ISL70419SEH

Single Event Effects Testing

AN1944
Rev 0.00
July 17, 2014

Introduction

The intense heavy ion environment encountered in space applications can cause a variety of transient and destructive effects in analog circuits, including single-event latch-up (SEL), single-event transients (SET) and single-event burnout (SEB). These effects can lead to system-level failures including disruption and permanent damage. For predictable and reliable system operation, these components have to be formally designed and fabricated for SEE hardness, followed by detailed SEE testing to validate the design. This report discusses the results of SEE testing of Intersil's ISL70419SEH.

Related Documents

- ISL70419SEH Data Sheet

Product Description

The ISL70419SEH contains four very high precision amplifiers featuring the perfect combination of low noise vs power consumption. These devices are fabricated in a 40V advanced bonded wafer SOI process using deep trench isolation, resulting in a fully isolated structure. This choice of process technology results in latch-up free performance, whether by electrical or single event caused. These devices were also designed for enhance single event transient response resulting in fast SET recovery.

A super-beta NPN input stage with input bias current cancellation provides low input bias current, low input offset voltage, low input noise voltage, and low 1/f noise corner frequency. These amplifiers also feature high open loop gain for excellent CMRR and THD+N performance. A complementary bipolar output stage enables high capacitive load drive without external compensation.

These amplifier are designed to operate over a wide supply range of 4.5V to 36V. Applications for these amplifiers include precision active filters, low noise front ends, loop filters, data acquisition and charge amplifiers.

The combination of high precision, low noise, low power and radiation tolerance provide the user with outstanding value and flexibility relative to similar competitive parts.

The part is packaged in a 14 lead hermetic ceramic flat pack and operates over the extended temperature range of -55°C to +125°C. A summary of key full temperature range and radiation specifications follow:

- Input Offset Voltage . . . . 110µV, max.
- Offset Voltage Drift . . . . 1µV/°C, max.
- Input Offset Current . . . . 10nA, max.
- Input Bias Current . . . . 15nA, max.
- Supply Current/Amplifier . . . . 0.75mA, max.
- Gain Bandwidth Product . . . . 1.5MHz, typ.

Key SEE Test Results

- SOI process results in single event latch-up immunity
- No SEB up to 36V supply, LET = 86.4MeV•cm^2/mg
- Ultra fast recovery time from SET: < 10µs

SEE Test Objective

The objective of SEE testing of the ISL70419SEH were to evaluate its susceptibility to destructive events induced by single event effects, such as single event burnout and to determine its SET behavior.

SEE Test Facility

Testing was performed at the Texas A&M University (TAMU) Cyclotron Institute heavy ion facility. This facility is coupled to a K500 super-conducting cyclotron, which is capable of generating a wide range of test particles with the various energy, flux and fluence levels needed for advanced radiation testing.

SEE Test Procedure

The part was tested for single event burnout, using Au ions at 0°C incidence (LET = 86.4MeV•cm^2/mg) with a case temperature of +125°C, and single event transient characterized using Ar, Kr, Ag and Pr ions with a case temperature of +25°C.

The device under test (DUT) was mounted in the beam line and irradiated with heavy ions of the appropriate species. The parts were assembled in 14 lead dual in-line packages with the metal lid removed for beam exposure. The beam was directed onto the exposed die and the beam flux, beam fluence and errors in the device outputs were measured.

The tests were controlled remotely from the control room. All input power was supplied from portable power supplies connected via cable to the DUT. The supply currents were monitored along with the device outputs. All currents were measured with digital ammeters, while all the output waveforms were monitored on a digital oscilloscope for ease of identifying the different types of SEE, displayed by the part. Events were captured by triggering on changes in the output.

Cross Section Calculation

Cross sections (CS) are calculated as shown by Equation 1:

$$CS\,(LET) = N/F \qquad \text{(EQ. 1)}$$

where:

- CS is the SET cross section (cm^2), expressed as a function of the heavy ion LET
- LET is the linear energy transfer in $MeV{\cdot}cm^2/mg$, corrected according to the incident angle, if any
- N is the total number of SET events
- F is fluence in particles/cm^2

A value of 1/F is the assumed cross section when no event is observed.

Single Event Burnout Results

The first testing sequence looked at destructive effects due to burnout. A burnout condition is indicated by a permanent change in the device supply current after application of the beam. If the increased current can be reset by cycling power, it is termed a latch-up. No burnout was observed using Au ions at 0° up a supply voltage of ±18V. Testing was performed on four parts at T_C = +125°C. All parts commenced testing with V_S = ±18V and on subsequent tests V_S voltage was increased by 2V until failure. All test runs were run to a fluence of $2.5x10^6/cm^2$. A power supply applied a DC voltage of 200mV to the non-inverting inputs of the amplifiers during the test. Functionality of all outputs were verified after exposure. I_{DD} and I_{EE} were recorded pre and post exposure and summed up. A 5% change in total supply current indicates permanent damage to the op amp. Test results demonstrated that all parts passed with V_S = ±18V however, failed when the supply voltage was increased to V_S = ±19V. Test data for V_S = ±18V and V_S = ±19V is shown in Tables 1 and 2, respectively.

Single Event Transient Results

Test Setup

A a simplified schematic of the configuration of each op amp on board used during testing is shown in Figure 1.

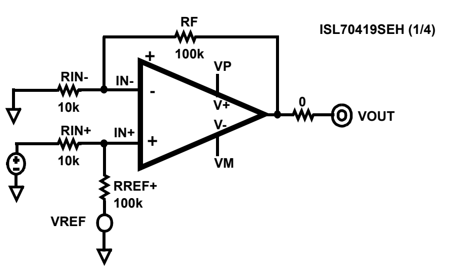

FIGURE 1. ISL70419SEH SEE TEST SCHEMATIC

Each operational amplifier was set up in a non-inverting operation with G = 10V/V. The IN- inputs were grounded and the input signal was applied to the IN+ pin. The reference input was also grounded. All the outputs were fed into a summer op amp which was out of the beam line. The output of the summer amp was used to trigger the scope, while channels 1 through 4 of the scope capture changes on the output of op amp A, B, C, and D of each device. The complete board schematic and silk screen of the board are included in Appendix A.

Biasing used for SET test runs was V_S = ±5V and ± 15V. Similar to SEL/B testing, a DC voltage of 200mV was applied to the non-inverting inputs of the amplifiers. Signals from the switch board in the control room were connected to four LECROY oscilloscopes to capture SETs on devices 5, 6, 7 and 8. Summary of the scope settings are as follows:

TRIGGER CONNECTIONS

- Scope 1 is set to capture Device 5
- Scope 2 is set to capture Device 6
- Scope 3 is set to capture Device 7
- Scope 4 is set to capture Device 8

CHANNEL CONNECTION ON ALL SCOPES FOR V_S = ±5V

- CH1 = OUTA 1V/div, CH2 = OUTB 1V/div
- CH3 = OUTC 1V/div, CH4 = OUTD 1V/div
- External trigger connected to output of summer amplifier

CHANNEL CONNECTION ON ALL SCOPES FOR V_S = ±15V

- CH1 = OUTA 2V/div, CH2 = OUTB 2V/div
- CH3 = OUTC 2V/div, CH4 = OUTD 2V/div
- External trigger connected to output of summer amplifier

Events are recorded when movement on output during beam exposure exceeds the definition of a SET. For the ISL70419SEH a SET is a transient that exceeds the set window trigger of ±200mV for V_S = ±5V and for V_S = ±15V.

Cross Section Results

One approach to characterize the SET response of an integrated circuit is to represent the data on a LET threshold plot. Figure 2 shows the overall cross section of the four devices tested versus the LET level, for V_S = ±5V and ±15V. It can be noted that the cross section is independent of the supply voltage. Data from Figure 2 is represented in Table 3. Figures 3 and 4 show the LET threshold plot of each device independently for V_S = ±5V and ±15V. The graphs also show that there is no part-to-part sensitivity as the graphs lie almost directly on top of each other. Complete data for Figures 3 and 4 are available in Appendix A.

TABLE 1. ISL70419SEH DETAILS OF SEB/L TESTS AT VS = LET = 86.4MeV · cm^2/mg

TEMP (°C)	LET (MeV . cm^2/mg)	SUPPLY VOLTAGE (V)	SUPPLY CURRENT PRE-EXPOSURE (mA)	SUPPLY CURRENT POST-EXPOSURE (mA)	DESTRUCTIVE EVENTS	CUMULATIVE FLUENCE (PARTICLES/cm^2)	CUMULATIVE CROSS SECTION (cm^2)	DEVICE ID	SEB
+125	86.4	±18	4.901	4.949	0	2.5×10^6	5.0×10^{-7}	1	PASS
+125	86.4	±18	4.701	4.842	0	2.5×10^6	5.0×10^{-7}	2	PASS
+125	86.4	±18	5.263	5.280	0	2.5×10^6	5.0×10^{-7}	3	PASS
+125	86.4	±18	5.335	5.340	0	2.5×10^6	5.0×10^{-7}	4	PASS
				TOTAL EVENTS	0				
					OVERALL FLUENCE	1.0×10^7			
						OVERALL CS	1.25×10^{-7}		
							TOTAL UNITS	4	

TABLE 2. ISL70419SEH DETAILS OF SEB/L TESTS AT LET = 86.4MeV · cm^2/mg

TEMP (°C)	LET (MeV . cm^2/mg)	SUPPLY VOLTAGE (V)	SUPPLY CURRENT PRE-EXPOSURE (mA)	SUPPLY CURRENT POST-EXPOSURE (mA)	DESTRUCTIVE EVENTS	CUMULATIVE FLUENCE (PARTICLES/cm^2)	CUMULATIVE CROSS SECTION (cm^2)	DEVICE ID	SEB
+125	86.4	±19	4.980	18.780	1	2.5×10^6	5.0×10^{-7}	1	FAIL
+125	86.4	±19	4.877	18.146	1	2.5×10^6	5.0×10^{-7}	2	FAIL
+125	86.4	±19	5.318	19.550	1	2.5×10^6	5.0×10^{-7}	3	FAIL
+125	86.4	±19	5.377	19.900	1	2.5×10^6	5.0×10^{-7}	4	FAIL

TABLE 3. DETAILS OF THE LET THRESHOLD PLOT OF THE ISL70419SEH

SUPPLY VOLTAGE (V)	ION	ANGLE	EFFECTIVE LET (MeV . cm^2/mg)	FLUENCE PER RUN (PARTICLES/cm^2)	NUMBER OF DEVICES TESTED	TOTAL SET	EVENT CS (cm^2)
±5	Ar	0	8.5	2.0×10^6	4	690	8.63×10^{-5}
±5	Kr	0	28	2.0×10^6	4	8566	1.07×10^{-3}
±5	Ag	0	43	2.0×10^6	4	9025	1.13×10^{-3}
±5	Pr	0	59.2	2.0×10^6	4	9588	1.2×10^{-3}
±15	Ar	0	8.5	2.0×10^6	4	695	8.69×10^{-5}
±15	Kr	0	28	2.0×10^6	4	8103	1.01×10^{-3}
±15	Ag	0	43	2.0×10^6	4	9344	1.17×10^{-3}
±15	Pr	0	59.2	2.0×10^6	4	9735	1.22×10^{-3}

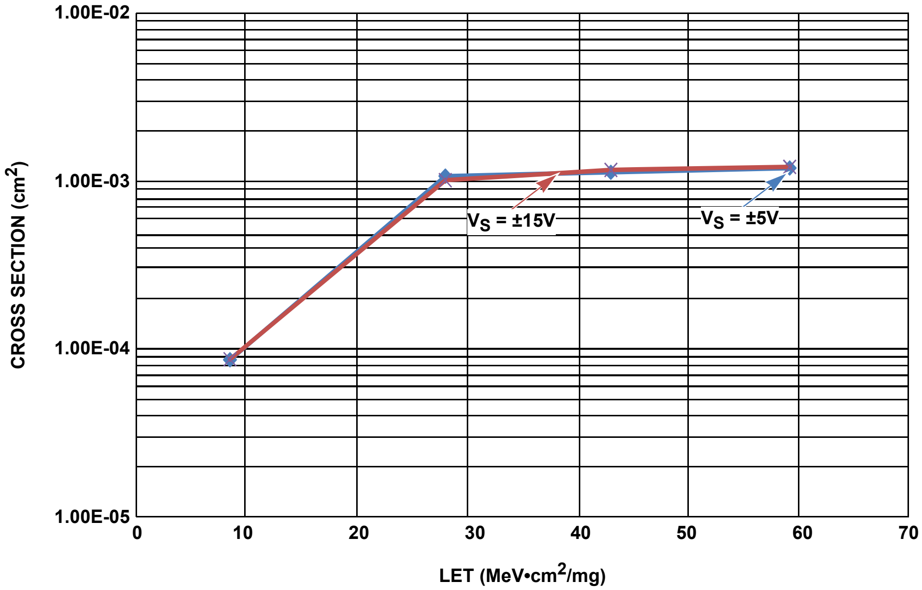

FIGURE 2. SET CROSS SECTION vs LINEAR ENERGY TRANSFER vs SUPPLY VOLTAGE

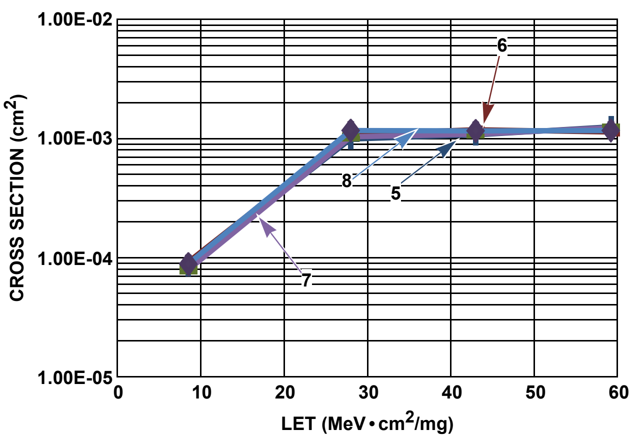

FIGURE 3. SET CROSS SECTION vs LET WITH V_S = ±5V FOR DEVICES 5, 6, 7 and 8

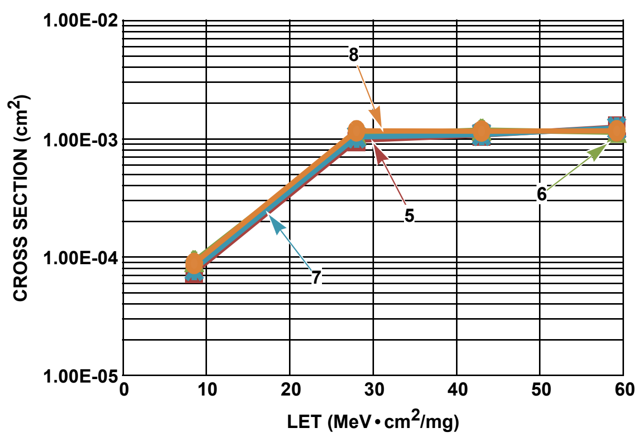

FIGURE 4. SET CROSS SECTION vs LET WITH V_S = ±15V FOR DEVICES 5, 6, 7 and 8

Single Event Transient Response

The ISL70419SEH was designed for single event transient (SET) mitigation with a goal of recovering from an SET in 10µs or less. Figures 5 through 16 plot the SET duration outside the ±200mV window versus the extreme deviation for the various devices tested and channels. This data is representative of the typical response of the ISL70419SEH and provides a quick way of categorizing the SET by magnitude and duration. All captured SET had durations of equal or less than 10µs outside of the ±200mV window about the nominal amplifier output of 2V.

There are both positive and negative deviation on most of the captures, while the rest of the transients were either only positive or negative. Figures 17 through 28 are the composite plots of the scatter plots shown in Figures 5 through 16.

Single Event Transient Recovery Time vs Peak Deviation, V_S = ±5V

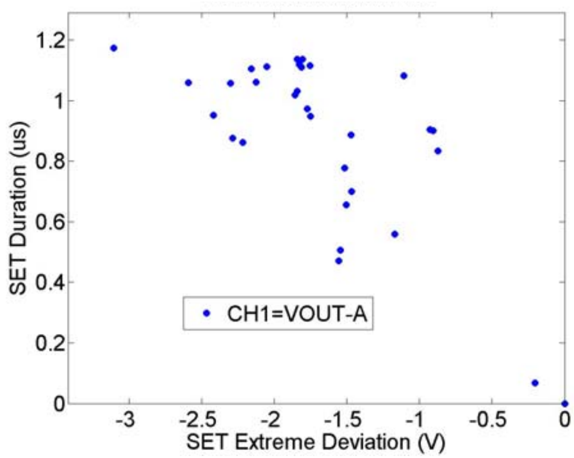

FIGURE 5. DEVICE 5, CHANNEL A, RUN 101, V_S = ±5V, LET = 8.5MeV · cm^2/mg

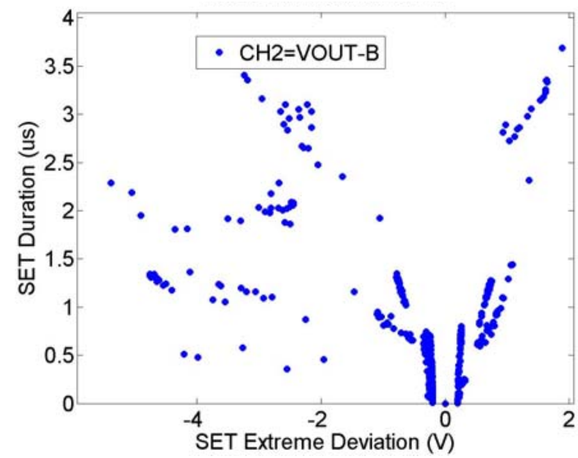

FIGURE 6. DEVICE 6, CHANNEL B, RUN 201, V_S = ±5V, LET = 28MeV · cm^2/mg

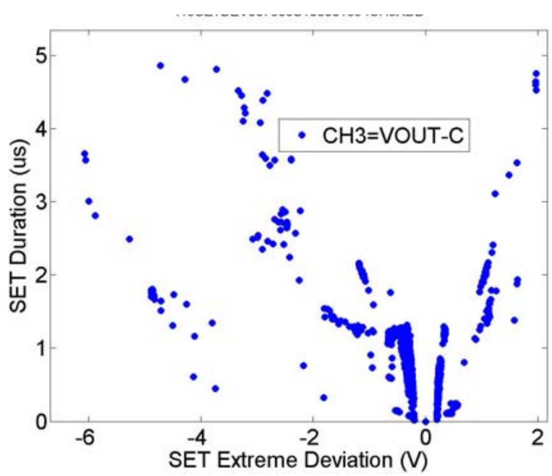

FIGURE 7. DEVICE 7, CHANNEL C, RUN 301, V_S = ±5V, LET = 43MeV · cm^2/mg

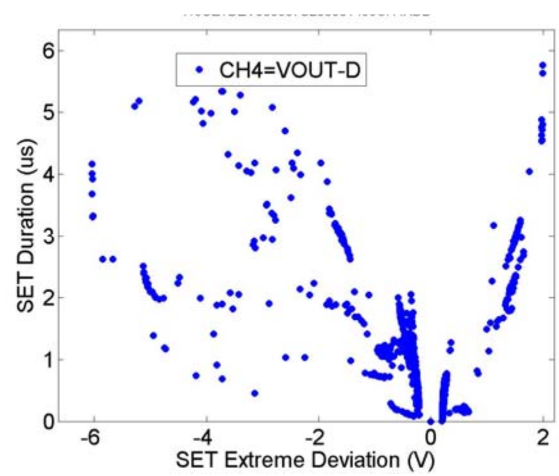

FIGURE 8. DEVICE 8, CHANNEL D, RUN 307, V_S = ±5V, LET = 59.2MeV · cm^2/mg

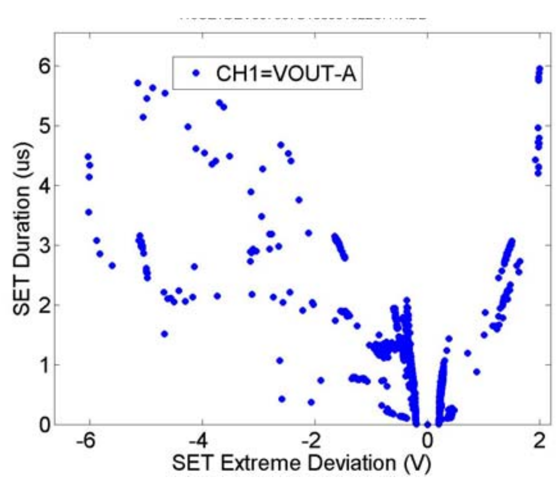

FIGURE 9. DEVICE 7, CHANNEL A, RUN 307, V_S = ±5V, LET = 59.2MeV · cm^2/mg

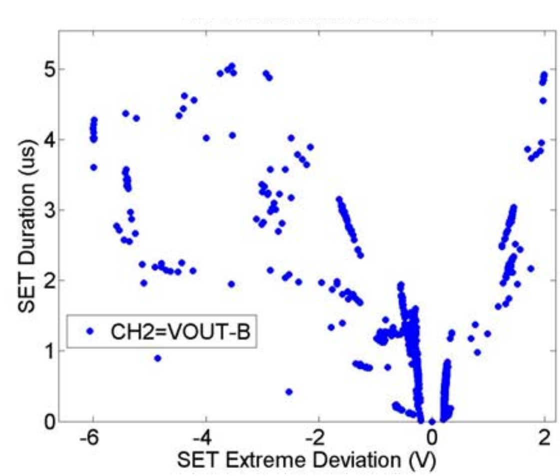

FIGURE 10. DEVICE 6, CHANNEL B, RUN 306, V_S = ±5V, LET = 59.2MeV · cm^2/mg

Single Event Transient Recovery Time vs Peak Deviation, V_S = ±15V

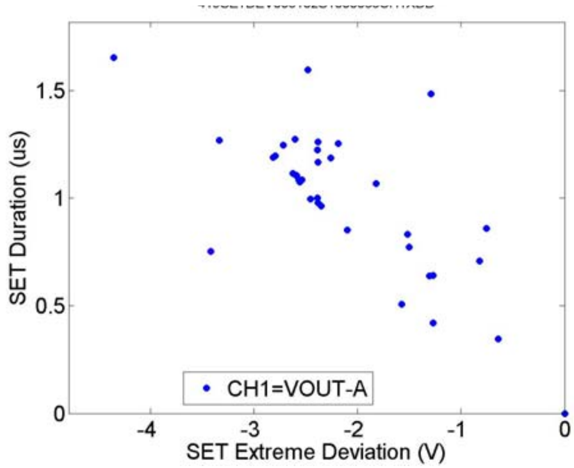

FIGURE 11. DEVICE 5, CHANNEL A, RUN 102, V_S = ±15V, LET = 8.5MeV · cm^2/mg

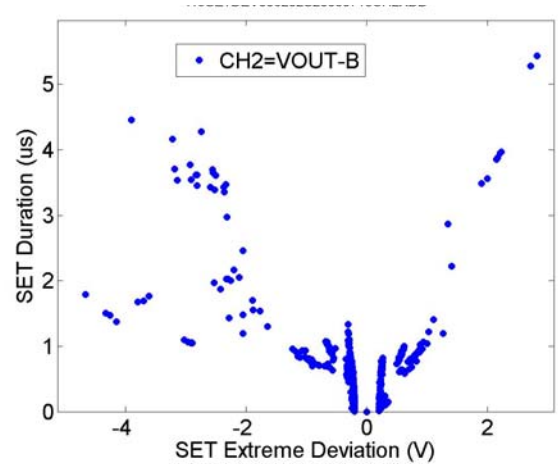

FIGURE 12. DEVICE 6, CHANNEL B, RUN 202, V_S = ±15V, LET = 28MeV · cm^2/mg

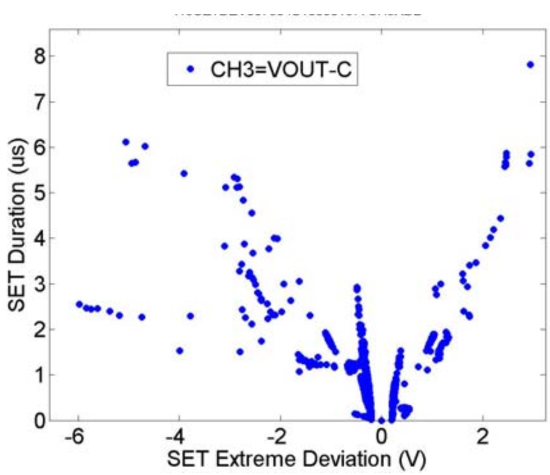

FIGURE 13. DEVICE 7, CHANNEL C, RUN 304, V_S = ±15V, LET = 43MeV · cm^2/mg

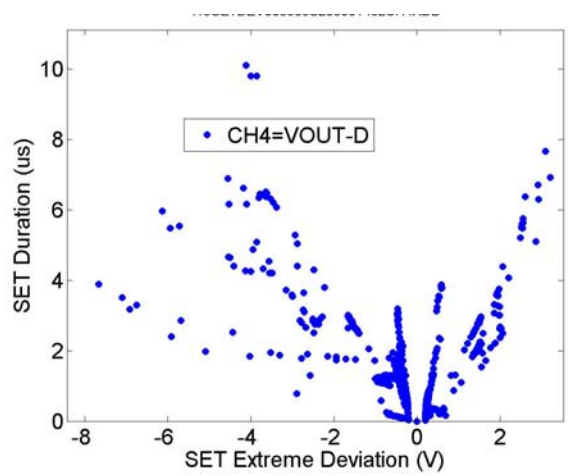

FIGURE 14. DEVICE 8, CHANNEL D, RUN 308, V_S = ±15V, LET = 59.2MeV · cm^2/mg

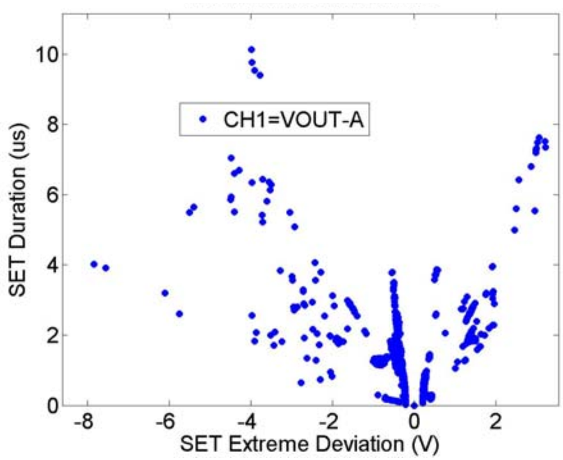

FIGURE 15. DEVICE 7, CHANNEL A, RUN 308, V_S = ±15V, LET = 59.2MeV · cm^2/mg

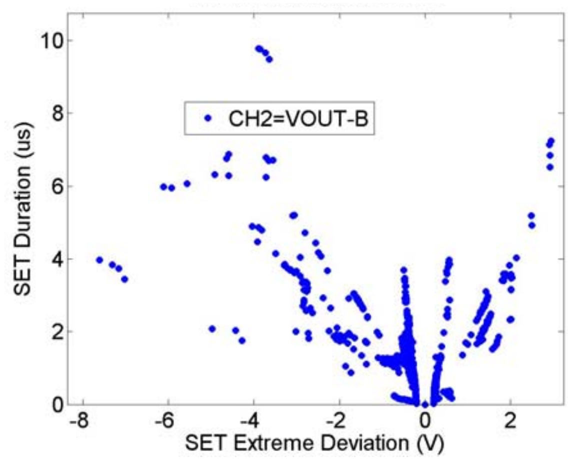

FIGURE 16. DEVICE 8, CHANNEL B, RUN 308, V_S = ±15V, LET = 59.2MeV · cm^2/mg

Single Event Transient Composite Plots, V_S = ±5V

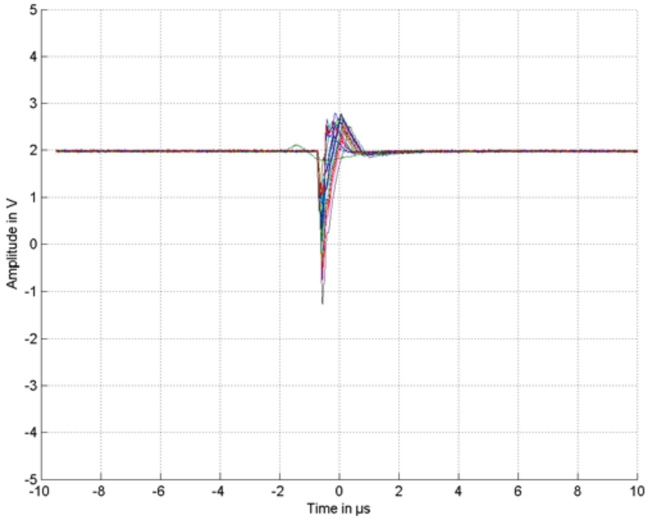

FIGURE 17. DEVICE 5, CHANNEL A, RUN 101, V_S = ±5V, LET = 8.5MeV · cm^2/mg

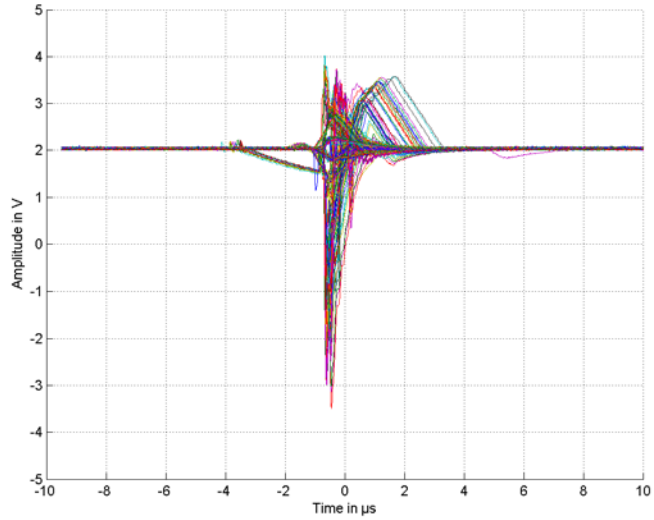

FIGURE 18. DEVICE 6, CHANNEL B, RUN 201, V_S = ±5V, LET = 28MeV · cm^2/mg

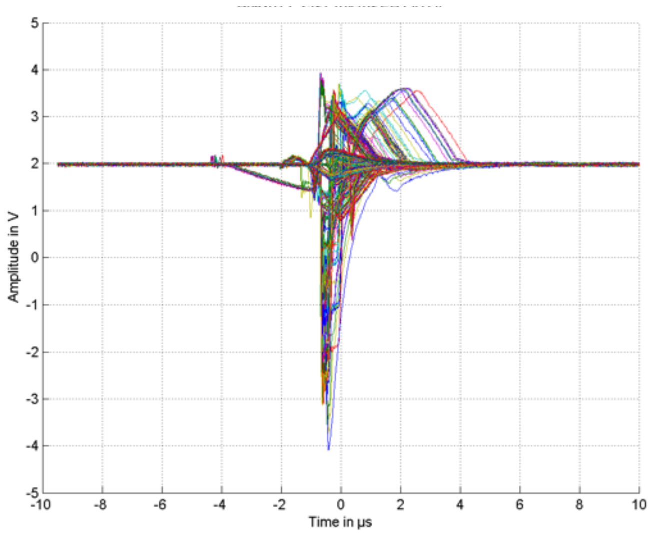

FIGURE 19. DEVICE 7, CHANNEL C, RUN 301, V_S = ±5V, LET = 43MeV · cm^2/mg

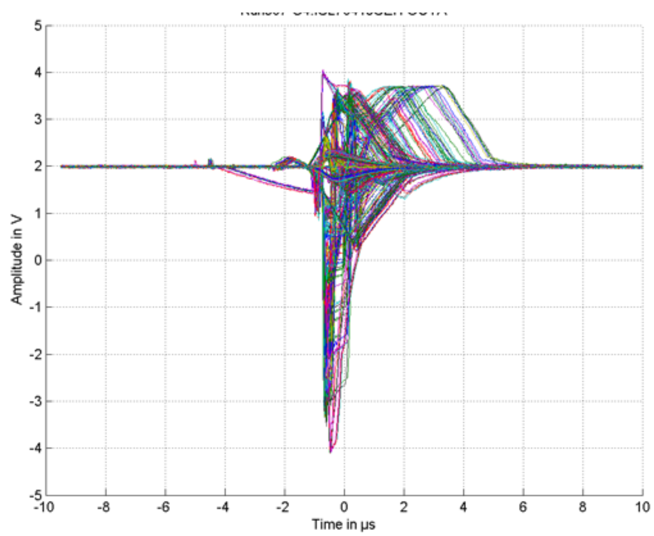

FIGURE 20. DEVICE 8, CHANNEL D, RUN 307, V_S = ±5V, LET = 59.2MeV · cm^2/mg

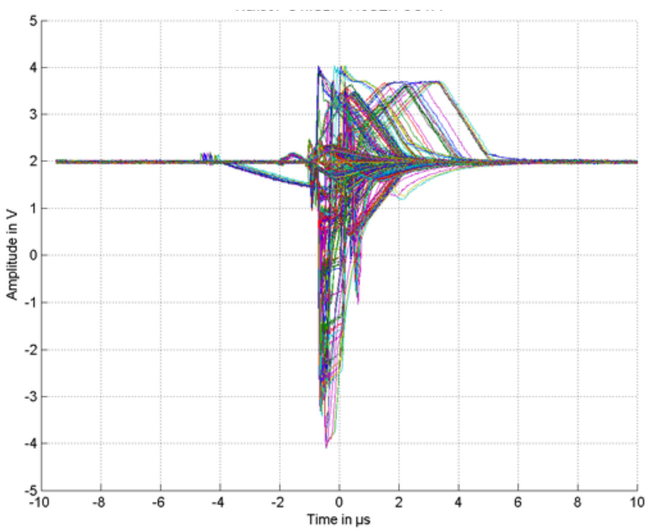

FIGURE 21. DEVICE 7, CHANNEL A, RUN 307, V_S = ±5V, LET = 59.2MeV · cm^2/mg

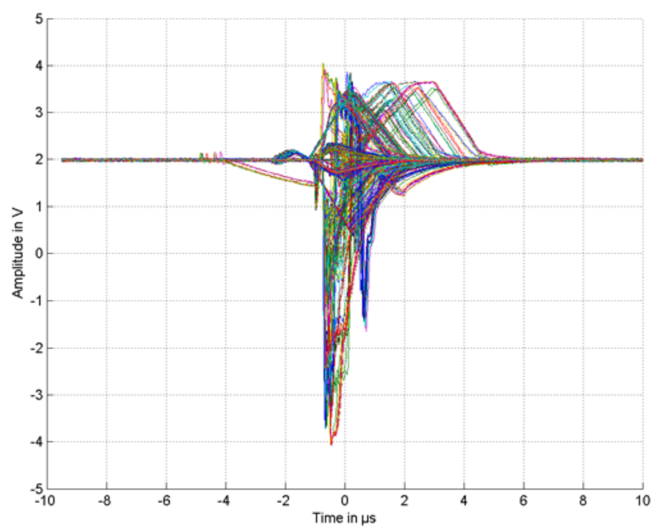

FIGURE 22. DEVICE 6, CHANNEL B, RUN 306, V_S = ±5V, LET = 59.2MeV · cm^2/mg

Single Event Transient Recovery Composite Plots, V_S = ±15V

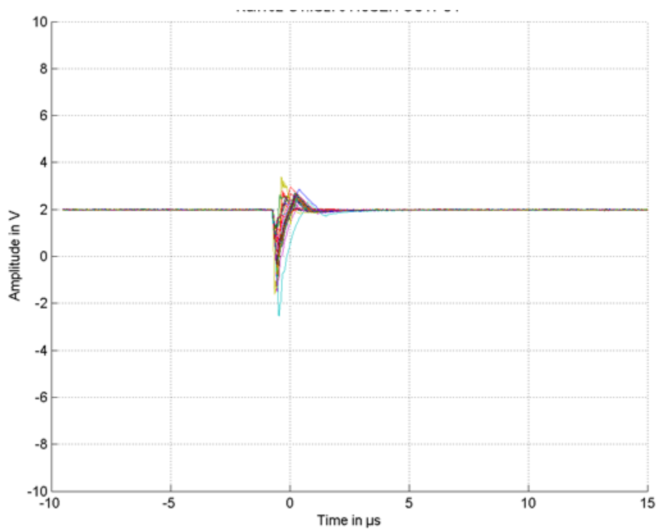

FIGURE 23. DEVICE 5, CHANNEL A, RUN 102, V_S = ±15V, LET = 8.5MeV · cm^2/mg

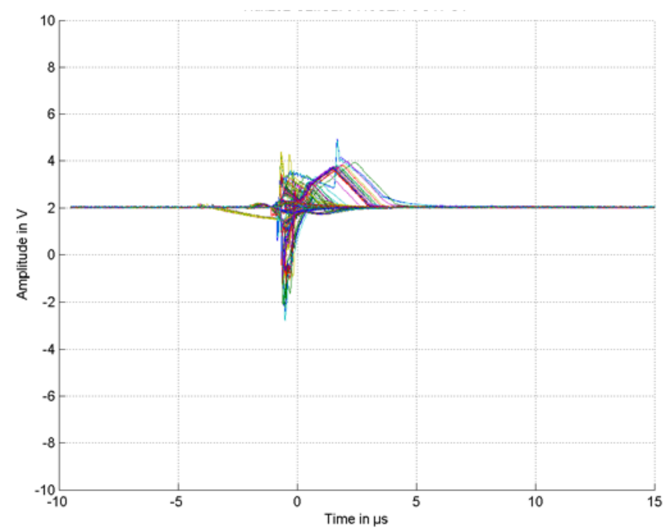

FIGURE 24. DEVICE 6, CHANNEL B, RUN 202, V_S = ±15V, LET = 28MeV · cm^2/mg

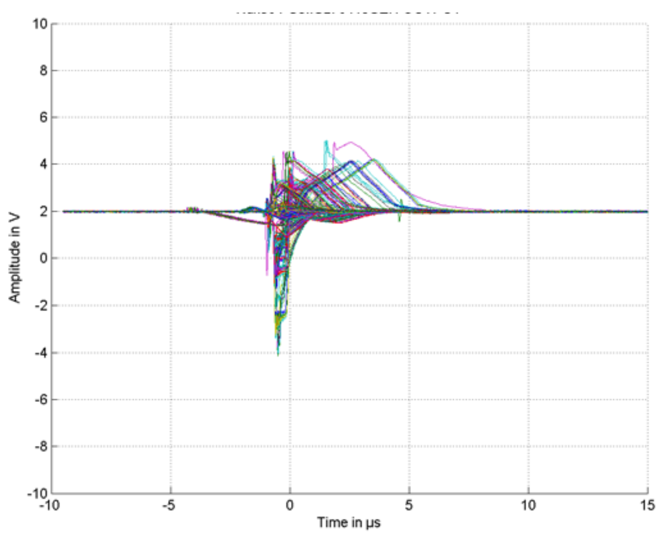

FIGURE 25. DEVICE 7, CHANNEL C, RUN 304, V_S = ±15V, LET = 43MeV · cm^2/mg

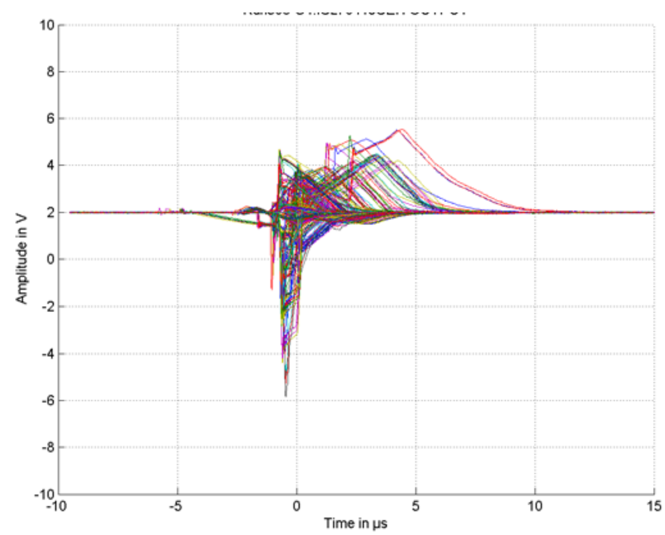

FIGURE 26. DEVICE 8, CHANNEL D, RUN 308, V_S = ±15V, LET = 59.2MeV · cm^2/mg

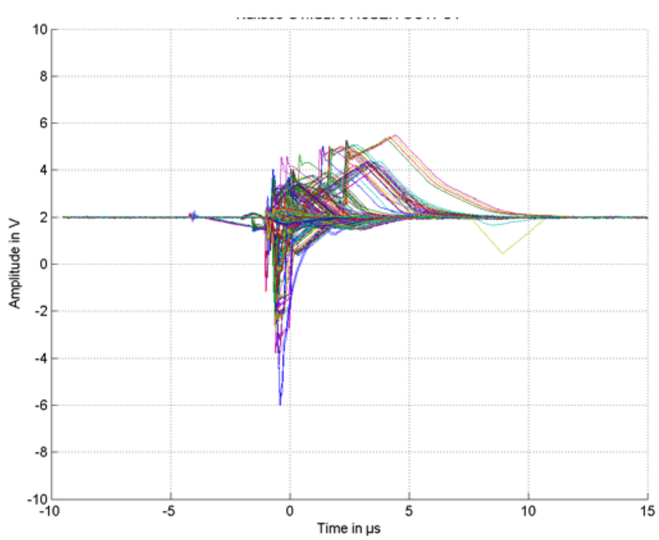

FIGURE 27. DEVICE 7, CHANNEL A, RUN 308, V_S = ±15V, LET = 59.2MeV · cm^2/mg

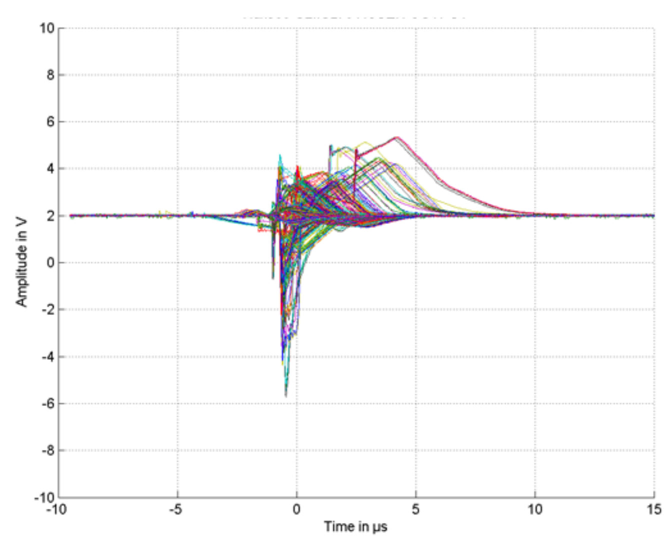

FIGURE 28. DEVICE 8, CHANNEL B, RUN 308, V_S = ±15V, LET = 59.2MeV · cm^2/mg

There is correlation to the duration of the SET with respect to the linear energy transfer. Lower LET values e.g. 8.5MeV · cm^2/mg had the quicker response times returning the SET window of ±200mV. As the LET increases so does the recovery time until it saturates at LET = 43MeV · cm^2/mg. The same correlation is found on the extreme voltage deviation versus LET. Reviewing Figures 5 through 16 shows that lower LET have a smaller deviation than the SETs caused by higher LET values.

Another interesting note is the correlation of channel-to-channel common SET occurrences at higher LET values. For example on run 305, which is tested with LET = 59.2MeV · cm^2/mg, roughly 75% of the SET were common on all channels. For run 101, which is tested with LET = 8.5MeV · cm^2/mg, 0% of the SET were common to all four channels. This correlation start to occur when the LET = 28MeV · cm^2/mg. An explanation of the commonality is that a device or circuit which is common to all amplifiers is being upset. For example the ESD clamps which are common to all four amplifiers within the IC, could be susceptible at hIgher LET and causing SETs on the output of all four channels. Figures 29 and 30 are SETs of Channel 1 (OUT A) and Channel 2 (OUT B) of device 5 in run 201.These events occurred simultaneously on all four channels.

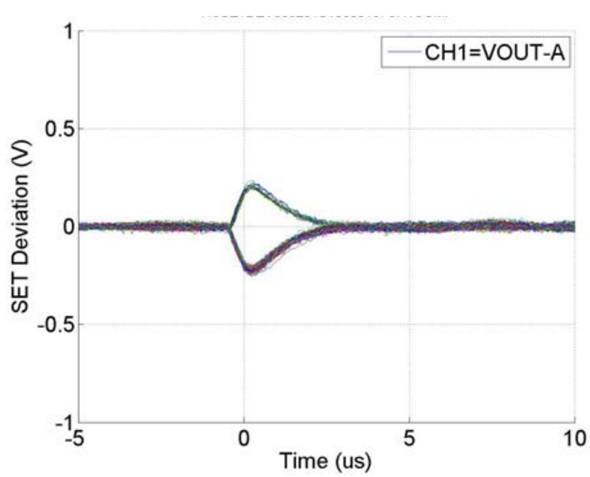

FIGURE 29. CHANNEL 1 COMPOSITE PLOT OF COMMON SETs

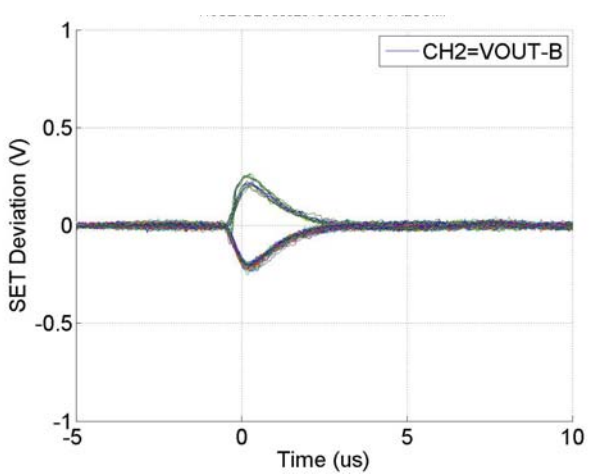

FIGURE 30. CHANNEL 2 COMPOSITE PLOT OF COMMON SETs

Summary

Single Event Burnout

No single event burnout (SEB) was observed for the device up to an LET of 86.4MeV · cm^2/mg (+125°C) at a maximum voltage supply of V_S = ± 18V. This gives 20% margin on the recommended supply voltage of V_S = ± 15V. Since the operational amplifier has no internal ground reference, the 36V supply range can be partitioned as desired, for example have a single supply where the V^+ pin can be tied to 36V and the V^- pin tied to ground (0V).

It is also not surprising that since the process is an SOI process, there was no latch-up observed on the device.

Single Event Transient

Based on the results presented, the ISL70419SEH op amp offers advantages over the competitors part by having better SET performance yet keeping the high accuracy of a precision op amp. The length of worst case SETs can be 6µs for devices with V_S = ±5V and 10µs for devices with V_S = ±15V. This part does not experience the long recovery time (>100µs) during a single event transient seen on other competitor op amps in a comparator application. This may be explained by the higher drive capability of the ISL70419SEH and its ability to drive highly capacitive loads. Magnitude of the deviation for V_S = ±5V was to 1V below the rail in the positive direction and 1V above the rail in the negative direction, limited by the VOH and VOL specifications of the amplifier. For amplifiers supplied with a V_S = ±15V, the transient excursions were much larger, however they do not extend to the expected VOH or VOL levels of ±13.5V. All the transients observed were 8.5V deviations or less with all the larger transient occurring in the negative direction. Recovery time of the transients were less than or equal to 10µs.

Overall, the ISL70419SEH is very well behaved in a heavy ion environment. In space flight applications, the ISL70419SEH should not require filtering or other types of SET mitigation techniques. The ISL70419SEH offers a competitive advantage over other rad hard op amps by offering the following:

- No single event burnout up to ±36V
- SOI process for latch-up immunity
- Fast recovery from single event transients

Appendix A

Appendix A includes the data from Figures 3 and 4 in tabular format, complete test schematic, and board silk screen images.

TABLE 4. DATA OF CHANNEL CROSS SECTION OF THE ISL70419SEH REPRESENTED IN FIGURE 3

SUPPLY VOLTAGE (V)	LET (MeV . cm^2/mg)	DEVICE	RUN NUMBER	FLUENCE PER RUN (PARTICLES/cm^2)	EVENTS	EVENT CS (cm^2)
± 5	8.5	5	101	2.0×10^6	171	8.55×10^{-5}
± 5	28	5	201	2.0×10^6	1988	9.94×10^{-4}
± 5	43	5	301	2.0×10^6	2155	1.08×10^{-3}
± 5	59.2	5	306	2.0×10^6	2511	1.26×10^{-3}
± 5	8.5	6	101	2.0×10^6	184	9.20×10^{-5}
± 5	28	6	201	2.0×10^6	2173	1.09×10^{-3}
± 5	43	6	301	2.0×10^6	2373	1.19×10^{-3}
± 5	59.2	6	306	2.0×10^6	2268	1.13×10^{-3}
± 5	8.5	7	103	2.0×10^6	158	7.90×10^{-5}
± 5	28	7	203	2.0×10^6	2074	1.04×10^{-3}
± 5	43	7	303	2.0×10^6	2172	1.09×10^{-3}
± 5	59.2	7	307	2.0×10^6	2472	1.24×10^{-3}
± 5	8.5	8	103	2.0×10^6	177	8.85×10^{-5}
± 5	28	8	203	2.0×10^6	2331	1.17×10^{-3}
± 5	43	8	303	2.0×10^6	2325	1.16×10^{-3}
± 5	59.2	8	307	2.0×10^6	2337	1.17×10^{-3}

TABLE 5. DATA OF CHANNEL CROSS SECTION OF THE ISL70419SEH REPRESENTED IN FIGURE 4

SUPPLY VOLTAGE (V)	LET (MeV · cm^2/mg)	DEVICE	RUN NUMBER	FLUENCE PER RUN (PARTICLES/cm^2)	EVENTS	EVENT CS (cm^2)
± 15	8.5	5	102	2.0×10^6	149	7.45×10^{-5}
± 15	28	5	202	2.0×10^6	1942	9.71×10^{-4}
± 15	43	5	302	2.0×10^6	2273	1.14×10^{-3}
± 15	59.2	5	305	2.0×10^6	2703	1.35×10^{-3}
± 15	8.5	6	102	2.0×10^6	170	8.50×10^{-5}
± 15	28	6	202	2.0×10^6	2082	1.04×10^{-3}
± 15	43	6	302	2.0×10^6	2362	1.18×10^{-3}
± 15	59.2	6	305	2.0×10^6	2561	1.28×10^{-3}
± 15	8.5	7	104	2.0×10^6	178	8.90×10^{-5}
± 15	28	7	204	2.0×10^6	1990	9.95×10^{-4}
± 15	43	7	304	2.0×10^6	2331	1.17×10^{-3}

TABLE 5. DATA OF CHANNEL CROSS SECTION OF THE ISL70419SEH REPRESENTED IN FIGURE 4 (CONTINUED)

SUPPLY VOLTAGE (V)	LET (MeV · cm^2/mg)	DEVICE	RUN NUMBER	FLUENCE PER RUN (PARTICLES/cm^2)	EVENTS	EVENT CS (cm^2)
± 15	59.2	7	308	2.0×10^6	2301	1.15×10^{-3}
± 15	8.5	8	104	2.0×10^6	198	9.90×10^{-5}
± 15	28	8	204	2.0×10^6	2089	1.04×10^{-3}
± 15	43	8	304	2.0×10^6	2378	1.19×10^{-3}
± 15	59.2	8	308	2.0×10^6	2170	1.09×10^{-3}

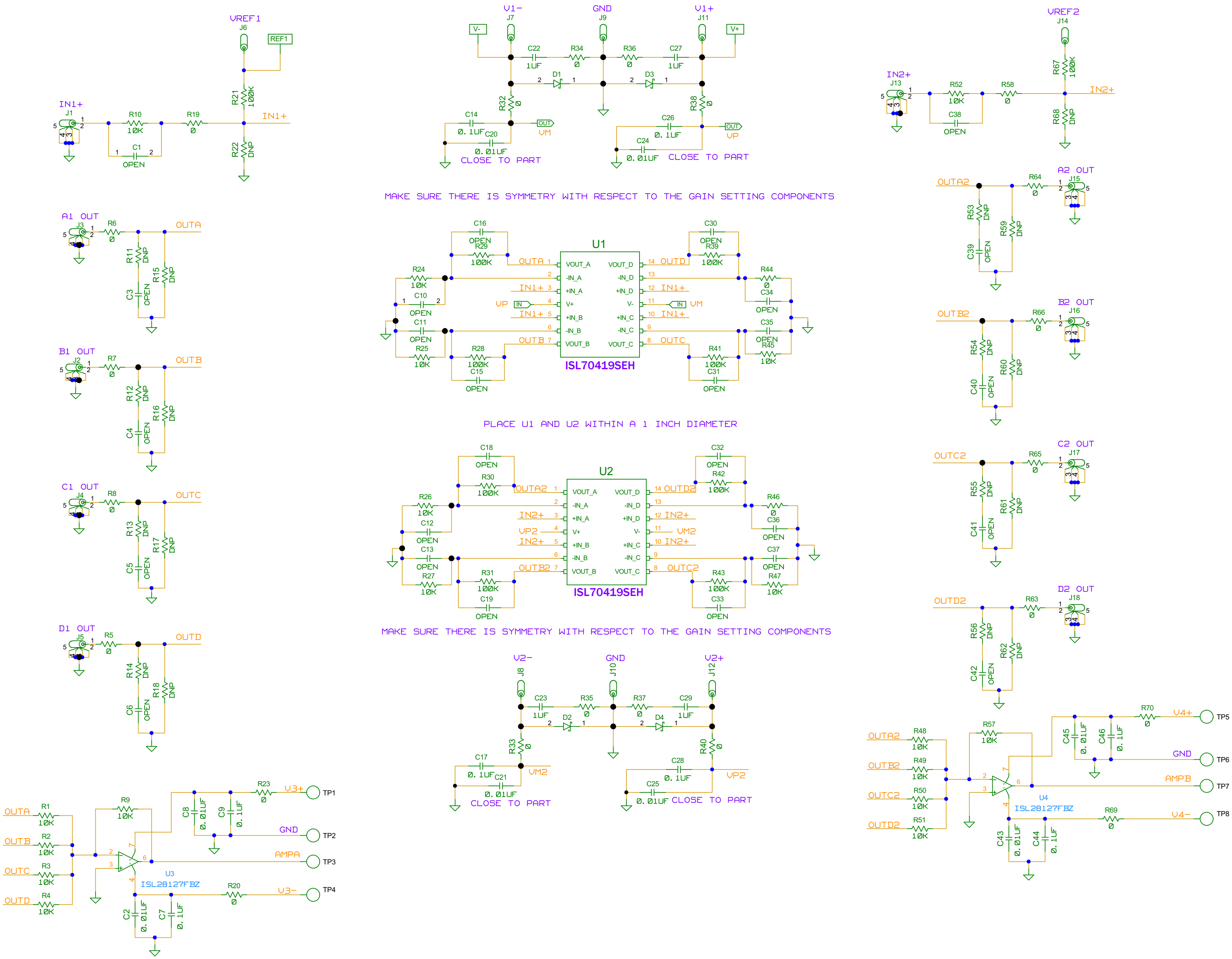

FIGURE 31. ISL70419SEH SEE TEST BOARD SCHEMATIC

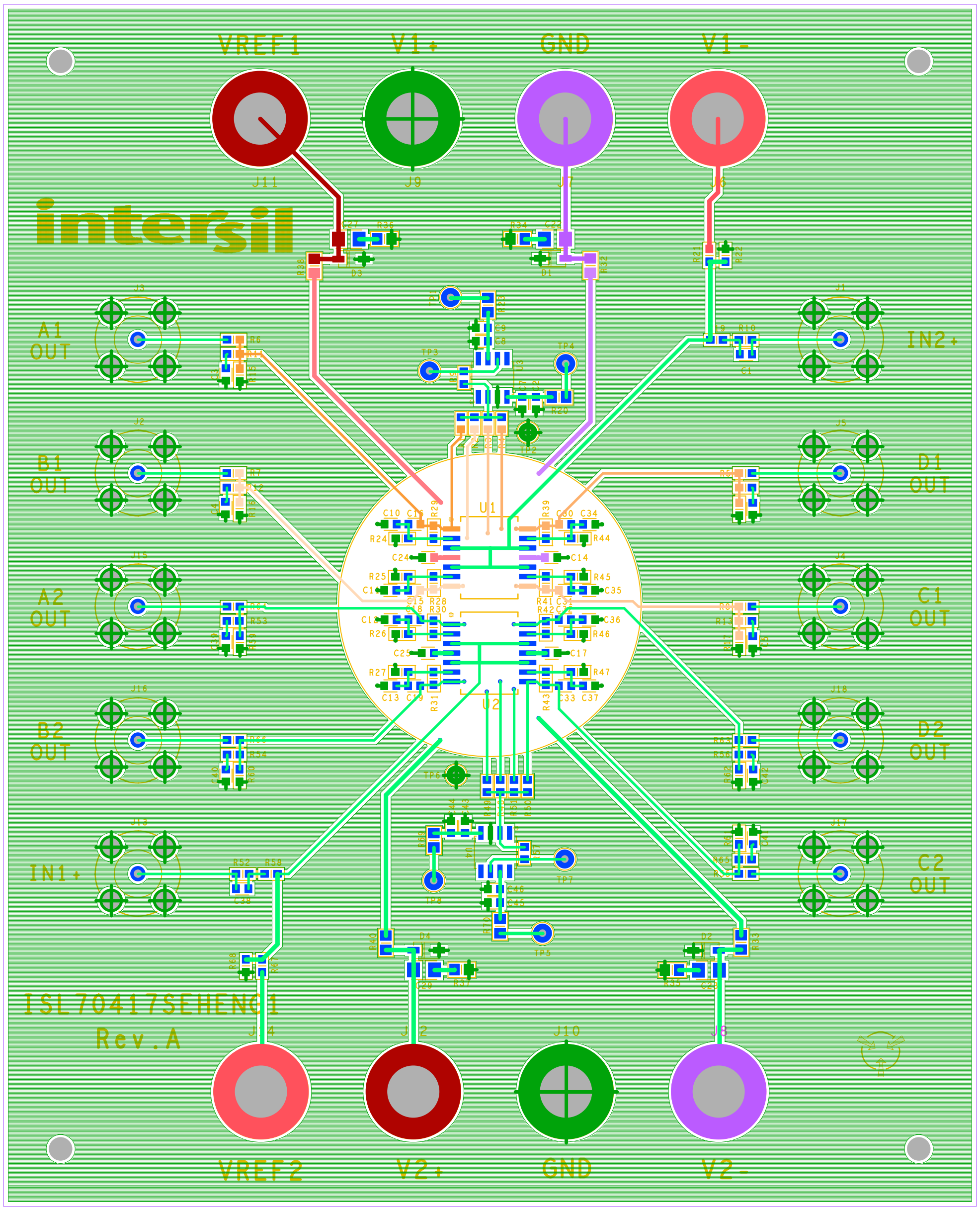

FIGURE 32. ISL70419SEH SEE TEST BOARD TOP VIEW

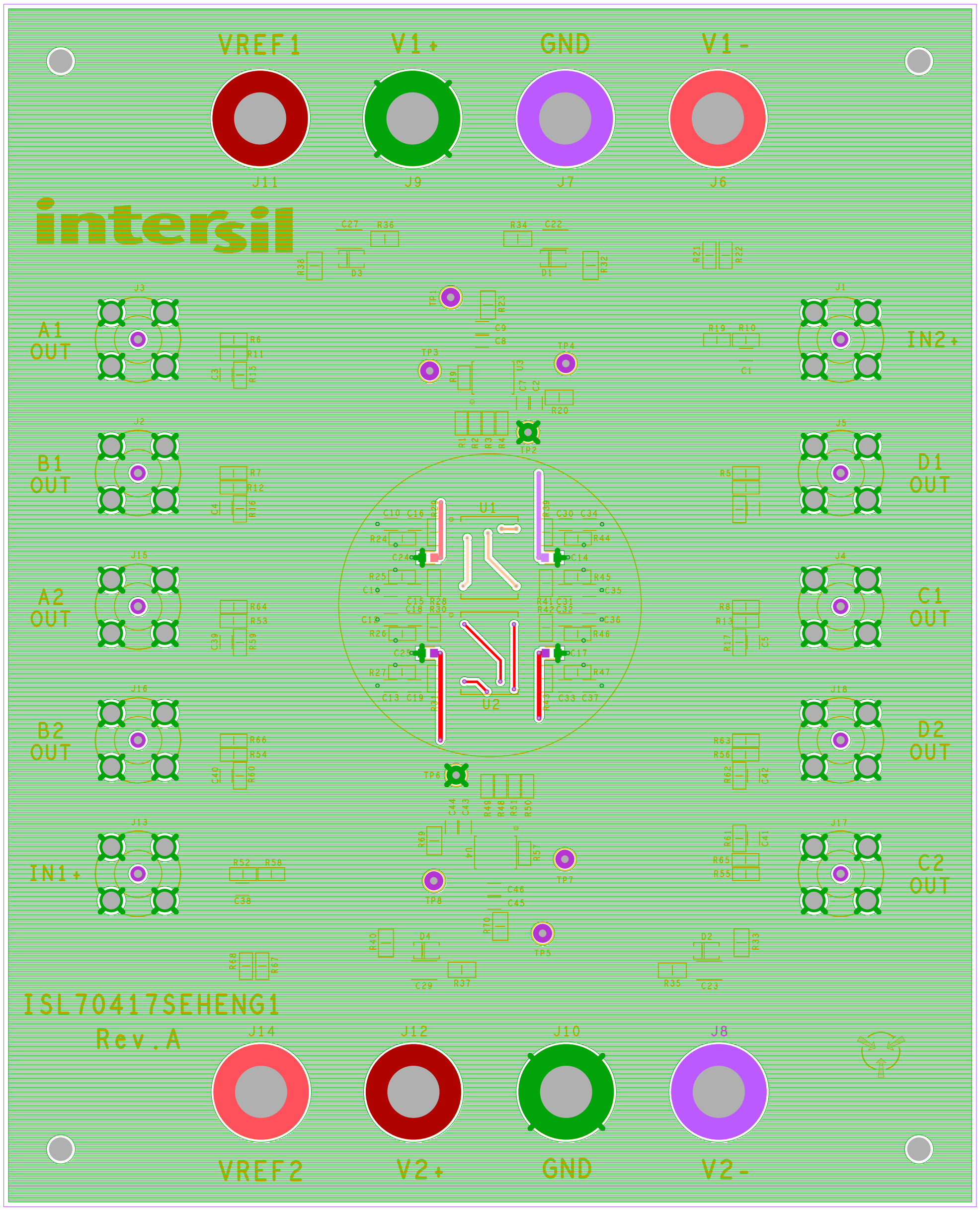

FIGURE 33. ISL70419SEH SEE TEST BOARD BOTTOM VIEW

SALES OFFICES

Renesas Electronics Corporation

http://www.renesas.com

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Renesas Electronics America Inc.
1001 Murphy Ranch Road, Milpitas, CA 95035, U.S.A.
Tel: +1-408-432-8888, Fax: +1-408-434-5351

Renesas Electronics Canada Limited
9251 Yonge Street, Suite 8309 Richmond Hill, Ontario Canada L4C 9T3
Tel: +1-905-237-2004

Renesas Electronics Europe Limited
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K
Tel: +44-1628-651-700, Fax: +44-1628-651-804

Renesas Electronics Europe GmbH
Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-6503-0, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.
Room 1709 Quantum Plaza, No.27 ZhichunLu, Haidian District, Beijing, 100191 P. R. China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.
Unit 301, Tower A, Central Towers, 555 Langao Road, Putuo District, Shanghai, 200333 P. R. China
Tel: +86-21-2226-0888, Fax: +86-21-2226-0999

Renesas Electronics Hong Kong Limited
Unit 1601-1611, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2265-6688, Fax: +852 2886-9022

Renesas Electronics Taiwan Co., Ltd.
13F, No. 363, Fu Shing North Road, Taipei 10543, Taiwan
Tel: +886-2-8175-9600, Fax: +886 2-8175-9670

Renesas Electronics Singapore Pte. Ltd.
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre, Singapore 339949
Tel: +65-6213-0200, Fax: +65-6213-0300

Renesas Electronics Malaysia Sdn.Bhd.
Unit 1207, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

Renesas Electronics India Pvt. Ltd.
No.777C, 100 Feet Road, HAL 2nd Stage, Indiranagar, Bangalore 560 038, India
Tel: +91-80-67208700, Fax: +91-80-67208777

Renesas Electronics Korea Co., Ltd.
17F, KAMCO Yangjae Tower, 262, Gangnam-daero, Gangnam-gu, Seoul, 06265 Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5338

Colophon 7.0