Neutron testing of the ISL70417SEH hardened quad operational amplifier

Nick van Vonno
Intersil Corporation

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Revision 1

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1. Introduction

This report summarizes results of 1 MeV equivalent neutron testing of the ISL70417SEH quad operational amplifier ('op amp'). The test was conducted in order to determine the sensitivity of the part to the displacement damage caused by the neutron environment. Neutron fluences ranged from 2 x 10^{12} n/cm^2 to 1 x 10^{14} n/cm^2 in an approximately logarithmic sequence. This project was carried out in collaboration with Honeywell Aerospace (Clearwater, FL), and their support is gratefully acknowledged.

2: Part Description

The ISL70417SEH hardened quad operational amplifier contains four independent high precision amplifiers featuring a combination of low noise and low power consumption. Low offset voltage, input bias current and temperature drift making this device a good choice for applications requiring both high DC accuracy and AC performance. The combination of competitive electrical performance and small footprint provides the user with outstanding value and flexibility relative to similar competitive parts. Applications for these amplifiers include precision active filters, signal processing and precision power supply controls. The ISL70417SEH uses an industry standard pin configuration and is offered in a 14 lead hermetic ceramic flatpack package. The device operates over the standard military temperature range of -55°C to +125°C.

The ISL70417SEH is implemented in the PR40 process, which is a complementary bipolar flow using bonded wafer DI substrates. The process is used for a wide range of commercial and hardened operational amplifiers, voltage references and temperature sensors. The DI substrates enable vertical NPN and PNP devices, unlike the vertical NPN/lateral PNP combination used in commercial junction isolated processes. The vertical PNP device improves amplifier AC performance, while the DI substrate eliminates latchup by either electrical or SEE conditions. The process is in volume production under MIL-PRF-38535 certification in the Palm Bay, Florida Intersil wafer fabrication facility.

3: Test Description

3.1 Irradiation Facilities

Neutron irradiation was performed by the Honeywell team at the Fast Burst Reactor facility at White Sands Missile Range (White Sands, NM), which provides a controlled 1MeV equivalent neutron flux. Parts were tested in an unbiased configuration with all leads open. As neutron irradiation activates many of the elements found in a packaged integrated circuit, the parts exposed at the higher neutron levels required (as expected) significant ‘cooldown time’ before being shipped back to Palm Bay for electrical testing.

3.2 Characterization equipment and procedures

Electrical testing was performed before and after irradiation using the production automated test equipment (ATE). All electrical testing was performed at room temperature.

3.3 Experimental matrix

Testing proceeded in general accordance with the guidelines of MIL-STD-883 Test Method 1017. The experimental matrix consisted of five samples irradiated at 2×10^{12} n/cm^2, five samples irradiated at 1×10^{13} n/cm^2, five samples irradiated at 3×10^{13} n/cm^2 and five samples irradiated at 1×10^{14} n/cm^2. Two control units were used.

4: Results

4.1 Test results

Neutron testing of the ISL70417SEH is complete and the results are reported in the balance of this report.

4.2 Variables data

The plots in Figs. 1 through 28 show data plots for key parameters before and after irradiation to each level. The plots show the median of each parameter as a function of neutron irradiation for each of the four channels, with the exception of the two power supply current plots which report the sum of the supply currents (positive and negative) of all of the four channels. We chose to plot the median because of the relatively small sample sizes involved. Data is shown for the +/-15V (Figs. 1 – 17) and +/-5V (Figs. 18 – 28) supply cases. It should be realized when reviewing the data that each neutron irradiation was made on a different 5-unit sample; this is not total dose testing, where the damage is cumulative.

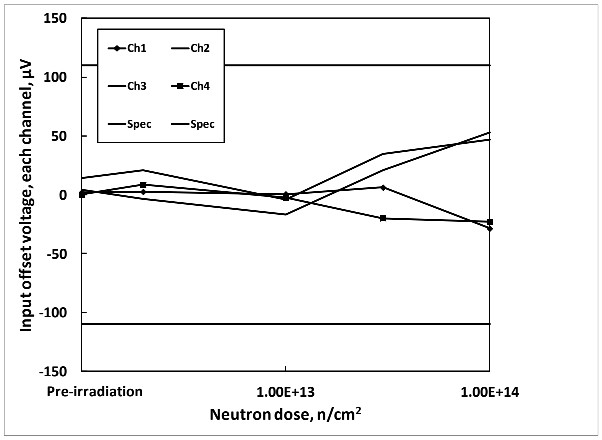

Fig. 1: ISL70417SEH input offset voltage, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -120µV to 120µV.

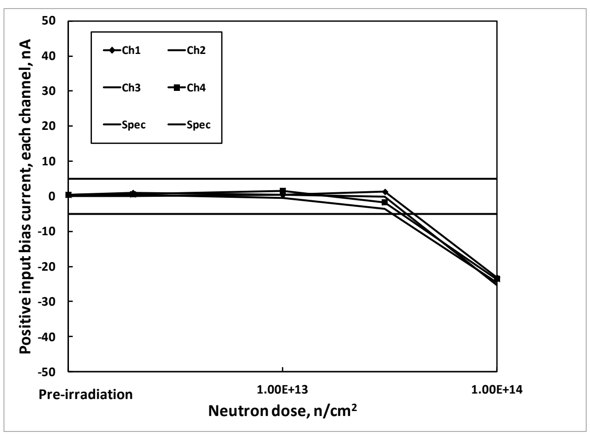

Fig. 2: ISL70417SEH positive input bias current, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -5nA to 5nA.

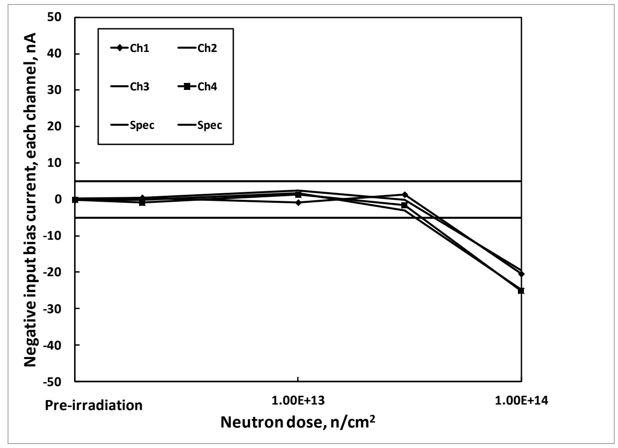

Fig. 3: ISL70417SEH negative input bias current, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -5nA to 5nA.

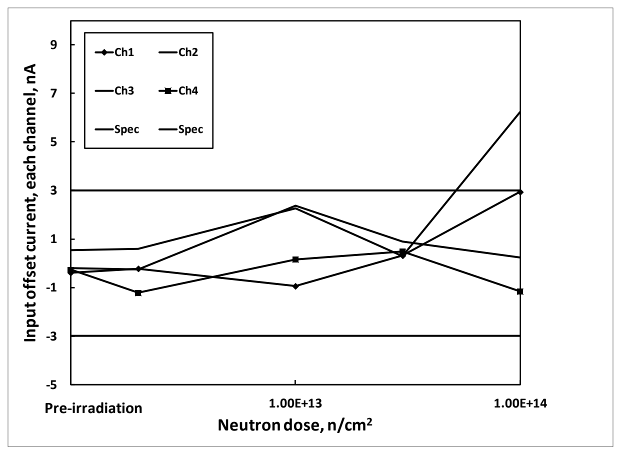

Fig. 4: ISL70417SEH input offset current, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -3nA to 3nA.

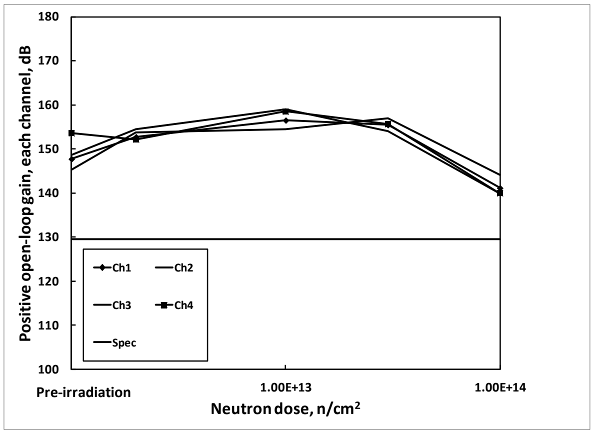

Fig. 5: ISL70417SEH positive open-loop voltage gain, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 3000V/mV (129.5dB) minimum.

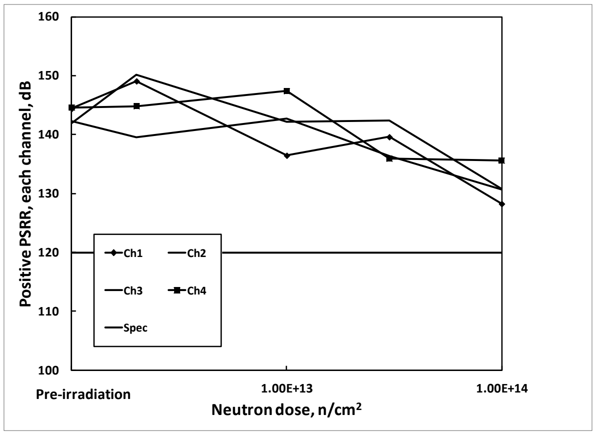

Fig. 7: ISL70417SEH positive power supply rejection ratio (PSRR), +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 120dB minimum.

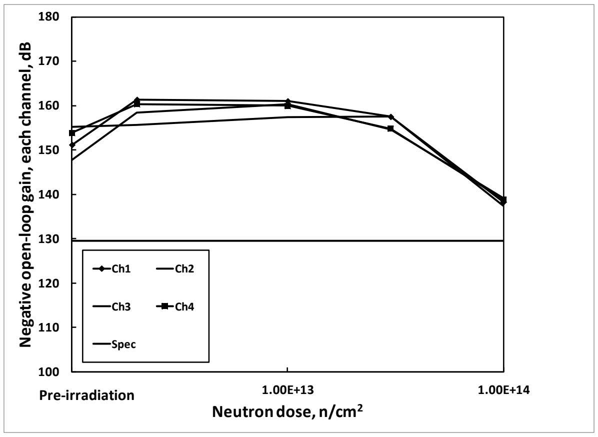

Fig. 6: ISL70417SEH negative open-loop voltage gain, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 3000V/mV (129.5dB) minimum.

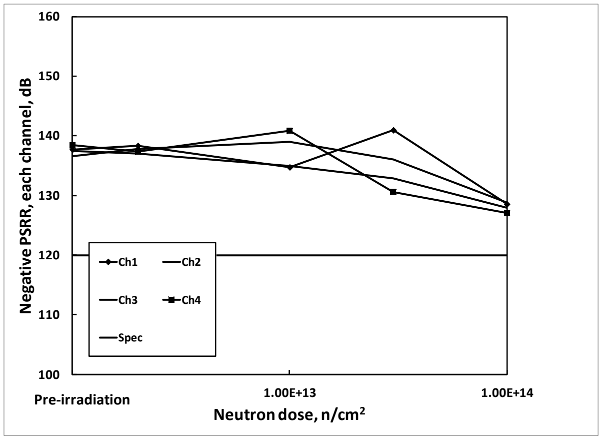

Fig. 8: ISL70417SEH negative power supply rejection ratio (PSRR), +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 120dB minimum.

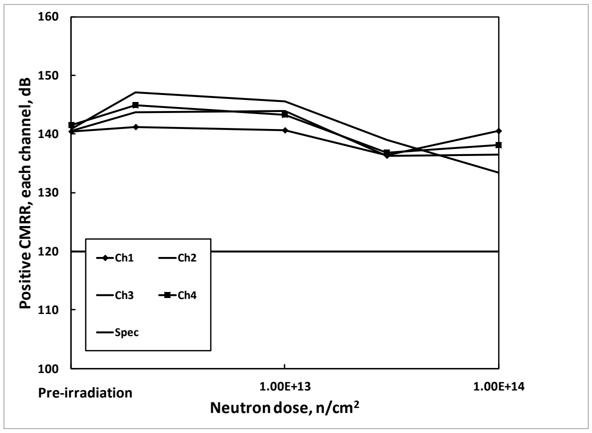

Fig. 9: ISL70417SEH positive common-mode rejection ratio (CMRR), +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 120dB minimum.

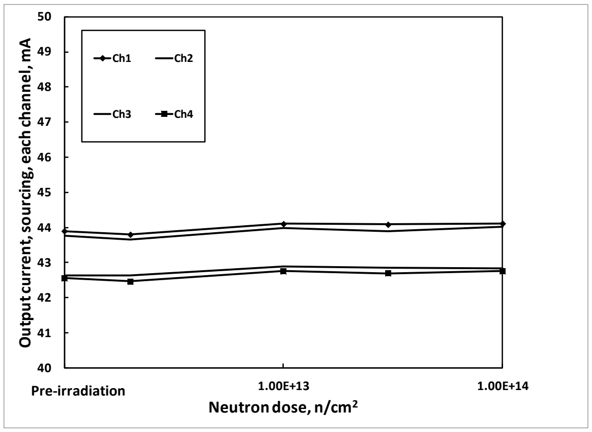

Fig. 11: ISL70417SEH sourcing output current, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. This parameter is not formally specified.

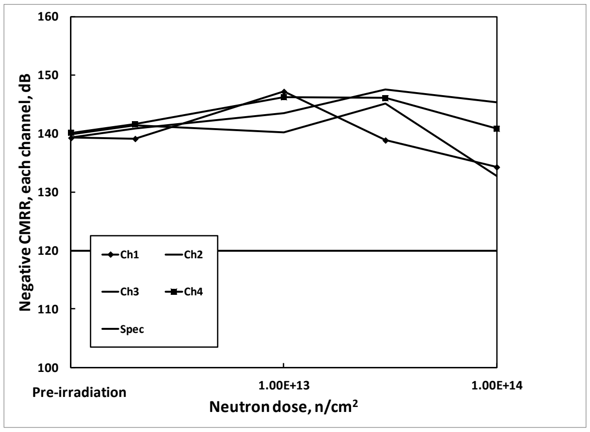

Fig. 10: ISL70417SEH negative common-mode rejection ratio (CMRR), +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 120dB minimum.

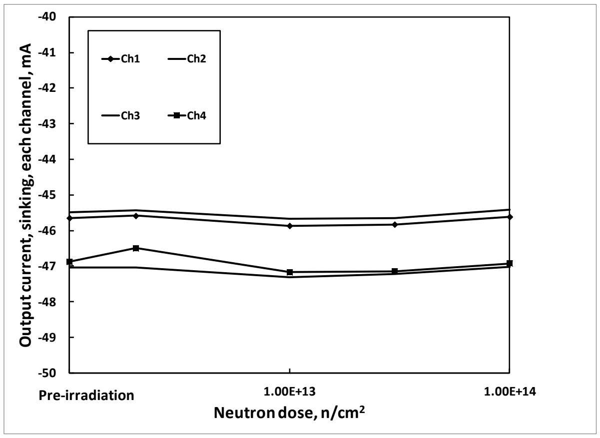

Fig. 12: ISL70417SEH sinking output current, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. This parameter is not formally specified.

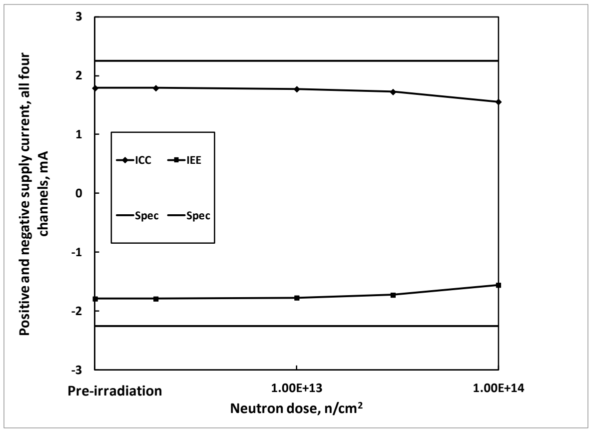

Fig. 13: ISL70417SEH positive and negative supply current, all four channels, +/-15V supplies, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is +/-2.72mA maximum.

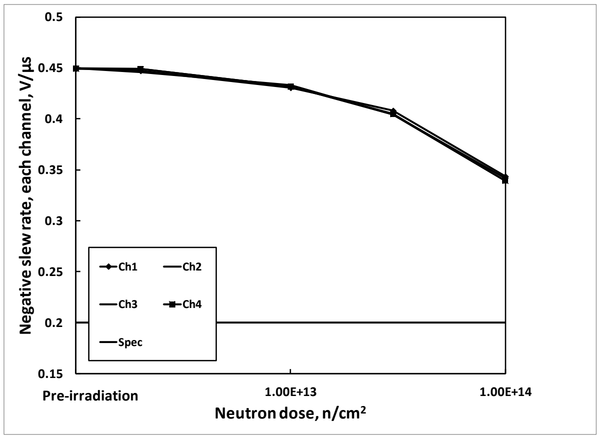

Fig. 15: ISL70417SEH negative slew rate, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 0.2V/µs minimum.

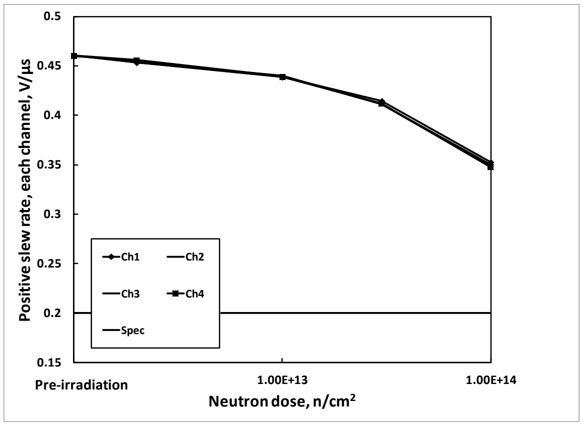

Fig. 14: ISL70417SEH positive slew rate, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 0.2V/µs minimum.

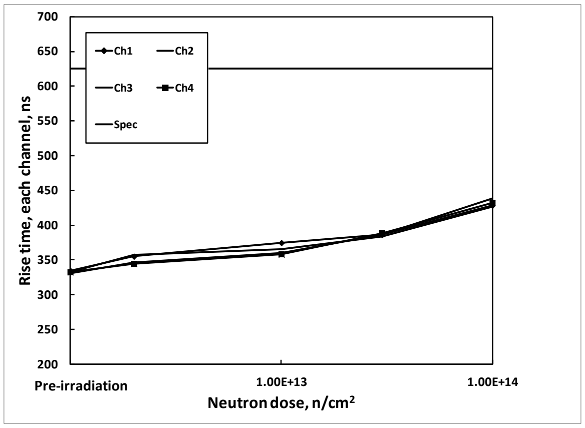

Fig. 16: ISL70417SEH small-signal rise time, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 625ns maximum.

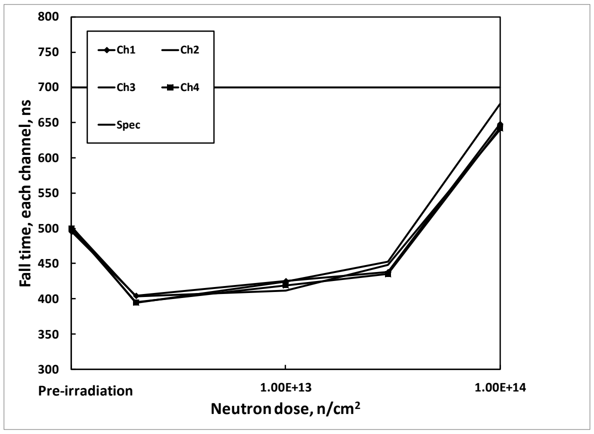

Fig. 17: ISL70417SEH small-signal fall time, +/-15V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 700ns maximum.

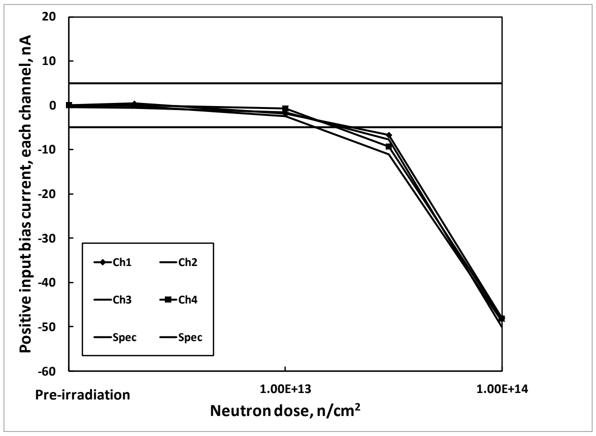

Fig. 19: ISL70417SEH positive input bias current, +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -5nA to 5nA.

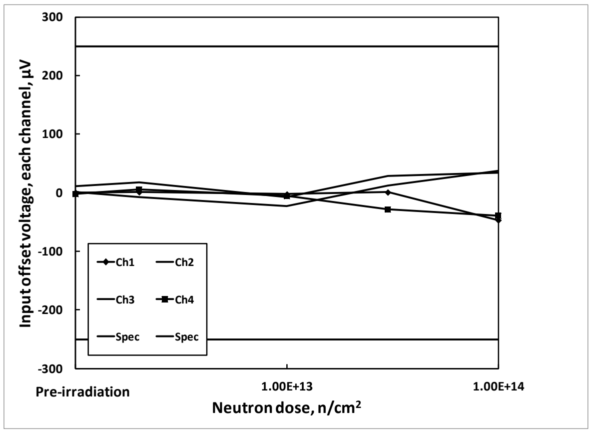

Fig. 18: ISL70417SEH input offset voltage, +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -250µV to 250µV.

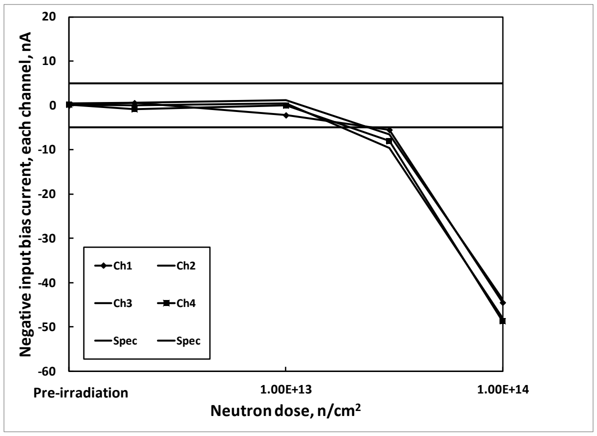

Fig. 20: ISL70417SEH negative input bias current, +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -5nA to 5nA.

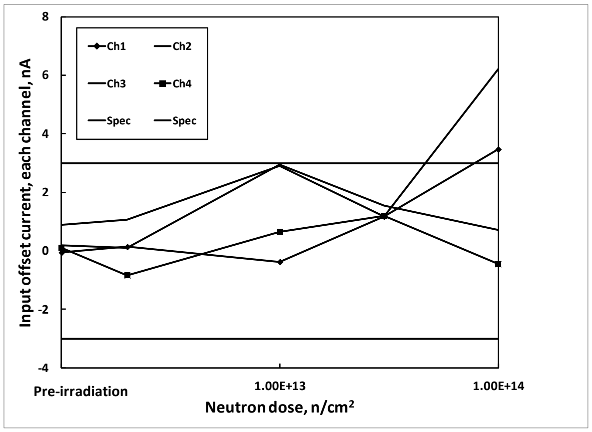

Fig. 21: ISL70417SEH input offset current, +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -3nA to 3nA.

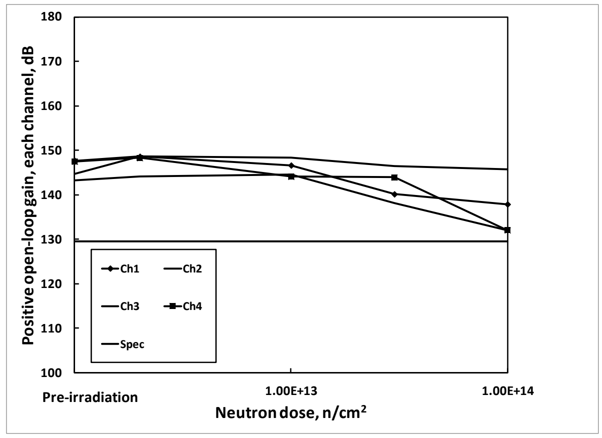

Fig. 23: ISL70417SEH positive open-loop voltage gain, +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 3000V/mV (129.5dB) minimum.

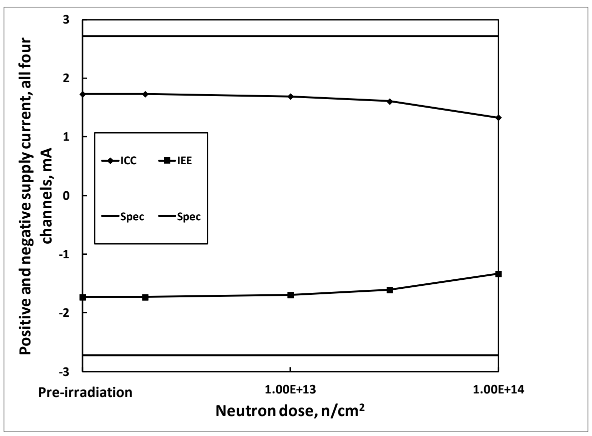

Fig. 22: ISL70417SEH positive and negative supply current, all four channels, +/-5V supplies, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is +/-2.72mA maximum.

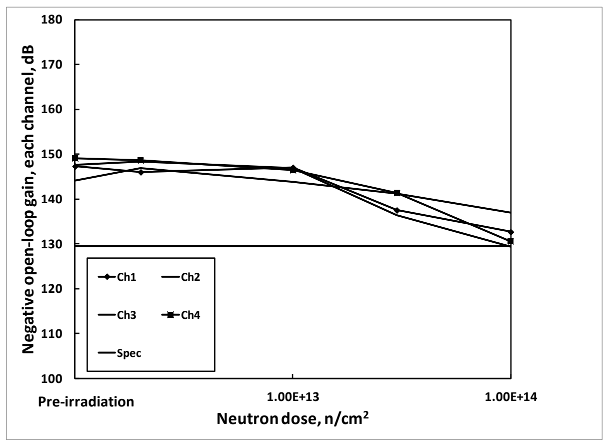

Fig. 24: ISL70417SEH negative open-loop voltage gain, +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 3000V/mV (129.5dB) minimum.

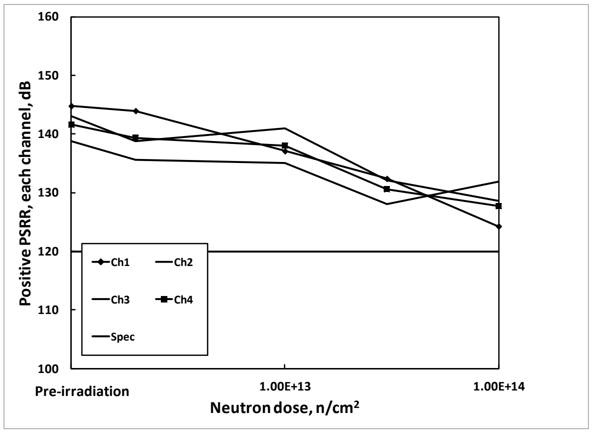

Fig. 25: ISL70417SEH positive power supply rejection ratio (PSRR), +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 120dB minimum.

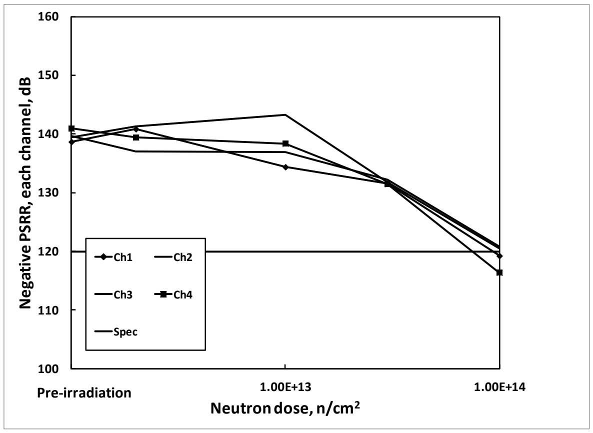

Fig. 26: ISL70417SEH negative power supply rejection ratio (PSRR), +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 120dB minimum.

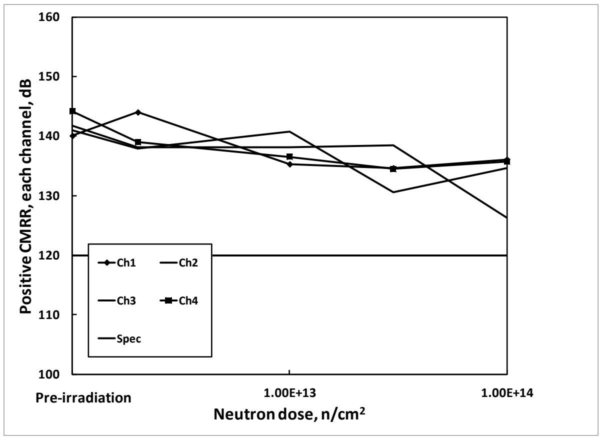

Fig. 27: ISL70417SEH positive common-mode rejection ratio (CMRR), +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 120dB minimum.

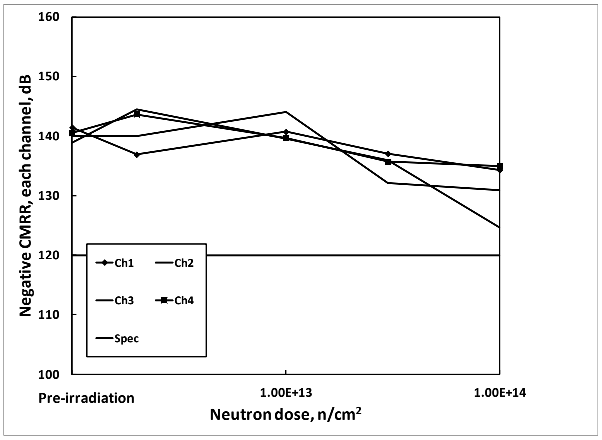

Fig. 28: ISL70417SEH negative common-mode rejection ratio (CMRR), +/-5V supplies, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 120dB minimum.

5: Discussion and conclusion

This document reports the results of neutron testing of the ISL70417SEH dual precision operational amplifier. Samples were irradiated to levels of 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2, 3 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2. ATE characterization testing was performed before and after the irradiations, and three control units were used to insure repeatable data. Variables data for selected parameters is presented in Figs. 1 through 28. We will discuss the results on a parameter by parameter basis. It should be realized when reviewing the data that each neutron irradiation was made on a different 5-unit sample; this is not total dose testing, where the damage is cumulative. The 2 x 10^{12} n/cm^2 level is of some interest in the context of recent developments in the JEDEC community, where the discrete component vendor community have signed up for characterization testing (but not for acceptance testing) at this level.

The ISL70417SEH is not formally designed for neutron hardness. The part is built in a DI complementary bipolar process. These bipolar transistors are minority carrier devices, obviously, and may be expected to be sensitive to displacement damage (DD) at the higher levels. This expectation turned out to be correct. We will discuss the results on a parameter by parameter basis and then draw some conclusions.

Input parameters are key to operational amplifier performance. The input offset voltage for both the +/-15V and +/-5V cases (Figs. 1 and 18) showed surprising stability, with both parameters well within their post-radiation SMD limits. The positive and negative input bias current results (Figs. 2, 3, 19 and 20) were very stable and stayed well within the tight 5nA SMD limits through the 3 x 10^{13} n/cm^2 level, and degraded to approximately +/-25nA through the 1 x 10^{14} n/cm^2 level. The +/-5V data showed similar performance, with good stability at the 1 x 10^{13} n/cm^2 point and with readings at the 3 x 10^{13} n/cm^2 well within a derated -10.0nA to 10.0nA range. The input bias current data fell within the -3.0nA to 3.0nA SMD limits at the 3 x 10^{13} n/cm^2 level.

The positive and negative open-loop voltage gain (Figs. 5 and 6) at +/-15V were stable out to 3 x 10^{13} n/cm^2 and dropped at the 1 x 10^{14} n/cm^2 level while still retaining good margin over the SMD limits. The open-loop voltage gain at +/-5V (Fig. 23 and 24) showed similar behavior but was very near the SMD limits at 1 x 10^{14} n/cm^2.

The positive and negative power supply rejection ratio (PSRR) at +/-15V (Figs. 7 and 8) showed gradual degradation out to 1 x 10^{14} n/cm^2, with good margin over the SMD limits. The power supply rejection ratio (PSRR) at +/-5V (Figs. 25 and 26) showed the same behavior but was very near the SMD limits at 1 x 10^{14} n/cm^2.

The positive and negative common-mode rejection ratio (CMRR) at +/-15V (Figs. 9 and 10) was stable out to 1 x 10^{14} n/cm^2 with some variation, but with good margin over the SMD limits. The common-mode rejection ratio (CMRR) at +/-5V (Figs. 27 and 28) showed the same behavior.

Output sourcing and sinking current was measured at +/-15V only. This is an informational parameter and is not specified in the SMD. The parameter showed good stability out to 1 x 10^{14} n/cm^2 (Figs. 11 and 12).

Power supply current for the positive and negative rails was measured at both supply voltages. The parameter showed (Figs. 13 and 22) a gradual decrease for both supply voltages but remained well within the SMD limits. The current decrease is consistent with DD causing reduction in the current gain of the PNP and NPN transistors that compose the device.

AC parameters were tested at +/-15V only and included slew rate and rise and fall time. The positive and negative slew rates (Figs. 14 and 15) showed a gradual decrease but remained well within the SMD limits. The small-signal rise time (Figs. 16) showed similar behavior, but the fall time showed significant degradation from the 3 x 10^{13} n/cm^2 level to the 1 x 10^{14} n/cm^2 level, although the parameter remained within the 700ns SMD specification.

We conclude that the ISL70417SEH is capable of post 3 x 10^{13} n/cm^2 operation with selected parametric relaxations, mostly in the input bias current specification. A relaxation to +/-100nA from the current +/-5nA would be typical. The part is not capable of post 1 x 10^{14} n/cm^2 operation as several parameters changed drastically; the part did, however, remain functional.

6: Appendices

6.1: Reported parameters.

Fig.	Parameter	Limit, low	Limit, high	Units	Notes
1	Input offset voltage	-120	120	µV	+/-15V
2	Positive input bias current	-5	5	nA	+/-15V
3	Negative input bias current	-5	5	nA	+/-15V
4	Input offset current	-3	3	nA	+/-15V
5	Positive open-loop gain	129.5	-	dB	+/-15V
6	Negative open-loop gain	129.5	-	dB	+/-15V
7	Positive power supply rejection ratio	120	-	dB	+/-15V
8	Negative power supply rejection ratio	120	-	dB	+/-15V
9	Positive common-mode rejection ratio	120	-	dB	+/-15V
10	Positive common-mode rejection ratio	120	-	dB	+/-15V
11	Output current, sourcing	-	-	mA	+/-15V
12	Output current, sinking	-	-	mA	+/-15V
13	Positive and negative power supply current	-	2.72	mA	+/-15V
14	Positive slew rate	625	-	V/µs	+/-15V
15	Negative slew rate	700	-	V/µs	+/-15V
16	Positive rise time	1.0	-	ns	+/-15V
17	Negative rise time	3.0	-	ns	+/-15V
18	Input offset voltage	-250	250	µV	+/-5V
19	Positive input bias current	-5	5	nA	+/-5V
20	Negative input bias current	-5	5	nA	+/-5V
21	Input offset current	-3	3	nA	+/-5V
22	Positive and negative power supply current	-	2.72	mA	+/-5V
23	Positive open-loop gain	129.5	-	dB	+/-5V
24	Negative open-loop gain	129.5	-	dB	+/-5V
25	Positive power supply rejection ratio	120	-	dB	+/-5V
26	Negative power supply rejection ratio	120	-	dB	+/-5V
27	Positive common-mode rejection ratio	120	-	dB	+/-5V
28	Positive common-mode rejection ratio	120	-	dB	+/-5V

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7: Document revision history

Revision	Date	Pages	Comments
0	3 April 2013	All	Original issue
1	5 April 2013	3, 10	Corrected Figs. 2 and 3 and conclusions