Total dose testing of the HS-OP470AEH radiation hardened quad operational amplifier

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Revision 0
January 2014

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1. Introduction

This report reports the results of a low and high dose rate total dose test of the HS-OP470AEH quad operational amplifier. The test was conducted in order to determine the sensitivity of the part to the total dose environment and to determine if dose rate and bias sensitivity exist. It should be noted that these samples were taken from a Palm Bay Fab 59 production lot that used Silox passivation as opposed to the silicon nitride used in earlier production, and evaluating the effects of this process change was an added objective of this work. The low dose rate irradiations were followed by a 100^{o}C biased anneal for 168 hours.

The HS-OP470AEH and HS-OP470ARH use the same die design and differ only in the passivation technology and total dose acceptance testing flow, which is performed on a wafer by wafer basis. The HS-OP470AEH uses silicon dioxide (‘silox’) passivation while the HS-OP470ARH uses silicon nitride (‘nitride’) passivation. Additionally the HS-OP470AEH is acceptance tested at low and high dose rate, while the HS-OP470ARH is acceptance tested at high dose rate only.

2. Reference Documents

MIL-STD-883G test method 1019
HS-OP470AEH data sheet
DLA Standard Microcircuit Drawing (SMD) 5962-98533

3: Part Description

The HS-OP470AEH is a hardened monolithic quad operational amplifier intended to provide reliable performance in harsh radiation environments. Its excellent noise characteristics coupled with competitive AC specifications make this amplifier well suited for satellite system applications. Dielectrically isolated bipolar processing makes this device immune to single-event latchup. Complementing these specifications is a post radiation open loop gain in excess of 40 kV/V (92 dB). The part uses an industry standard quad operational amplifier pinout.

Specifications for Rad Hard QML devices are controlled by the Defense Logistics Agency, Land and Maritime (DLA). Detailed electrical specifications are contained in SMD 5962-98533. A "hot-link" is provided on the Intersil homepage for access to the SMD.

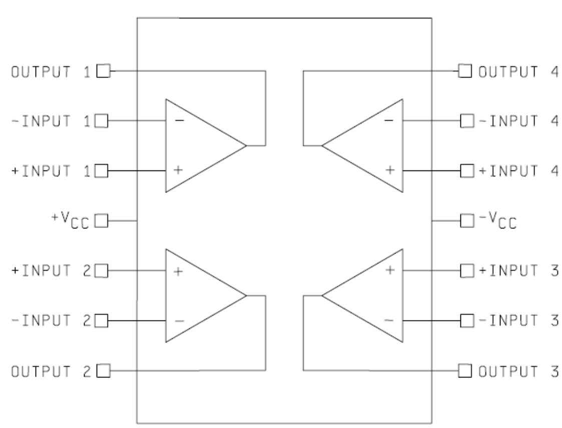

Fig. 1: HS-OP470AEH block diagram.

4: Test Description

4.1 Irradiation Facilities

High dose rate testing was performed using a Gammacell 220 ^{60}Co irradiator located in the Palm Bay, Florida Intersil facility. Low dose rate testing was performed using the Hopewell Designs (Alpharetta, GA) N40 panoramic ^{60}Co irradiator, also located in the Palm Bay facility. The high dose rate irradiations were done at 65 rad(Si)/s and the low dose rate work was performed at 0.010 rad(Si)/s, both per MIL-STD-883 Method 1019.7. The post low dose rate anneals were performed in a small temperature chamber.

4.2 Test Fixturing

Table 1, below, shows the configuration used for biased irradiation in conformance with Standard Microcircuit Drawing (SMD) 5962-98533.

Test	Ground	V+	V-	OUT to –IN, each amplifier
Radiation exposure	Pins 3, 5, 10, 12	Pin 4	Pin 11	Pins 1 to 2, 7 to 6, 8 to 9, 14 to 13

Table 1: Irradiation bias configuration for the HS-OP470AEH per Standard Microcircuit Drawing (SMD) 5962-98533. (T_A = +25°C ±5°C, V+ = 15V ±0.5V, V- = -15V ±0.5V)

4.3 Characterization equipment and procedures

All electrical testing was performed outside the irradiator using the production automated test equipment (ATE) with datalogging at each downpoint. Downpoint electrical testing was performed at room temperature.

4.4 Experimental matrix

Total dose irradiations proceeded in accordance with the guidelines of MIL-STD-883 Test Method 1019.7. The experimental matrix consisted of 28 samples irradiated at high dose rate under bias, 14 samples irradiated at low dose rate with all pins grounded and 14 samples irradiated at low dose rate under bias. All low dose rate samples were annealed under bias at 100^{o}C for 168 hours. Two control units were used to insure repeatable data.

Samples of the HS-OP470AEH die were drawn from Fab 59 production lot G2A7TEH and were packaged in the standard 14-pin solder-sealed hermetic flatpack (CDFP4-F14) production package. Samples were processed through the standard burnin cycle before irradiation, as required by MIL-STD-883, and were screened to the SMD 5962-98533 limits at room, low and high temperatures prior to the test.

4.5 Downpoints

Downpoints were 0, 50, 100 and 150 krad(Si) for the low dose rate test, followed by the anneal, and 0 and 100 krad(Si) for the high dose rate test.

5: Results

Testing at both dose rates of the HS-OP470AEH is complete.

5.1 Attributes data

Table 2: Attributes data.

Part	Dose rate, rad(Si)/s	Bias	Sample size	Downpoint	Pass (Note 1)	Fail
HS-OP470AEH	0.01	Table 1	14	Pre-irradiation	14	0
				50 krad(Si)	14	0
				100 krad(Si)	14	0
				150 krad(Si)	14	0
				Anneal	14	0
HS-OP470AEH	0.01	Grounded	14	Pre-irradiation	14	0
				50 krad(Si)	14	0
				100 krad(Si)	14	0
				150 krad(Si)	14	0
				Anneal	14	0
HS-OP470AEH	65	Table 1	28	Pre-irradiation	28	0
				100 krad(Si)	28	0

Note 1: 'Pass' indicates a sample that passes all post-irradiation SMD limits.

5.2 Variables data

The plots in Figures 2 through 18 show data for at all downpoints. The plots show the average of key parameters as a function of total dose for each of the three irradiation conditions. We chose to plot the average for these parameters due to the relatively substantial sample sizes involved. With the exception of the power supply current (which is the sum of the four individual channel supply currents) all plots show the responses of all four channels.

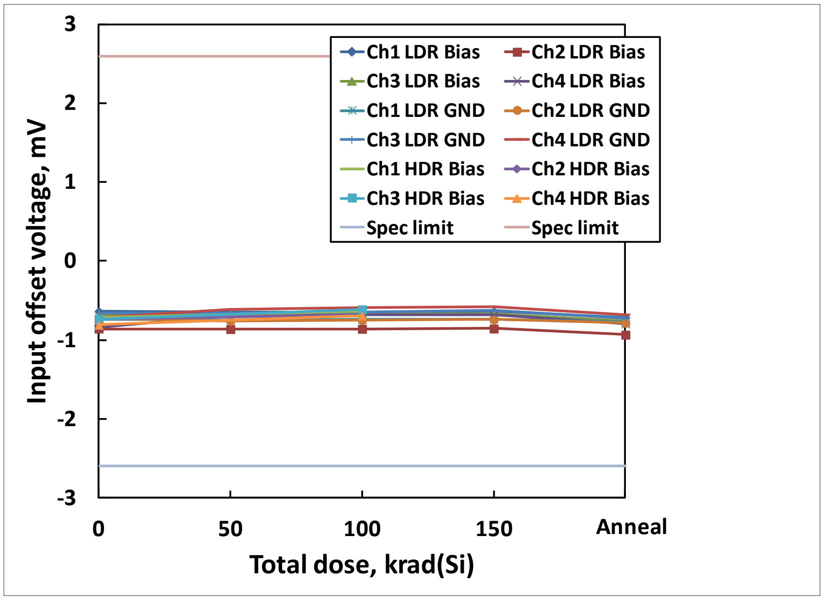

Fig. 2: HS-OP470AEH average input offset voltage in mV, each channel, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limits are -2.6 mV to +2.6 mV.

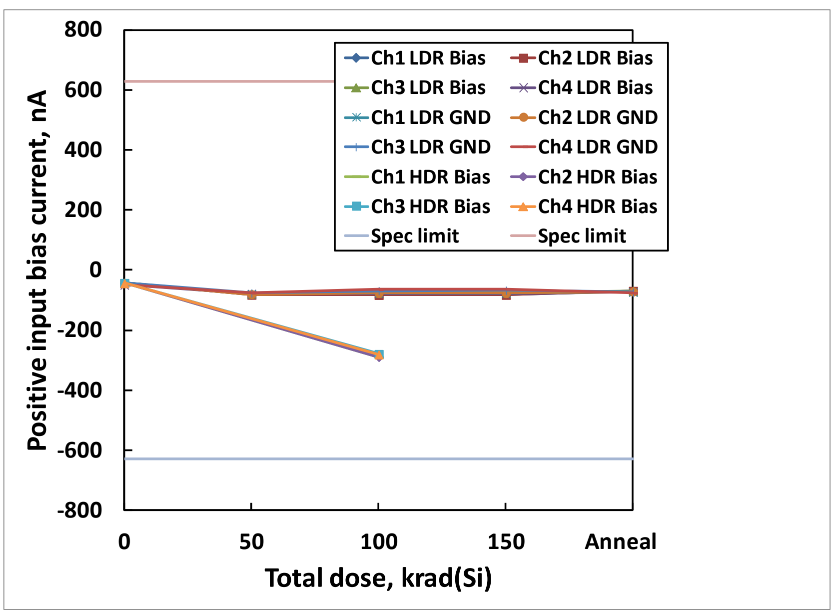

Fig. 3: HS-OP470AEH average positive input bias current in nA, each channel, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limits are -630 nA to +630 nA.

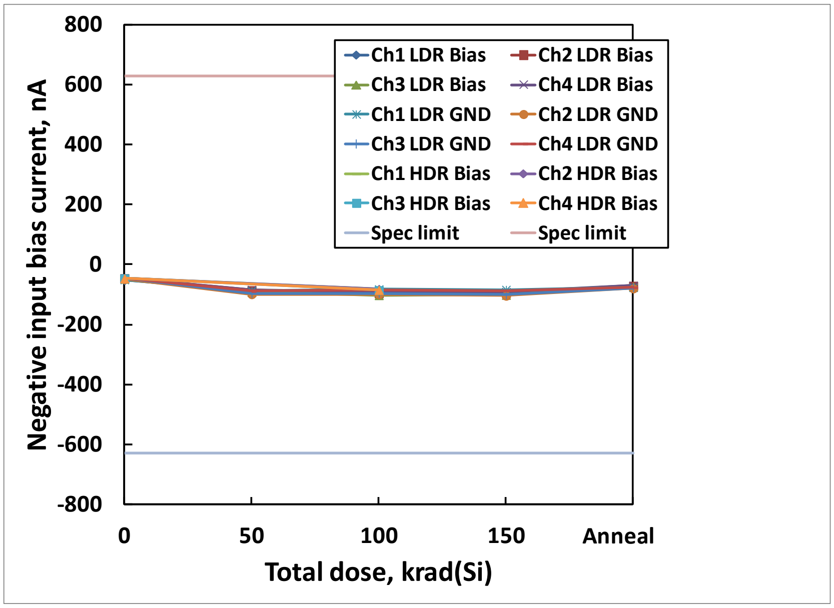

Fig. 4: HS-OP470AEH average negative input bias current in nA, each channel, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limits are -630 nA to +630 nA.

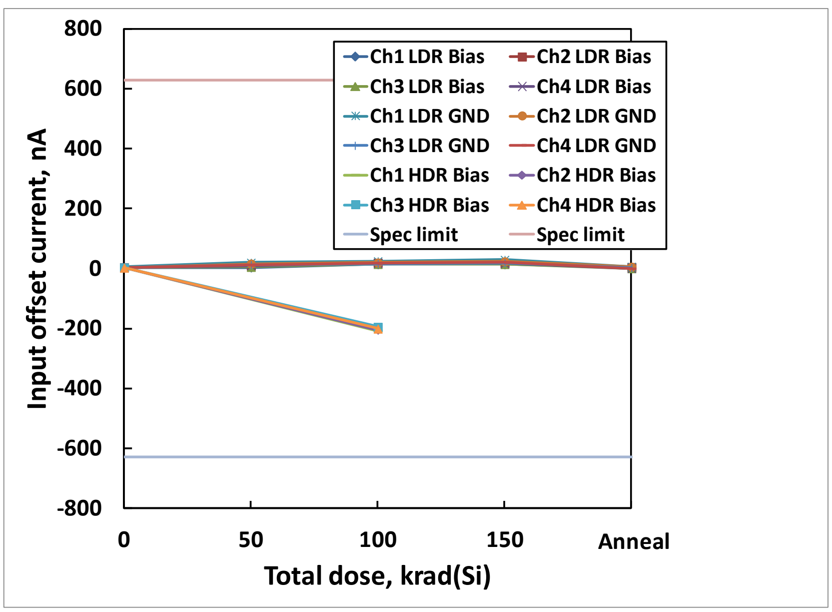

Fig. 5: HS-OP470AEH average input offset current in nA, each channel, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limits are -630.0 nA to +630 nA.

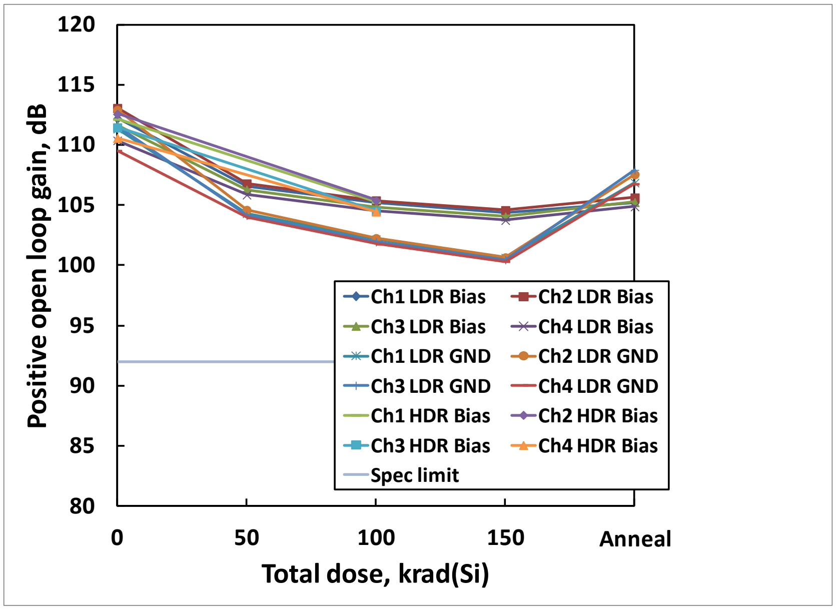

Fig. 6: HS-OP470AEH average positive open loop gain in dB, each channel, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 93 dB minimum.

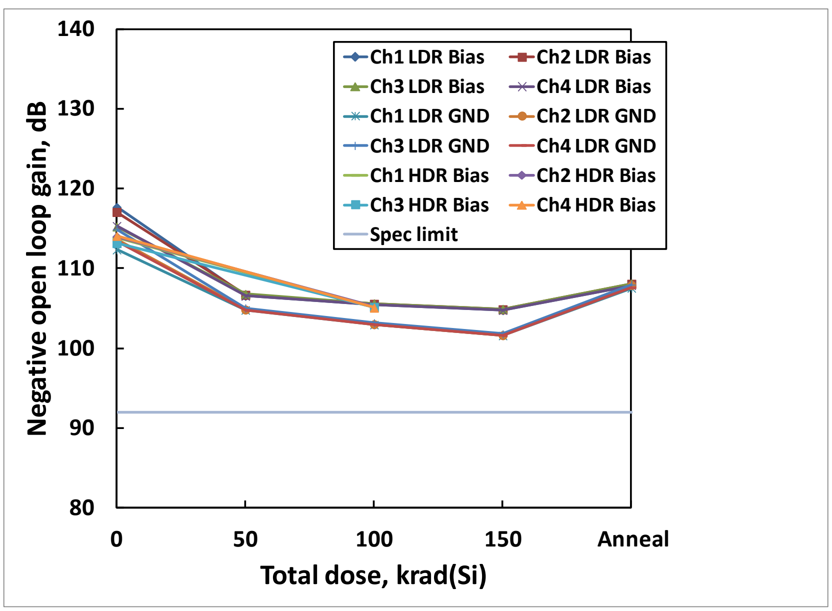

Fig. 7: HS-OP470AEH average negative open loop gain in dB, each channel, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 93 dB minimum.

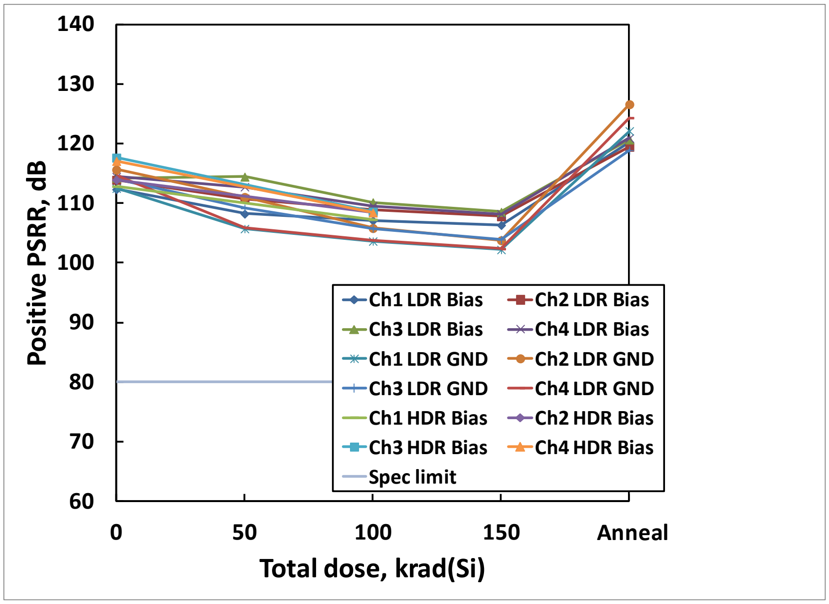

Fig. 8: HS-OP470AEH average positive power supply rejection ratio in dB, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 80 dB minimum.

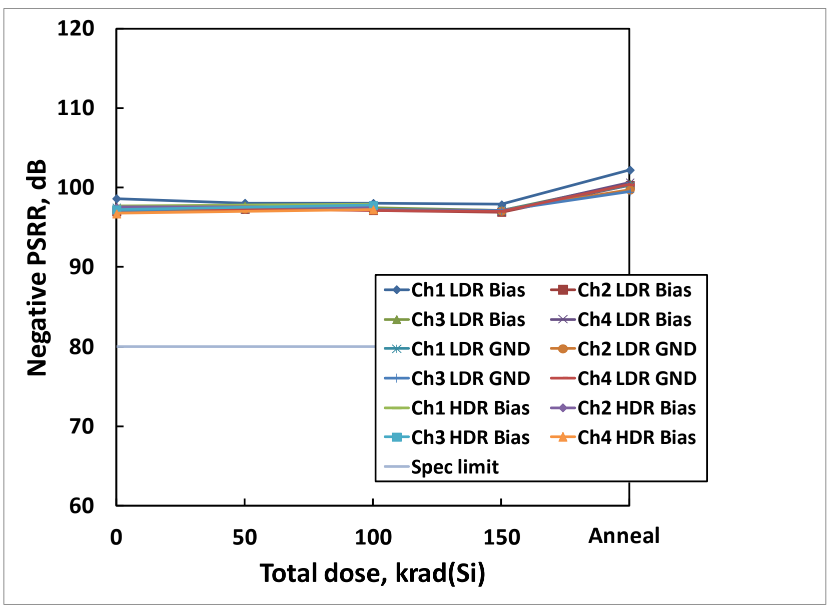

Fig. 9: HS-OP470AEH average negative power supply rejection ratio in dB, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 80 dB minimum.

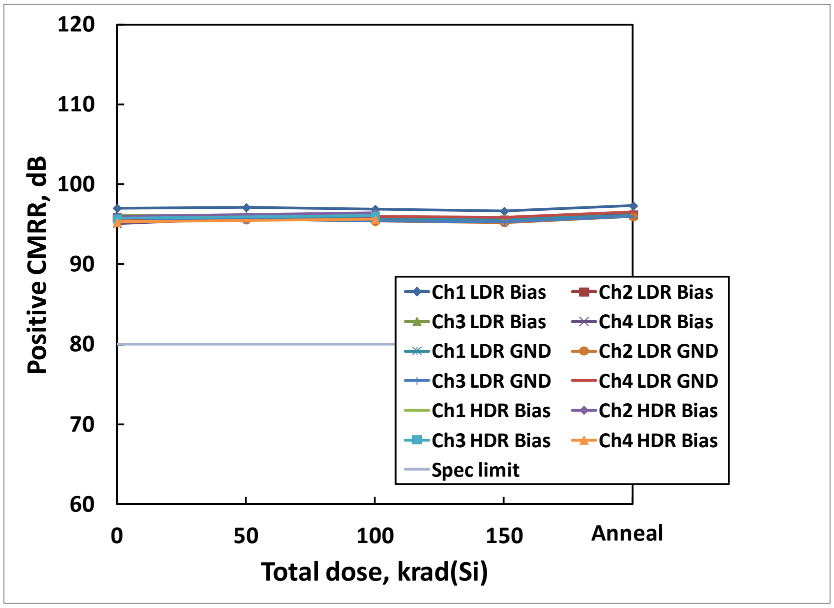

Fig. 10: HS-OP470AEH average positive common mode rejection ratio in dB, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 80 dB minimum.

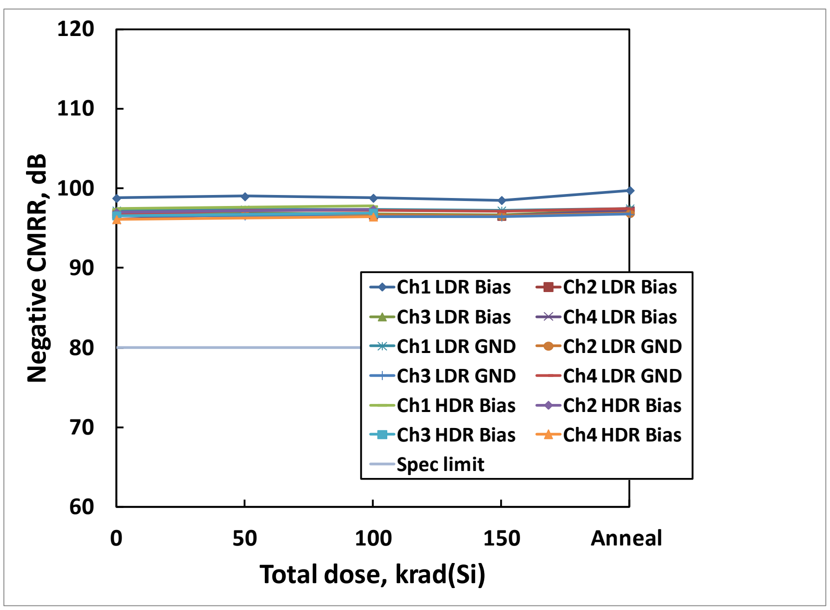

Fig. 11: HS-OP470AEH average negative common mode rejection ratio in dB, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 80 dB minimum.

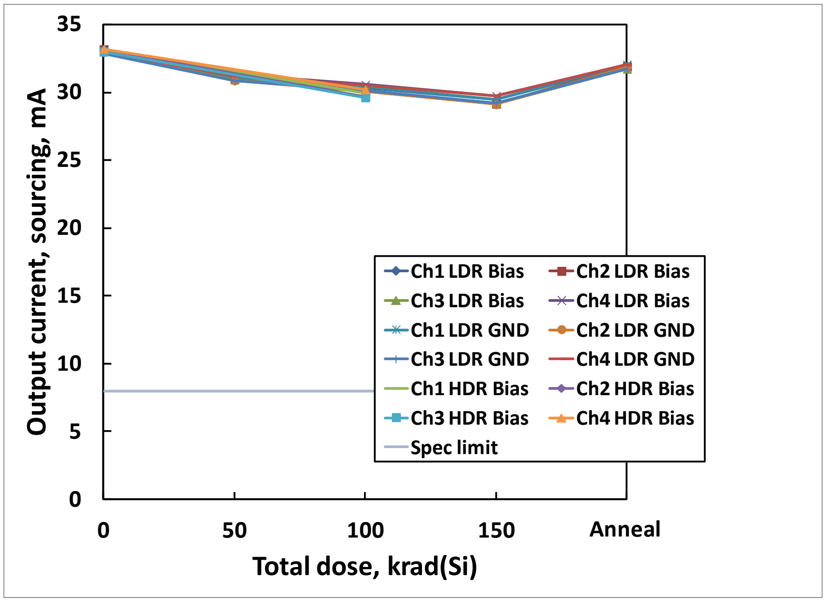

Fig. 12: HS-OP470AEH average output current in mA, sourcing, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 8.0 mA minimum.

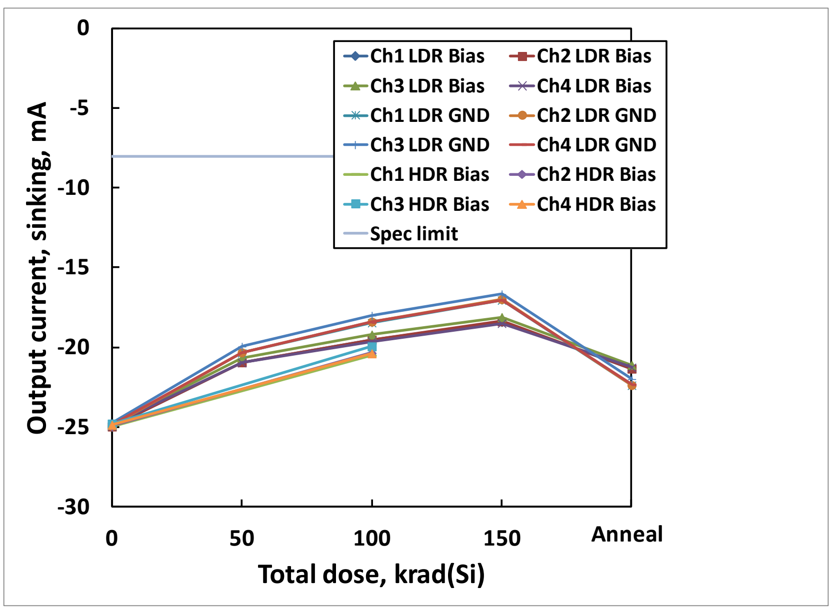

Fig. 13: HS-OP470AEH average output current in mA, sinking, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is -8.0 mA minimum.

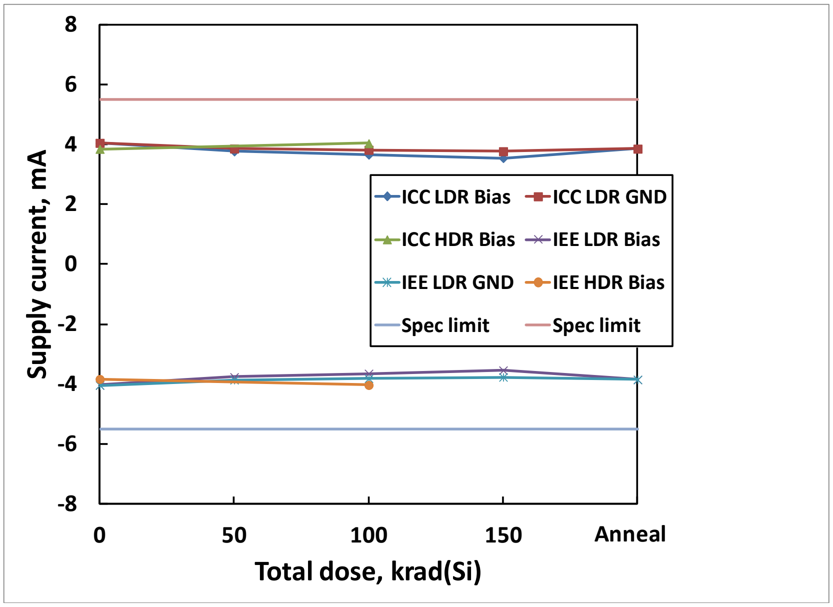

Fig. 14: HS-OP470AEH average positive and negative supply current in mA, as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limits are +5.5 mA and -5.5 mA maximum.

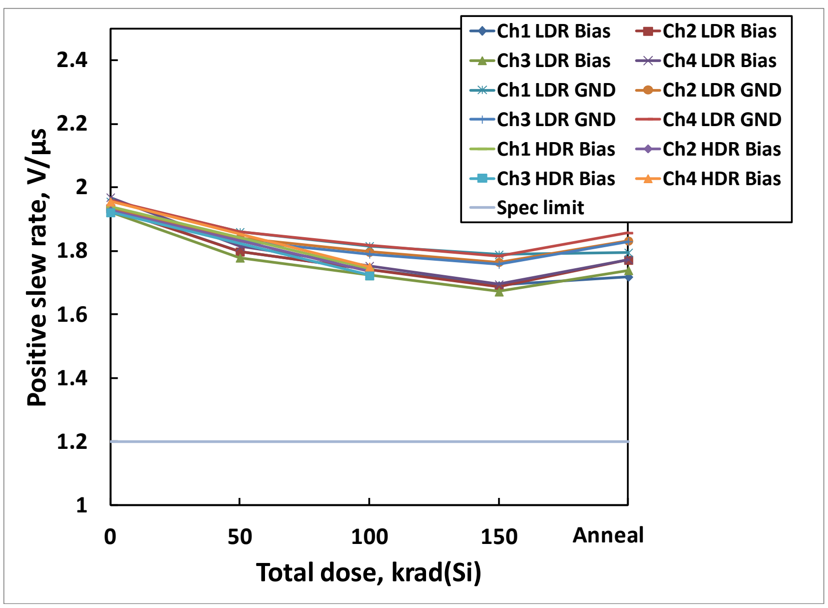

Fig. 15: HS-OP470AEH average positive slew rate in V/µs as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 1.2 V/µs minimum.

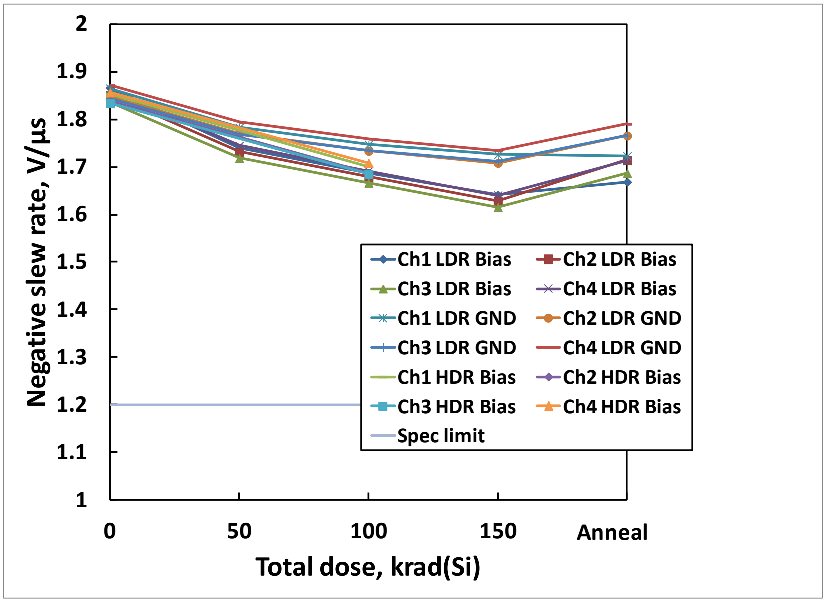

Fig. 16: HS-OP470AEH average negative slew rate in V/µs as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 1.2 V/µs minimum.

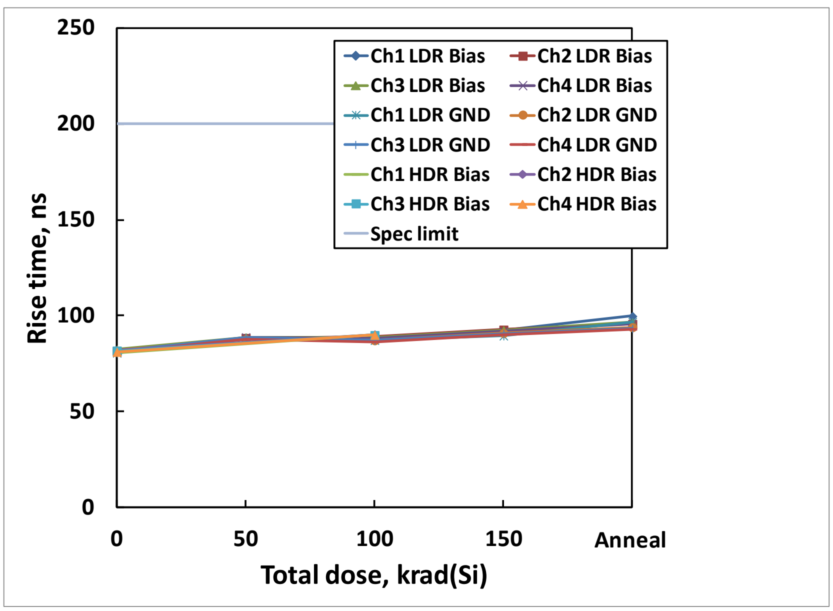

Fig. 17: HS-OP470AEH average rise time in ns as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100°C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 200 ns maximum.

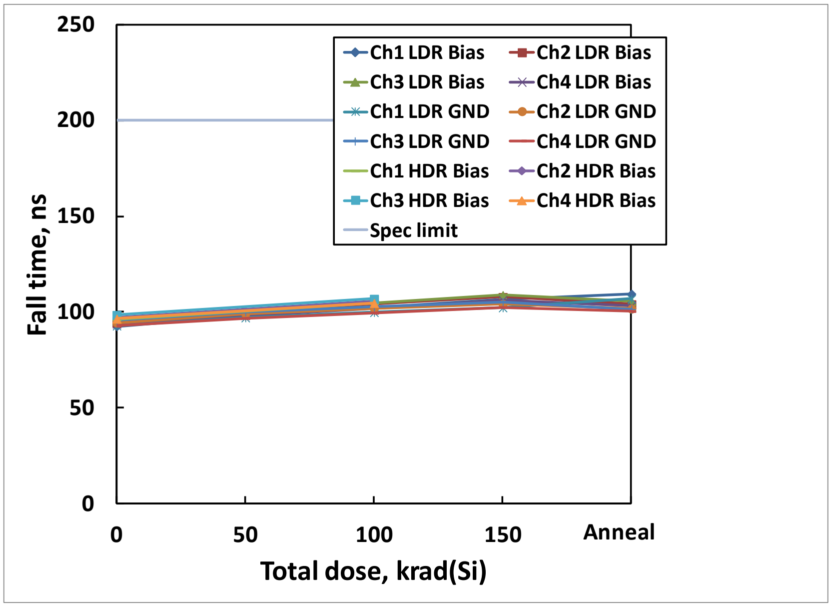

Fig. 18: HS-OP470AEH average fall time in ns as a function of total dose irradiation at low dose rate for the unbiased (all pins grounded) and the biased (per Table 1) cases, both of which were followed by a biased anneal at 100^{o}C for 168 hours, and at high dose rate for the biased case. The low dose rate was 0.01 rad(Si)/s and the high dose rate was 65 rad(Si)/s. Sample size was 14 for each of the low dose rate cells and 28 for the high dose rate cell. The post-irradiation SMD limit is 200 ns maximum.

6: Discussion and Conclusion

This document reports results of a total dose test of HS-OP470AEH quad operational amplifier samples using Silox passivation. Parts were tested at low dose rate under biased and unbiased conditions to a total dose of 150 krad(Si) followed by a 100^{o}C biased anneal for 168 hours. A second set of samples was irradiated at high dose rate to 100 krad(Si) but omitted the anneal.

The input offset voltage was stable and was well within the SMD post-irradiation specification at all downpoints. The positive input bias current remained very stable at all downpoints over low dose rate irradiation and subsequent anneal but showed some change at high dose rate; the parameter remained well within the SMD limits. The negative input bias current remained very stable at all downpoints over low and high dose rate irradiation and subsequent anneal. The input offset current also remained very stable at all downpoints over low dose rate irradiation and subsequent anneal but showed some change at high dose rate; the parameter remained well within the SMD limits. The offset current represents the difference between the two input bias current values and this expected behaviour reflects the input bias current response.

Positive and negative open-loop gain showed some degradation but was within the SMD post-irradiation limits after 150 krad(Si) at low dose rate. We noted a limited recovery of the parameter over the post low dose rate irradiation anneal.

Positive and negative power supply rejection ratio showed some degradation but were within the SMD post-irradiation limits after 150 krad(Si) at low dose rate. We again noted a limited recovery of the parameter over the post low dose rate irradiation anneal.

Positive and negative common mode rejection ratio showed excellent stability at all downpoints.

Sourcing and sinking output current showed some degradation but were well within the SMD post-irradiation limits after 150 krad(Si) at low dose rate. We again noted a limited recovery of the parameter over the post low dose rate irradiation anneal.

Positive and negative power supply current showed excellent stability at all downpoints.

Positive and negative slew rate showed some degradation but were within the SMD post-irradiation limits after 150 krad(Si) at low dose rate. We again noted a limited recovery of the parameter over the post low dose rate irradiation anneal.

Rise time and fall time showed excellent stability at all downpoints.

The part is implemented in the Intersil EBHF process modified by the use of Silox passivation. The HS-OP470AEH data showed little, if any, low dose rate or bias sensitivity, with the high dose rate biased condition marginally worst-case for some parameters. The part is not considered to be low dose rate sensitive. The data similarly showed little post low dose rate annealing.

7: Appendices

7.1: Reported parameters, SMD limits and figure numbers.

Fig.	Parameter	Limit, low	Limit, high	Units	Notes
2	Input offset voltage	-2.6	+2.6	mV	
3	Positive input bias current	-630	630	nA	
4	Negative input bias current	-630	630	nA	
5	Input offset current	-630	630	nA	
6	Positive open loop gain	92	-	dB	
7	Negative open loop gain	92	-	dB	
8	Positive power supply rejection ratio	80	-	dB	
9	Negative power supply rejection ratio	80	-	dB	
10	Positive common mode rejection ratio	80	-	dB	
11	Negative common mode rejection ratio	80	-	dB	
12	Output current, sourcing	8.0	-	mA	
13	Output current, sinking	-8.0	-	mA	
14	Supply current, positive and negative	-5.5	5.5	mA	
15	Positive slew rate	1.2	-	V/µs	
16	Negative slew rate	1.2	-	V/µs	
17	Rise time	200	-	ns	
18	Fall time	200	-	ns	

Note 1: Limits are taken from Standard Microcircuit Drawing (SMD) 5962-98533.

8: Document revision history

Revision	Date	Pages	Comments
0	January 2014	All	Original issue