Neutron testing of the ISL70227SEH hardened dual operational amplifier

Nick van Vonno
Intersil Corporation

3 November 2013

Revision 0

Table of Contents

1. Introduction

This report summarizes results of 1 MeV equivalent neutron ('displacement damage' or 'DD') testing of the ISL70227SEH dual operational amplifier ('op amp'). The test was conducted in order to determine the sensitivity of the part to displacement damage caused by the neutron environment. Neutron fluences ranged from 5 x 10^{11} 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 ISL70227SEH is a precision dual operational amplifier featuring very low noise, low offset voltage, low input bias current and low temperature drift. These features plus its radiation tolerance make the ISL70227SEH the ideal choice for applications requiring both high DC accuracy and AC performance. The combination of precision performance, low noise and small footprint provides the user with outstanding value and flexibility relative to similar competitive parts. Applications for these amplifiers include active filters and power supply controls. The ISL70227SEH is available in a 10 lead hermetic ceramic flatpack and operates over the extended temperature range of -55°C to +125°C.

The ISL70227SEH 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 substrate enables 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 and total dose hardness, while the DI substrate eliminates latchup by either electrical or SEE conditions. The PR40 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 (FBR) 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 5×10^{11} n/cm^2, five samples irradiated at 2×10^{12} n/cm^2, five samples irradiated at 1×10^{13} n/cm^2 and five samples irradiated at 1×10^{14} n/cm^2. Two control units were used to insure repeatable data.

4: Results

4.1 Test results

Neutron testing of the ISL70227SEH is complete and the results are reported in the balance of this report.

4.2 Variables data

The plots in Figs. 1 through 17 show data plots for key parameters before and after irradiation to each level. The plots show the average, minimum and maximum of each parameter as a function of neutron irradiation for each of the two channels, with the exception of the two power supply current plots which report the sum of the supply currents (positive and negative) of both of the two channels. It should be carefully noted 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. For guidance in interpreting the data we show the SMD post-total dose irradiation limits; the ISL70227SEH is not specified or guaranteed for the neutron environment.

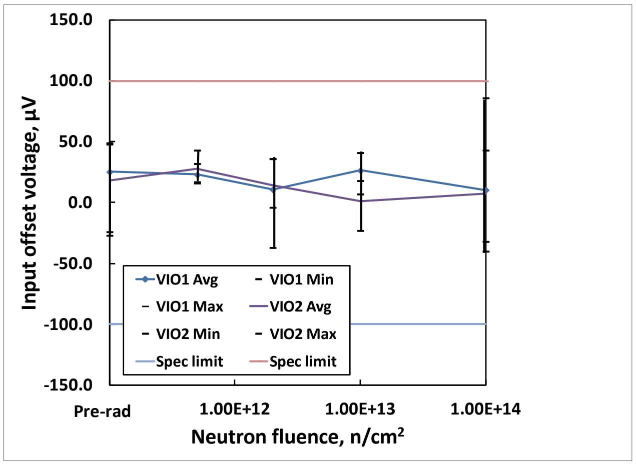

Fig. 1: ISL70227SEH input offset voltage, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -100.0µV to 100.0µV.

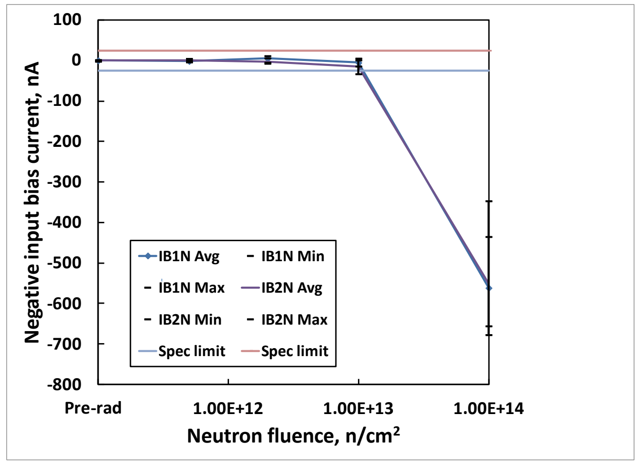

Fig. 3: ISL70227SEH negative input bias current, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -25.0nA to 25.0nA.

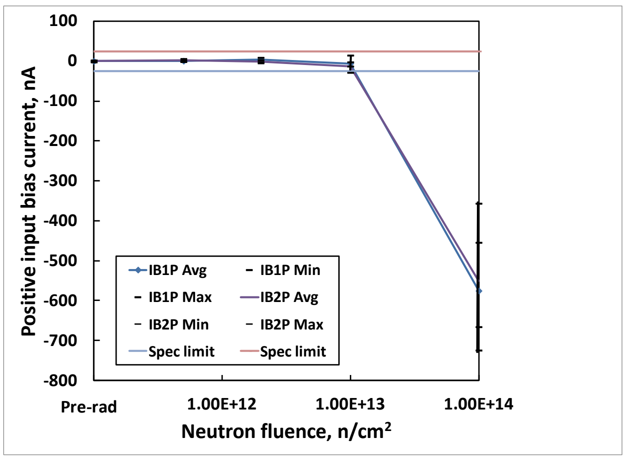

Fig. 2: ISL70227SEH positive input bias current, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -25.0nA to 25.0nA.

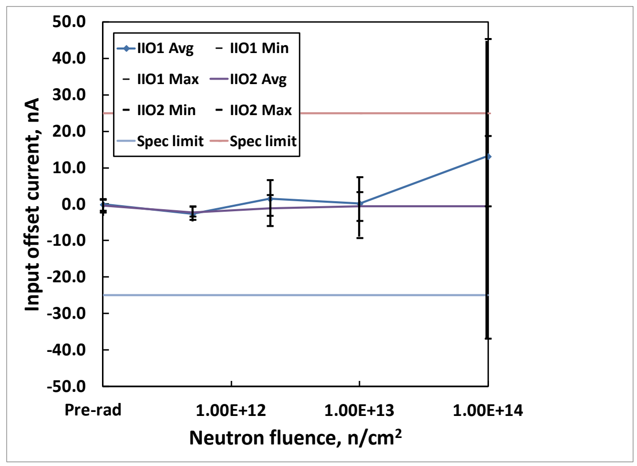

Fig. 4: ISL70227SEH input offset current, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limits are -25.0nA to 25.0nA.

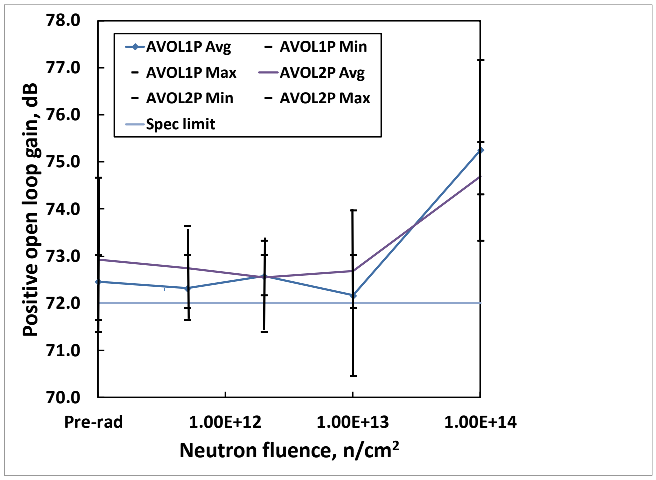

Fig. 5: ISL70227SEH positive open-loop voltage gain, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 60.0dB minimum.

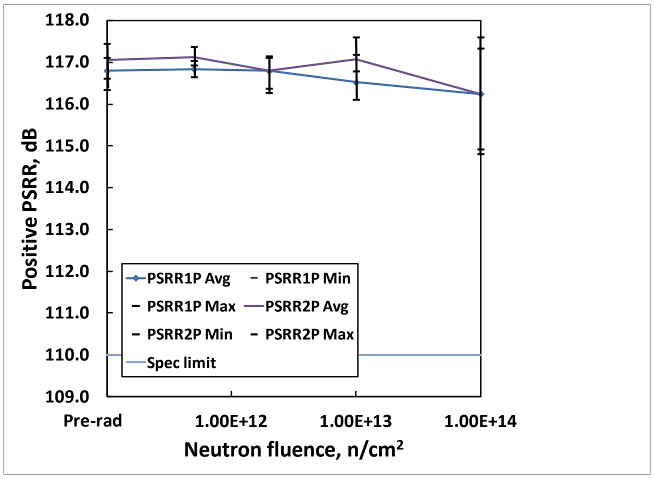

Fig. 7: ISL70227SEH positive power supply rejection ratio (PSRR), each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 110.0dB minimum.

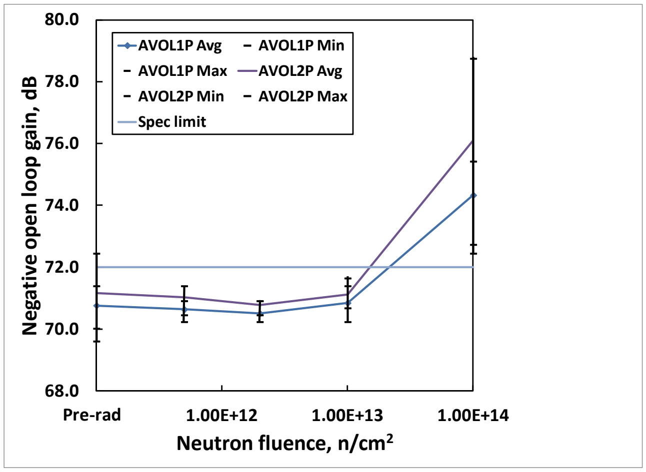

Fig. 6: ISL70227SEH negative open-loop voltage gain, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 60.0dB minimum.

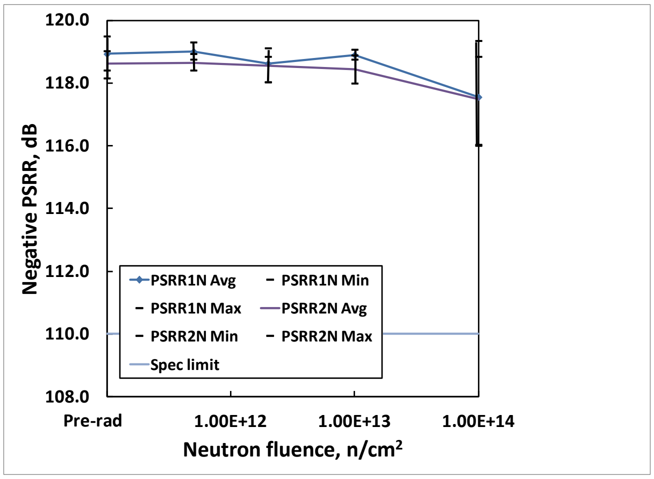

Fig. 8: ISL70227SEH negative power supply rejection ratio (PSRR), each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 110.0dB minimum.

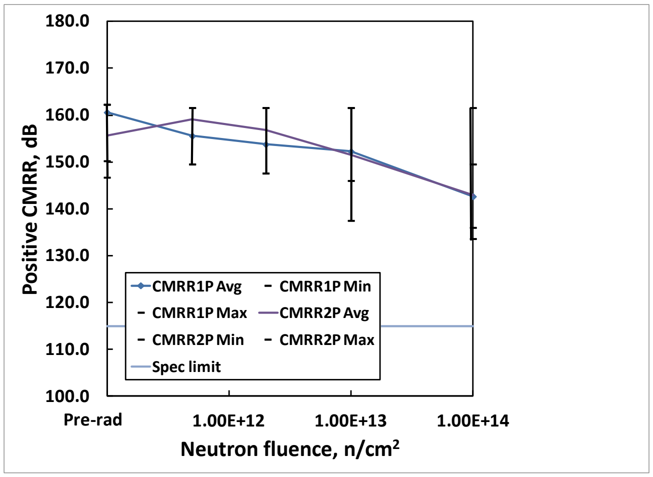

Fig. 9: ISL70227SEH positive common-mode rejection ratio (CMRR), each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 115.0dB minimum.

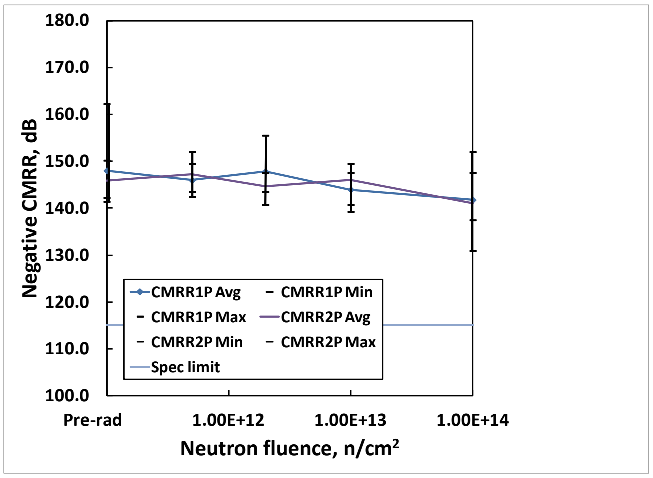

Fig. 10: ISL70227SEH negative common-mode rejection ratio (CMRR), each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 115.0dB minimum.

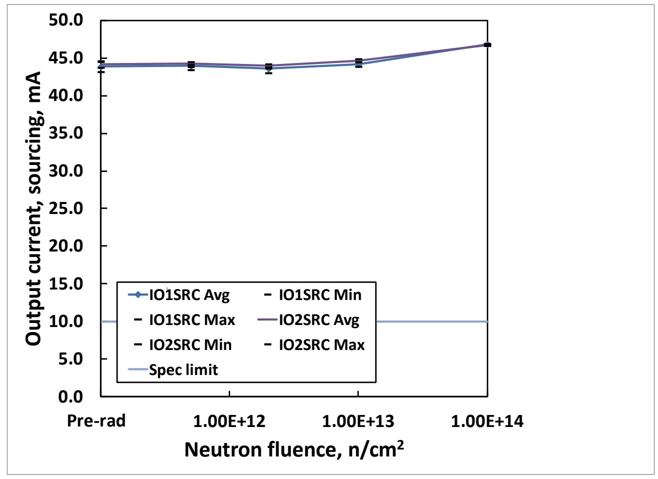

Fig. 11: ISL70227SEH sourcing output current, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. A post-irradiation SMD limit is not specified; the 10mA line is an ATE limit.

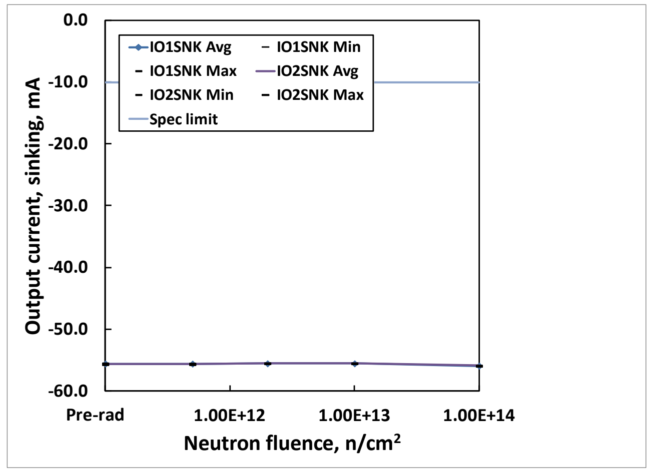

Fig. 12: ISL70227SEH sinking output current, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. A post-irradiation SMD limit is not specified; the 10mA line is an ATE limit.

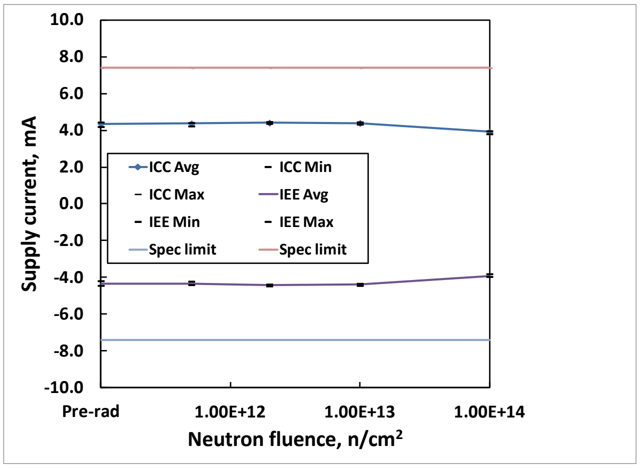

Fig. 13: ISL70227SEH positive and negative supply current, sum of both channels, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is +/- 7.4mA maximum.

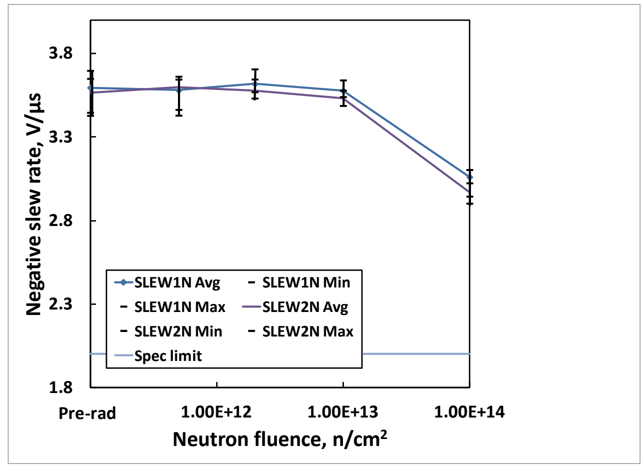

Fig. 15: ISL70227SEH negative slew rate, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 2.0V/µs minimum.

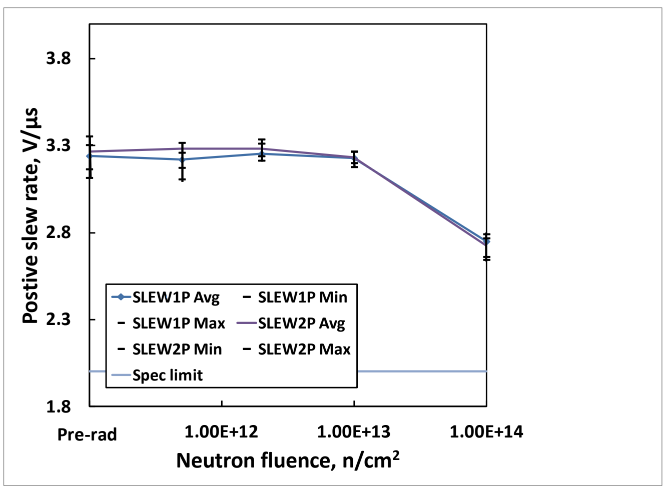

Fig. 14: ISL70227SEH positive slew rate, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 2.0V/µs minimum.

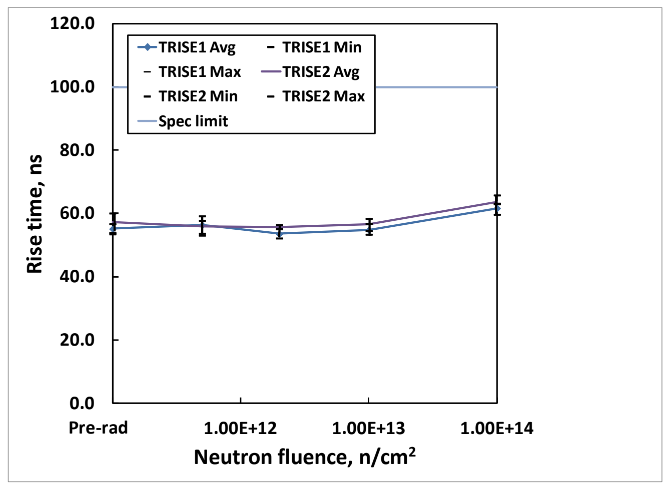

Fig. 16: ISL70227SEH small-signal rise time, each channel, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 100.0ns maximum.

intersil™

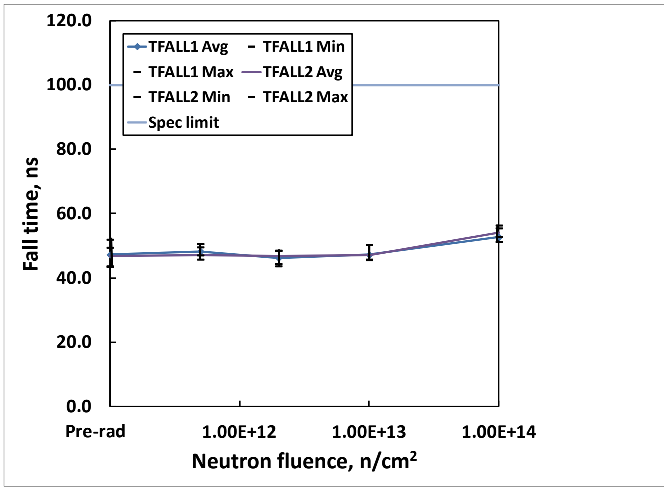

Fig. 17: ISL70227SEH small-signal fall time, +/-15V supplies, as a function of neutron irradiation. Sample size was 5 for each cell (5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 x 10^{13} n/cm^2 and 1 x 10^{14} n/cm^2), with two control units. The post-irradiation SMD limit is 100.0ns maximum.

5: Discussion and conclusion

This document reports the results of neutron testing of the ISL70227SEH dual operational amplifier. Samples were irradiated to levels of 5 x 10^{11} n/cm^2, 2 x 10^{12} n/cm^2, 1 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 two control units were used to insure repeatable data. Variables data for selected parameters is presented in Figs. 1 through 17. We will discuss the results on a parameter by parameter basis. It should be realized again 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 ISL70227SEH 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 (Fig. 1) showed good stability, with the parameter well within the +/-100µV post-radiation SMD limits. The positive and negative input bias current results (Figs. 2 and 3) were very stable and stayed well within the tight 25.0nA SMD limits through the 1 x 10^{13} n/cm^2 level, and degraded to approximately +/-500nA at the 1 x 10^{14} n/cm^2 level. The input offset current data (Fig. 4) fell within the -25.0nA to 25.0nA SMD limits at the 1 x 10^{13} n/cm^2 level.

The positive and negative open-loop voltage gain (Figs. 5 and 6) was stable out to 1 x 10^{13} n/cm^2 but increased significantly at the 1 x 10^{14} n/cm^2 level. The cause of this response is not known.

intersil™

The positive and negative power supply rejection ratio (PSRR) (Figs. 7 and 8) and the positive and negative common-mode rejection ratio (CMRR) (Figs. 9 and 10) showed gradual degradation out to 1 x 10^{14} n/cm^2, with good margin over the SMD limits.

The sourcing and sinking output current (Figs. 11 and 12) showed good stability out to 1 x 10^{14} n/cm^2.

The positive and negative power supply current (Fig. 13) showed good stability out to 1 x 10^{14} n/cm^2.

The positive and negative slew rate (Figs. 14 and 15) and the rise and fall time (Figs. 16 and 17) showed good stability out to 1 x 10^{14} n/cm^2.

We conclude that the ISL70227SEH is capable of post 1 x 10^{13} n/cm^2 operation with selected parametric relaxations, mostly in the input bias current specification. The part is not capable of post 1 x 10^{14} n/cm^2 operation as some parameters were outside the limits; the part did, however, remain functional.

6: Appendices

6.1: Reported parameters.

Fig.	Parameter	Limit, low	Limit, high	Units	Notes
1	Input offset voltage	-110	+110	µV	
2	Positive input bias current	-25	+25	nA	
3	Negative input bias current	-25	+25	nA	
4	Input offset current	-25	+25	nA	
5	Positive open-loop gain	60.0	-	dB	
6	Negative open-loop gain	60.0	-	dB	
7	Positive power supply rejection ratio	110	-	dB	
8	Negative power supply rejection ratio	110	-	dB	
9	Positive common-mode rejection ratio	115	-	dB	
10	Positive common-mode rejection ratio	115	-	dB	
11	Output current, sourcing	10.0	-	mA	
12	Output current, sinking	10.0	-	mA	
13	Positive and negative power supply current	-7.4	+7.4	mA	
14	Positive slew rate	2.0	-	V/µs	
15	Negative slew rate	2.0	-	V/µs	
16	Positive rise time	100.0	-	ns	
17	Negative rise time	100.0	-	ns	

7: Document revision history

Revision	Date	Pages	Comments
0	3 November 2013	All	Original issue