.566	7.367 - 12.341	7.346 - 14.365
Biased Average (krad)	5.250	8.464	3.843	8.082	9.596
Unbiased Average (krad)	6.388	11.408	5.150	9.257	10.195

Table 1: Spec Failure Details: Note that values were interpolated.

Concerning annealing, the $-\mathrm{I_b}$ further degraded after unbiased annealing for 26 hours, but then significantly improved—almost back to spec limits—after 165 hours of biased annealing. Additionally, the $\mathrm{I_q}$ fully recovered after 47 hours of unbiased annealing, and the $+\mathrm{I_b}$ and $\mathrm{I_{io}}$ substantially improved after 47 hours of biased annealing as well.

2. Part Info

Ten parts from the flight lot of AD620SQ were provided to Code 561 for total ionizing dose (TID) testing. Of the ten parts, two were used as controls. Additional info is found in Table 2 and Figure 1:

Qty	Part Number	LDC	Identifier #	Source	Package	Technology
10	AD620SQ	1708D	17-046	Analog Devices	CERDIP	Bipolar

Table 2: Part Identification Information

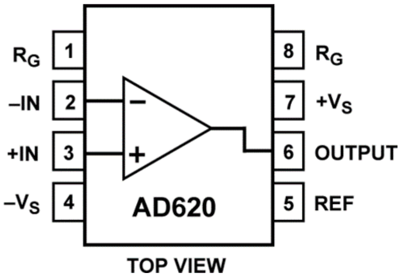

Figure 1: AD620SQ Pinout

According to the Analog Devices datasheet, the specification limits for the TID affected parameters are as follows:

Parameter	Min	Typ	Max	Units	Conditions (Vs = ±15 V, R_L = 2 kΩ unless otherwise noted)
Swing	-Vs + 1.1		+Vs - 1.2	V	R_L = 10 kΩ, Vs = ±2.3 V to ±5 V
V_{offset}		30	125	µV	Vs = ±5 V to ±15 V
Gain Error (1)		0.03	0.10	%	Vout = ±10 V
Gain Error (10)		0.15	0.30	%	Vout = ±10 V
I_q		0.9	1.3	mA	
$+I_b$		0.5	2	nA	
$-I_b$		0.5	2	nA	
I_{io}		0.3	1.0	nA	
PSRR (1)		80	100	dB	Vs = ±2.3 V to ±18 V
PSRR (10)		95	120	dB	Vs = ±2.3 V to ±18 V
Slew Rate	0.75	1.2		V/µs	

Table 3: Datasheet Specifications

3. Test Setup

The parameters listed in Table 3 were measured with the following.

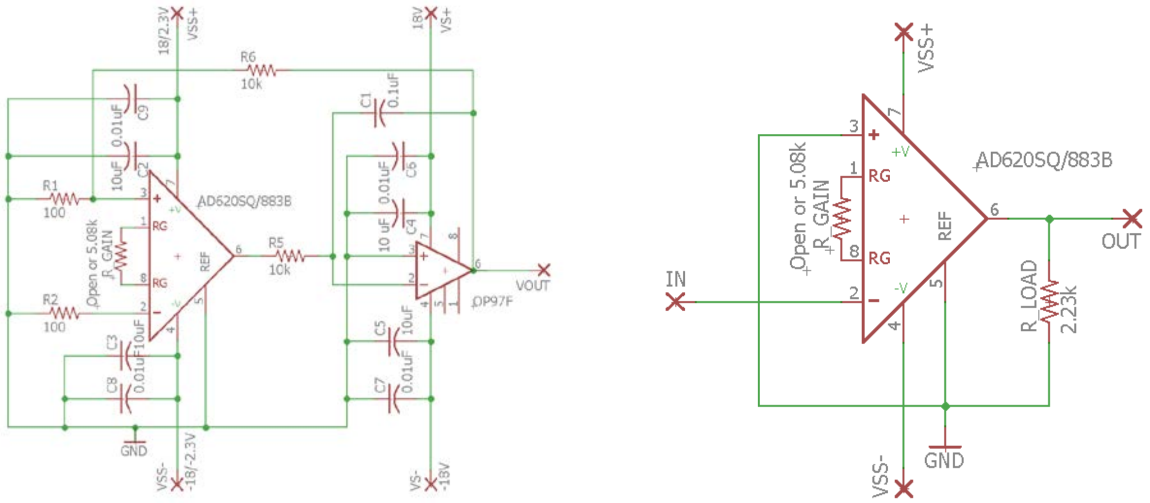

Figure 2: Boards used for PSRR, and Gain, Swing, and Voltage Offset Measurements, Respectively

For irradiation, biased and unbiased parts were attached to a wire-wrap board—all unbiased parts' pins were grounded, while biased parts were held at the following voltages:

V- (2)	V+ (3)	Vss+ (7)	Vss- (4)	Vout (6)	Ref (5)	Rg (1 & 8)
GND	GND	+15.0 V	-15.0 V	Floating	GND	5.09 kΩ

Table 4: Irradiation Bias Conditions

As it's been established that the AD620 is Enhanced Low Dose Rate Sensitivity (ELDRS) susceptible, a low dose rate (LDR) of 10mrads/s was used.

Similarly, biased conditions for annealing were the same as they were for irradiation—the power supply pins were held at ±15V, a 5.09 kΩ was used to induce a gain of 10, and all other pins were grounded, except for the output pin, which was open—and unbiased conditions were achieved by inserting all parts in an insulating foam.

4. Analysis

An accurate method of estimating the chance of part failure is the one using the cumulative distribution function (CDF) and probability density function (PDF), such as

$$P_{fail} = \int_{0}^{\infty} g(x) * \left(1 - H(x)\right) * dx$$

where g(x) is the PDF—the chance of part failure at x—H(x) is the CDF—the chance of radiation being higher than x—and x is the dose in krad. To begin, the probability density distributions for the positive bias current data and input offset current can be found by maximizing likelihood:

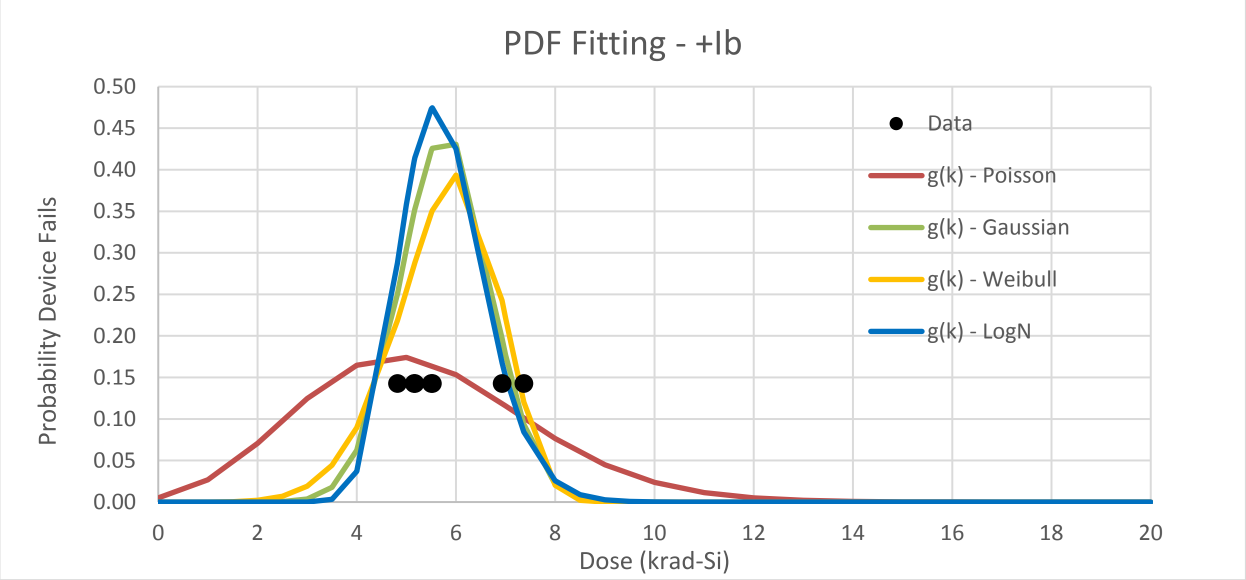

Figure 3: PDF vs. TID (krad-Si)

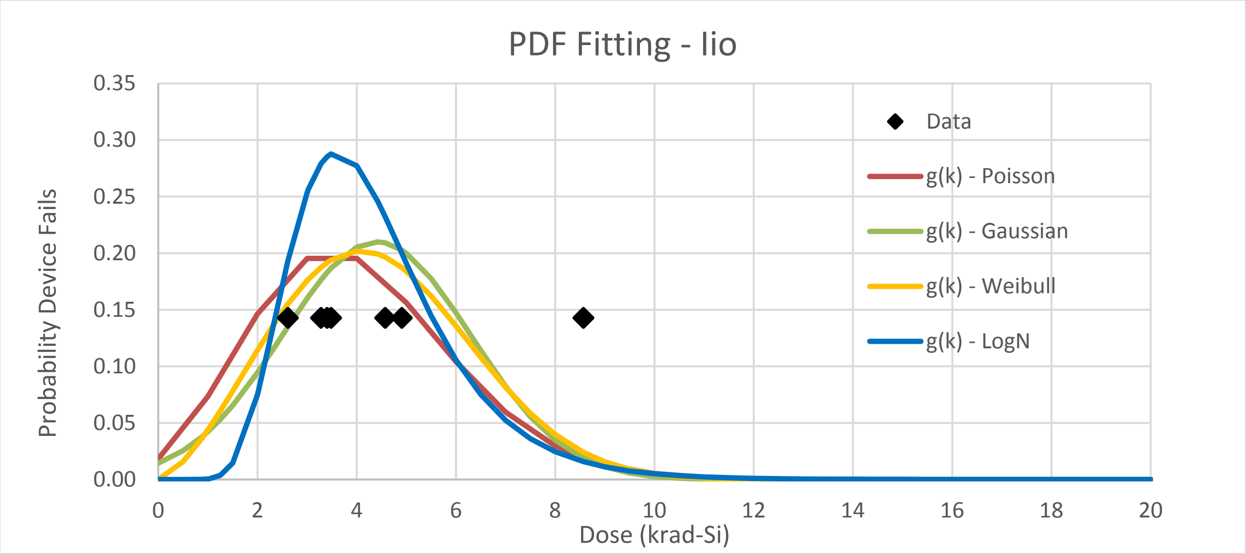

Figure 4: PDF vs. TID (krad-Si)

For the environment data (at Sun Synchronous Low Earth Orbit), because only 50% and 90% confidence level doses are given, a modified form of the previous equation is

$$P_{fail} = \int_{0}^{CF} g(x) * dx$$

In other words, we're determine the probabilities of failure up to the given environment doses; this equation is just the cumulative distribution function of the previous PDF's, with the confidence level doses being the x value:

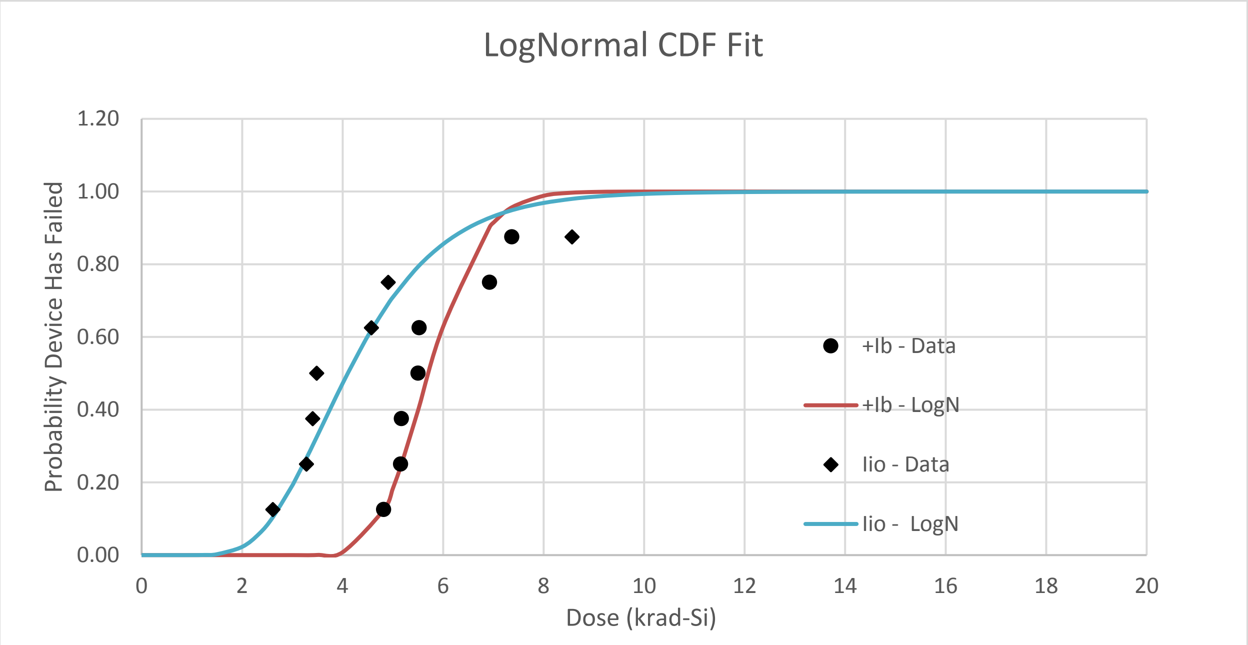

Figure 5: Lognormal Cumulative Distribution Functions for Data Fitting

The resulting data at each confidence level is:

Thickness (mils)	*Dose CL (%)*	*Dose (krad)*	*+I_b Fail (%)*	*I_{io} Fail (%)*
100	50	1.25	5.58E-23	0.047
	90	4.42	4.14	58.26
125	50	1.02	1.49E-29	0.0053
	90	3.03	0.00093	19.95
150	50	0.878	6.43E-35	0.00088
	90	*2.34*	8.44E-08	5.90

Table 5: Probability of Failure for Multiple Confidence Levels at Multiple Thicknesses

As a result, **at 100 mils and with a 90% confidence leve**l, the **positive input bias current ($+\mathbf{I_b}$)** and **input offset current ($\mathbf{I_{io}}$)** have a **4.14% and 58.26% chance of failure** during the mission respectively— the first being well below the desired 10%. In order to bring the latter down below 10% (with a 90% confidence level), project engineers could **use 150 mils of shielding,** yielding a **5.90% chance of failure**.

5. Appendix

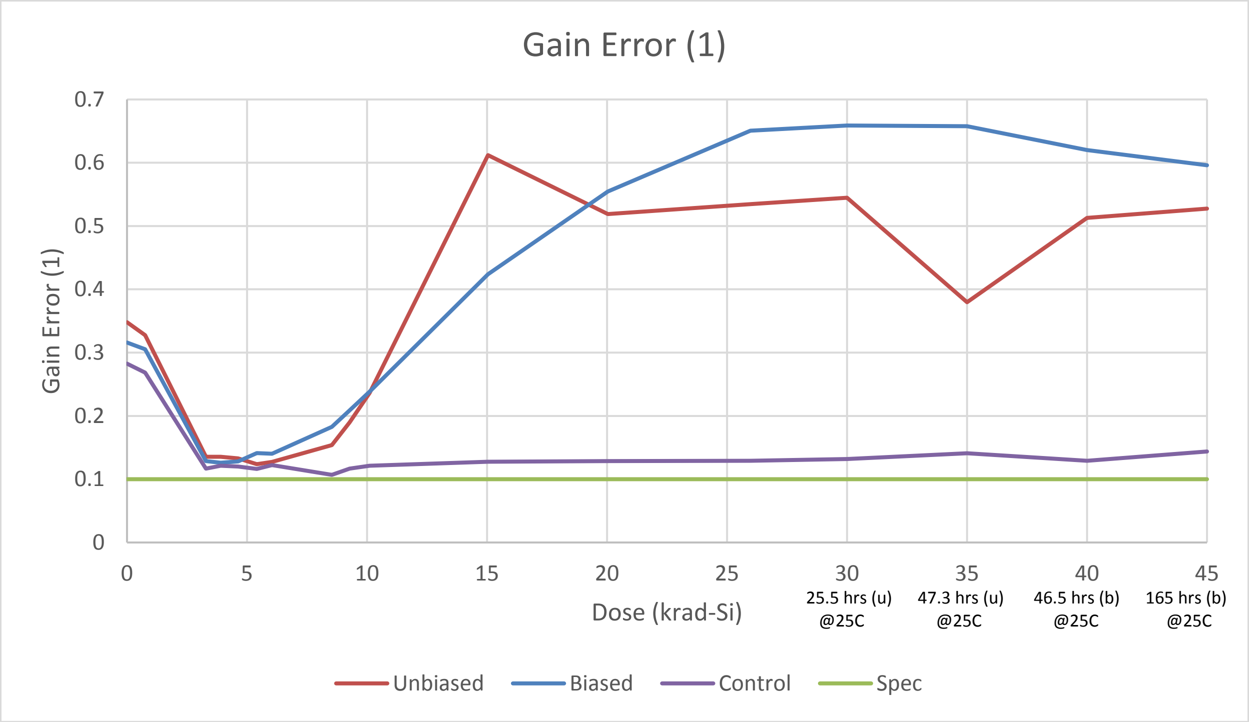

Figure 6: Gain Error (1) vs. TID (krad-Si)

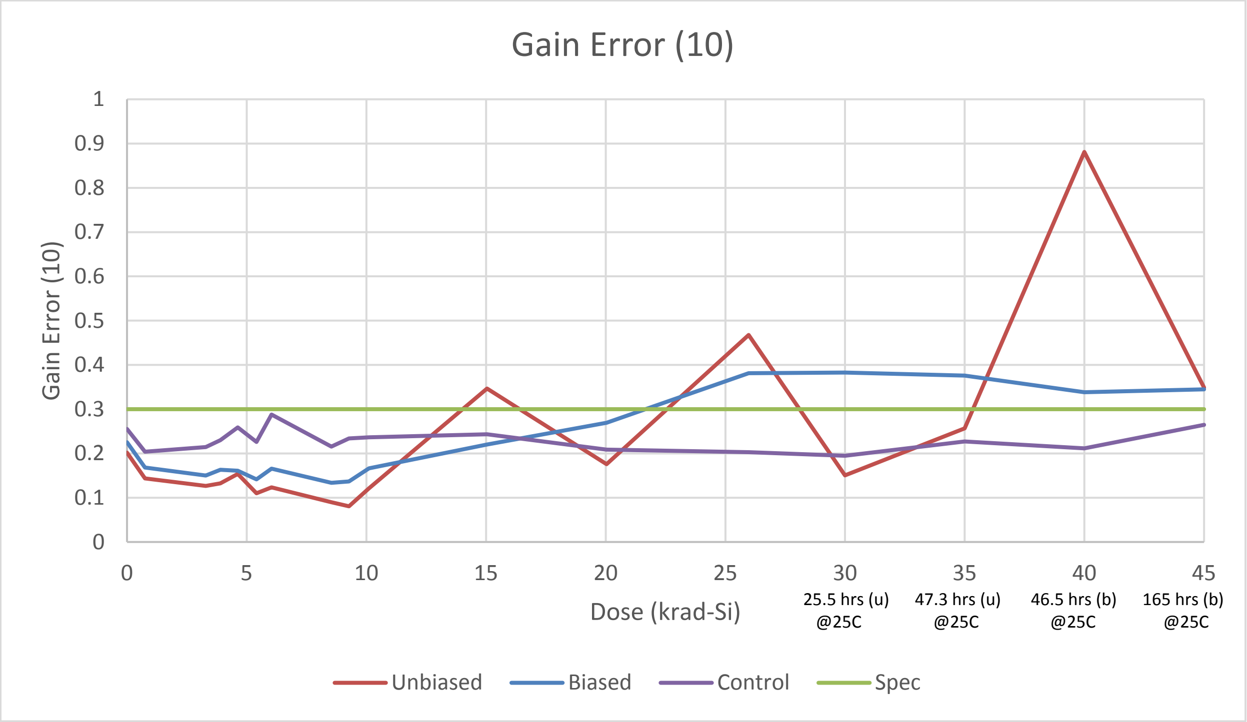

Figure 7: Gain Error (10) vs. TID (krad-Si)

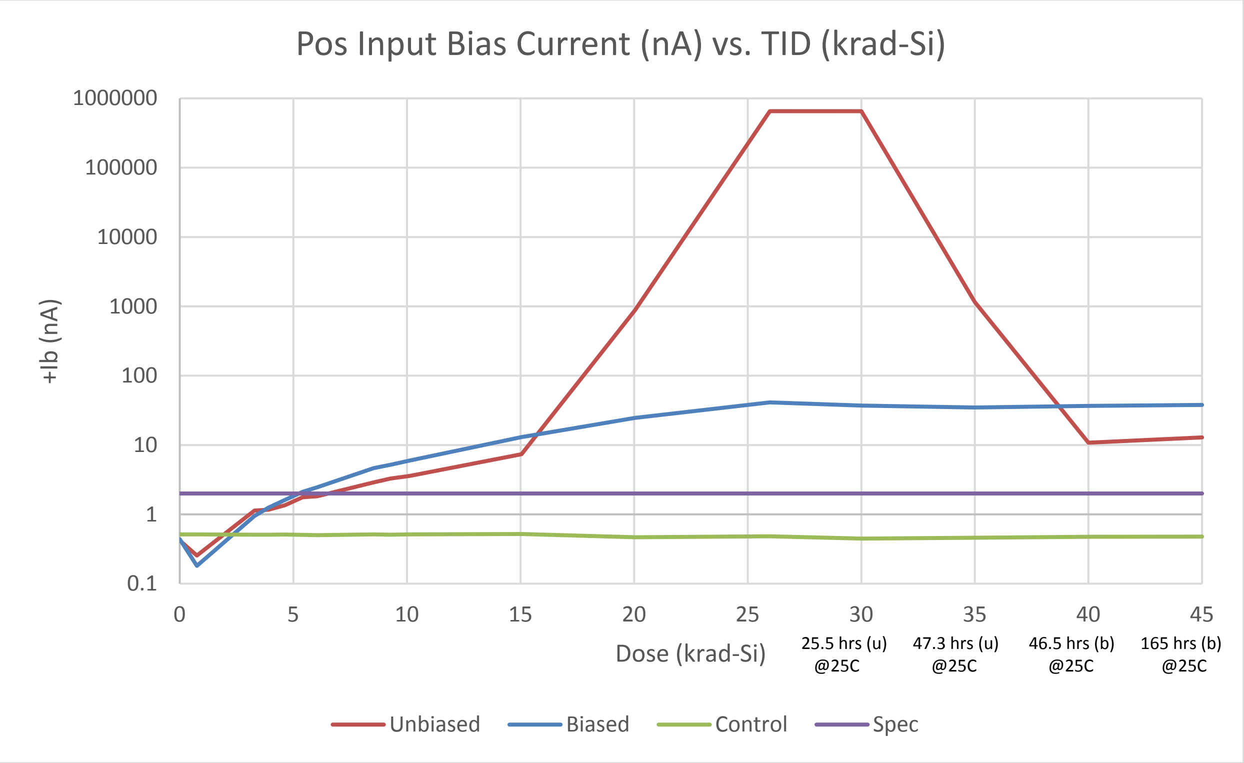

Figure 8: Positive Input Bias Current vs. TID (krad-Si)

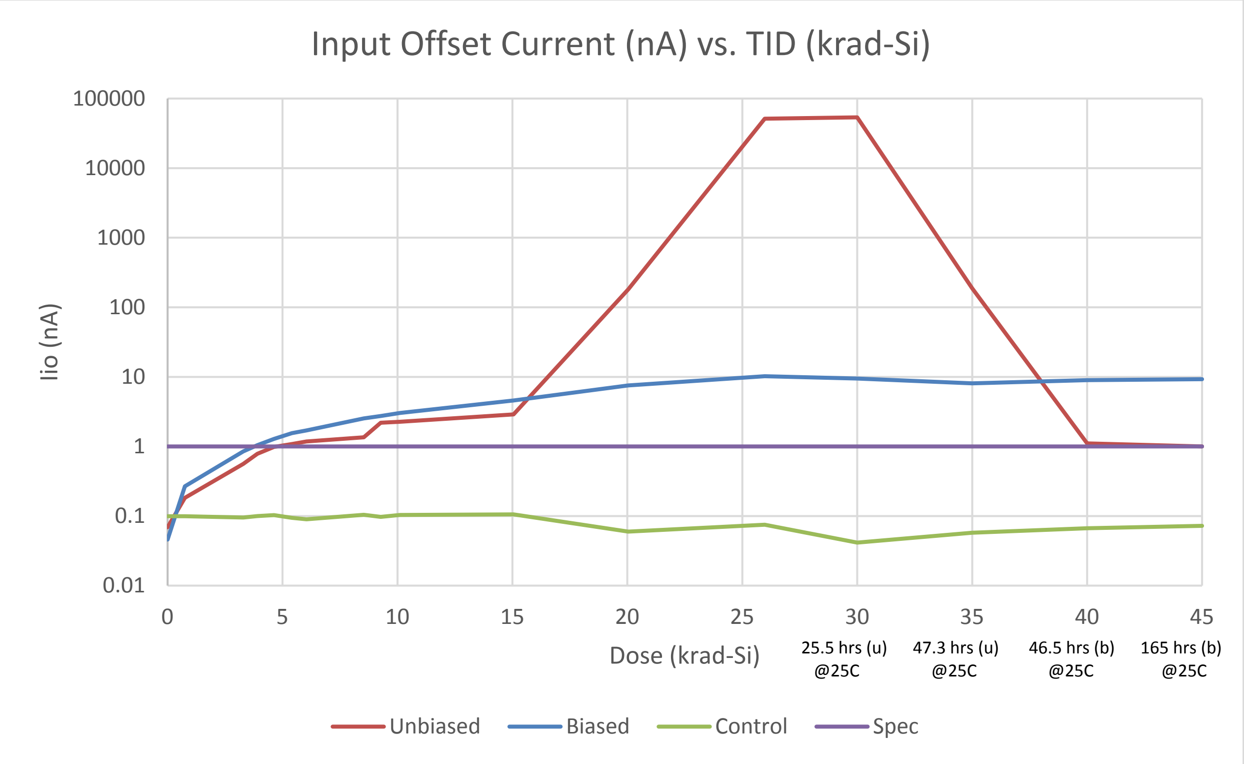

Figure 9: Input Offset Current vs. TID (krad-Si

Rad (krad-Si)	0	0.75	3.29	3.90	4.63	5.41	6.04	8.54	9.27	10.11	15.05	20.04	25.97	25.5 hrs unbiased @ 25 C	47.3 hrs unbiased @ 25 C	46.5 hrs biased @ 25 C	165 hrs biased @ 25 C
Part #	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	35.039	36.366
1	-0.402	-0.135	1.028	1.250	1.575	2.205	2.382	4.466	4.621	5.232	11.210	22.627	39.611	35.450	32.999	40.577	42.084
2	-0.458	-0.221	0.885	1.128	1.518	1.932	2.396	4.820	5.633	6.510	14.829	28.181	47.085	42.004	37.712	37.417	38.455
3	-0.456	-0.170	1.136	1.488	1.877	2.380	2.769	5.222	5.916	6.795	14.180	25.461	41.234	36.995	35.897	33.734	34.796
4	-0.439	-0.198	0.748	1.127	1.495	1.940	2.277	4.059	4.605	5.342	11.982	22.415	37.019	33.882	32.662	27	29.990
5	-0.467	-0.111	1.035	1.102	1.230	1.731	1.591	2.743	2.899	3.154	7.212	327.73	3390	3172	3123	N/A	N/A
6	-0.368	-0.060	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	16	19.371
7	-0.417	-0.417	0.939	0.836	1.076	1.440	1.654	2.305	2.568	2.739	5.586	7.243	375.3	399	348	-10.617	-10.666
8	-0.431	-0.431	1.438	1.565	1.745	2.112	2.227	3.622	4.414	4.842	9.316	2299.4	1.95E+06	1.96E+06	-10.620	-0.461	-0.464
9	-0.500	-0.500	-0.497	-0.494	-0.499	-0.494	-0.488	-0.500	-0.495	-0.502	-0.507	-0.452	-0.465	-0.433	-0.448	-0.490	-0.492
10	-0.528	-0.528	-0.519	-0.525	-0.527	-0.518	-0.514	-0.531	-0.521	-0.528	-0.535	-0.483	-0.498	-0.462	-0.473	35.039	36.366

Table 5: Positive Input Bias Current Data

Rad (krad-Si)	0	0.75	3.29	3.90	4.63	5.41	6.04	8.54	9.27	10.11	15.05	20.04	25.97	25.5 hrs unbiased @ 25 C	47.3 hrs unbiased @ 25 C	46.5 hrs biased @ 25 C	165 hrs biased @ 25 C
Part #	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	35.039	36.366
1	-0.443	-0.427	0.025	0.198	0.312	0.556	0.774	2.070	2.249	2.813	7.674	16.186	29.674	26.284	25.403	26.633	27.426
2	-0.520	-0.504	0.178	0.290	0.506	0.789	0.879	2.642	3.277	3.725	11.022	21.368	38.020	33.609	32.931	33.812	34.863
3	-0.548	-0.519	-0.102	-0.048	-0.044	0.060	0.350	1.494	1.711	2.197	6.849	14.365	27.015	23.921	23.098	24.005	24.948
4	-0.428	-0.345	0.295	0.368	0.545	0.852	1.031	2.230	2.562	3.026	8.350	16.637	29.364	26.660	25.587	26.415	27.451
5	-0.536	-0.420	0.091	-0.143	-0.061	0.082	-0.292	0.692	0.264	0.273	3.184	528.97	3700	3479	3416	19	21.828
6	-0.476	-0.382	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	-0.487	-0.487	0.415	0.321	0.063	0.616	0.729	1.232	0.988	1.086	2.222	4.607	628	655	599	11	14.051
8	-0.459	-0.459	1.224	0.967	1.100	1.337	1.493	2.679	2.049	2.574	8.056	2643.2	2.11E+06	2.12E+06	5.933	5.675	5.819
9	-0.413	-0.413	-0.408	-0.405	-0.405	-0.410	-0.407	-0.404	-0.407	-0.409	-0.414	-0.406	-0.403	-0.405	-0.399	-0.405	-0.401
10	-0.417	-0.417	-0.417	-0.415	-0.414	-0.414	-0.416	-0.419	-0.414	-0.414	-0.416	-0.410	-0.410	-0.407	-0.407	-0.412	-0.411

Table 6: Negative Input Bias Current Data

Rad (krad-Si)	0	0.75	3.29	3.90	4.63	5.41	6.04	8.54	9.27	10.11	15.05	20.04	25.97	25.5 hrs unbiased @ 25 C	47.3 hrs unbiased @ 25 C	46.5 hrs biased @ 25 C	165 hrs biased @ 25 C
Part #	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	35.039	36.366
1	0.041	0.292	1.003	1.053	1.263	1.649	1.608	2.396	2.373	2.419	3.535	6.440	9.937	9.166	7.596	8.407	8.940
2	0.061	0.283	0.707	0.838	1.013	1.143	1.517	2.178	2.357	2.785	3.807	6.813	9.065	8.395	4.781	6.765	7.222
3	0.092	0.350	1.237	1.536	1.922	2.320	2.419	3.729	4.205	4.598	7.331	11.096	14.219	13.073	12.799	13.412	13.507
4	-0.011	0.147	0.452	0.760	0.951	1.088	1.246	1.829	2.042	2.317	3.632	5.778	7.655	7.223	7.075	7.319	7.345
5	0.069	0.309	0.945	1.245	1.291	1.648	1.883	2.052	2.635	2.882	4.028	-201	-309	-307	-292.525	7.917	8.161
6	0.108	0.321	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	0.070	0.070	0.524	0.515	1.013	0.825	0.925	1.073	1.580	1.653	3.364	2.637	-252	-256	-250.627	5.051	5.320
8	0.029	0.029	0.213	0.598	0.646	0.774	0.735	0.942	2.366	2.268	1.259	-343.735	-1.54E+05	-1.60E+05	-16.553	-16.292	-16.485
9	-0.087	-0.087	-0.089	-0.089	-0.094	-0.084	-0.081	-0.096	-0.088	-0.093	-0.093	-0.047	-0.062	-0.028	-0.049	-0.056	-0.064
10	-0.112	-0.112	-0.102	-0.110	-0.112	-0.105	-0.098	-0.113	-0.107	-0.114	-0.118	-0.073	-0.088	-0.055	-0.066	-0.077	-0.081

Table 7: Input Offset Current

Rad (krad-Si)	0	0.75	3.29	3.90	4.63	5.41	6.04	8.54	9.27	10.11	15.05	20.04	25.97	25.5 hrs unbiased @ 25 C	47.3 hrs unbiased @ 25 C	46.5 hrs biased @ 25 C	165 hrs biased @ 25 C
Part #	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	35.039	36.366
1	98.5	98.2	97.4	99.8	97.0	96.5	96.4	70.5	68.8	68.4	71.8	70.9	83.7	71.1	75.8	76.7	78.7
2	98.0	97.7	96.8	96.6	96.6	96.3	95.8	66.1	66.3	66.2	75.5	58.5	61.6	59.4	45.5	62.7	61.5
3	107.6	107.0	112.0	111.7	112.6	114.8	115.7	79.7	67.4	67.1	67.8	54.8	67.8	46.2	75.2	71.8	69.0
4	102.6	102.2	102.9	103.2	103.2	103.8	104.4	92.1	61.9	62.2	65.5	46.8	50.4	57.7	45.0	50.2	51.3
5	120.5	116.4	134.5	116.8	128.4	127.1	117.6	65.1	64.9	65.0	52.2	46.4	48.9	62.9	53.8	45.9	52.2
6	122.4	119.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	102.6	102.8	101.5	101.7	101.3	101.3	100.8	98.1	97.8	92.7	64.6	61.5	42.8	57.3	56.4	56.8	56.3
8	116.4	115.7	118.4	119.9	122.4	127.1	111.7	61.0	61.5	66.8	50.7	48.2	49.6	47.3	102.2	103.1	103.2
9	116.8	115.7	116.0	116.4	117.6	116.4	116.4	116.8	116.4	118.9	118.0	116.4	117.2	116.4	115.4	116.4	117.2
10	108.3	108.7	107.7	107.6	107.4	107.6	107.4	107.4	107.7	107.7	107.5	107.6	107.2	107.6	107.6	107.5	107.4

Table 8: PSRR at Gain = 1 Data

Rad (krad-Si)	0	0.75	3.29	3.90	4.63	5.41	6.04	8.54	9.27	10.11	15.05	20.04	25.97	25.5 hrs unbiased @ 25 C	47.3 hrs unbiased @ 25 C	46.5 hrs biased @ 25 C	165 hrs biased @ 25 C
Part #	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	Mean (nA)	35.039	36.366
1	117.6	117.2	116.0	115.7	115.4	113.9	113.1	98.0	92.0	92.1	89.0	52.0	74.0	73.7	45.5	96.8	79.6
2	115.4	114.8	112.9	112.4	111.7	110.4	108.6	88.9	89.5	90.7	79.2	61.9	60.7	60.6	43.0	59.0	62.6
3	123.2	124.9	123.2	121.7	120.5	118.9	118.0	74.7	90.4	89.7	112.2	44.4	71.8	77.9	84.2	70.2	49.2
4	130.0	130.0	144.0	138.0	127.1	122.4	118.4	73.6	85.2	85.1	92.9	60.6	49.6	48.2	50.3	46.7	51.2
5	123.2	121.7	121.7	119.9	118.0	117.2	115.4	88.6	89.1	93.2	45.6	51.6	53.1	51.6	45.3	48.8	51.0
6	134.5	134.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	121.1	121.1	118.9	118.9	117.6	117.6	116.4	110.9	107.6	97.1	86.6	56.2	47.7	45.3	59.7	56.5	53.2
8	130.0	128.4	123.2	121.1	117.6	112.2	105.3	88.5	101.5	74.3	52.7	46.0	45.2	50.6	113.4	113.4	113.4
9	124.0	123.2	123.2	124.0	123.2	123.2	124.0	123.2	120.5	124.0	124.0	124.0	124.0	123.2	124.0	124.0	123.2
10	122.4	122.4	122.4	122.4	121.7	121.7	121.7	122.4	123.2	123.2	123.2	121.7	122.4	122.4	121.1	122.4	122.4

Table 9: PSRR at Gain = 10 Data