

ISL70061SEH, ISL73061SEH

SEE Test Report

Introduction

The intense proton and heavy ion environment encountered in space applications can cause a variety of Single Event Effects (SEE) in electronic circuitry, including Single Event Upset (SEU), Single Event Transient (SET), Single Event Functional Interrupt (SEFI), Single Event Latch-Up (SEL), Single Event Gate Rupture (SEGR), and Single Event Burnout (SEB). SEE can lead to system-level performance issues including disruption, degradation, and destruction. For predictable and reliable space system operation, individual electronic components should be characterized to determine their SEE response. This report discusses the results of SEE testing performed on the [ISL70061SEH](#) 10A, PMOS protection switch. This report also applies to the [ISL73061SEH](#) as the parts only differ in TID radiation assurance testing. The ISL73061SEH only sees 75krad(Si) of Low Dose Rate (LDR) (0.01rad(Si)/s) assurance testing, while the ISL70061SEH also undergoes assurance testing to 100krad(Si) at High Dose Rate (HDR) (50-300rad(Si)/s).

Product Description

The ISL70061SEH and ISL73061SEH are radiation hardened protection switches featuring a low resistance PMOS switch and a fixed slew rate controlled turn-on. These devices are capable of 10A continuous current, simple on/off logic control input, and reverse current protection to stop current from flowing toward the input when the output voltage increases above the input voltage. They also have a selectable internal 100Ω NMOS device to discharge the output when the switch is off. The discharge circuitry is active when DON input is high, and it is inactive when DON is low. The input and switched voltage can be from 3V to 5.5V. The ISL70061SEH and ISL73061SEH are offered in 14 Ld CDFP packages, see the pinout in [Figure 1](#).

The parts used for the testing described here were from wafer lot 22L3B01, wafer AWICE8W. The parts did not see temperature testing because they did not have lids installed to allow irradiation.

The input to the switch (SWI) are Pins 1 through 6. The switch output (SWO) are Pins 10 through 14. The control signals ON (switch command) and DON (discharge MOSFET control) are on Pins 7 and 9 respectively with ground, GND, on Pin 8.

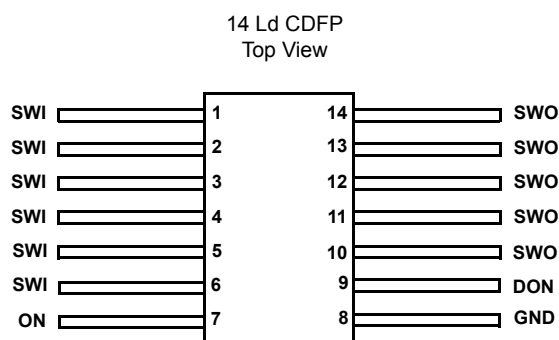


Figure 1. Pinout of the ISL70061SEH

Related Literature

For a full list of related documents, visit our website:

- [ISL70061SEH](#), [ISL73061SEH](#) device pages

1. SEE Testing

1.1 Test Objectives

The ISL70061SEH was tested to determine susceptibility to destructive single event effects (referred to herein as SEB to include SEL) and to characterize Single Event Transient (SET) behavior over different operating conditions.

1.2 Test Facility

Testing was performed at the Texas A&M University (TAMU) Radiation Effects Facility of the Cyclotron Institute heavy ion facility. This facility is coupled to a K500 super-conducting cyclotron that is capable of generating a wide range of particle beams with the various energy, flux, and fluence levels needed for advanced radiation testing. Further details on the test facility can be found on their [website](#). The Devices Under Test (DUTs) were located in air outside an Aramica window for the ion beam. Ion Linear Energy Transfer (LET) values are quoted at the DUT surface. Signals were communicated to and from the DUT test fixture through 20ft cables connecting to the control room. The testing reported here was conducted on October 14, 2018.

1.3 Test Set-Up

For SEE testing the general circuit configuration in [Figure 2](#) was used. Kelvin connections were provided to both the high current terminals, SWI and SWO, so that accurate voltages could be measured at the unit even under high current tests. Both ON and DON were brought out to be accessible.

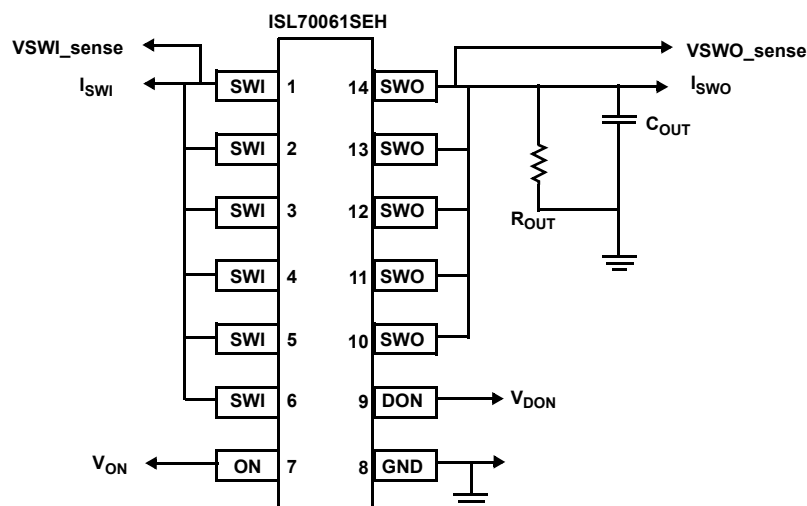


Figure 2. SEE Testing Configuration

For destructive SEE testing (termed SEB but to include SEL) three bias configurations were tested. All three configurations were without ROUT or COUT components. This allowed currents of the DUT to be measured without contributions from external components. In the first configuration the SWI, ON, and DON pins were provided with the input test voltage so that the switch was on but unloaded. In the second configuration the output, SWO, was remotely loaded with a 1kΩ resistor and the switch control, ON, was provided with a 100Hz square wave between 0V and 5V. For the third configuration the input, SWI, and the ON pin had a test voltage applied. The output, SWO, had a 12A current sink applied to it. This last case required the Kelvin connection to SWI so the voltage at the DUT could be monitored under high current conditions.

For SET testing the external components ROUT and COUT were populated with 1kΩ and 1μF. Four configurations were tested for SET. The first two conditions were with ON and DON pins biased at 0.4V (maximum logic low condition) and SWI at both 3.0V and 5.5V. Because the switch was biased off, the SET would indicate a momentary switch to the on condition. The other two SET configurations had ON and DON at 1.2V and a current sink connected to SWO to provide 3A load at SWI biased at 3.0V and a 5.5A load for SWI at 5.5V. This emulated the condition of a 1Ω load on the output. In this condition, SET on SWO would indicate cases where the switch tended toward an off condition.

1.4 ISL70061SEH Destructive SEE Testing with LET = 86MeV•cm²/mg

The first ISL70061SEH material (first of kind, FOK) was SEL tested at supply voltages of 6.5V, and 6.9V with normal incidence gold for 86MeV•cm²/mg, and at +125°C case temperature. The irradiations were done to 1x10⁷ions/cm² at a flux of about 1x10⁴ions/(cm²•s). The parts were biased during irradiation in the on state with no load and heated to +125 ±10°C case temperature.

Under these SEL testing conditions at 6.9V what appeared to be SEL occurrences were noted. The supply current jumped from a nominal value of about 25µA to 15mA and infrequently to 30mA. These high current states were not, in general, spikes in current but were maintained over considerable time periods (many seconds in some cases). These states terminated at seemingly random times with what appeared to be subsequent ion strikes. A record of the supply currents during irradiation for two parts exhibiting these high current events appears in [Figure 3](#). All four parts tested finished the irradiations at 6.9V in a high current state, but they all had the high current state terminated by a power cycle which returned the supply current to the nominal 25µA. This return to normal operation indicated that the SEL events were not damaging.

For a supply voltage of 6.5V, the nominal 25µA supply current fluctuated a bit but never exceeded 100µA nor stayed at an elevated level. This is a factor of 150, smaller than the states observed at a supply of 6.9V. This was interpreted as no SEL occurrences at the 6.5V bias.

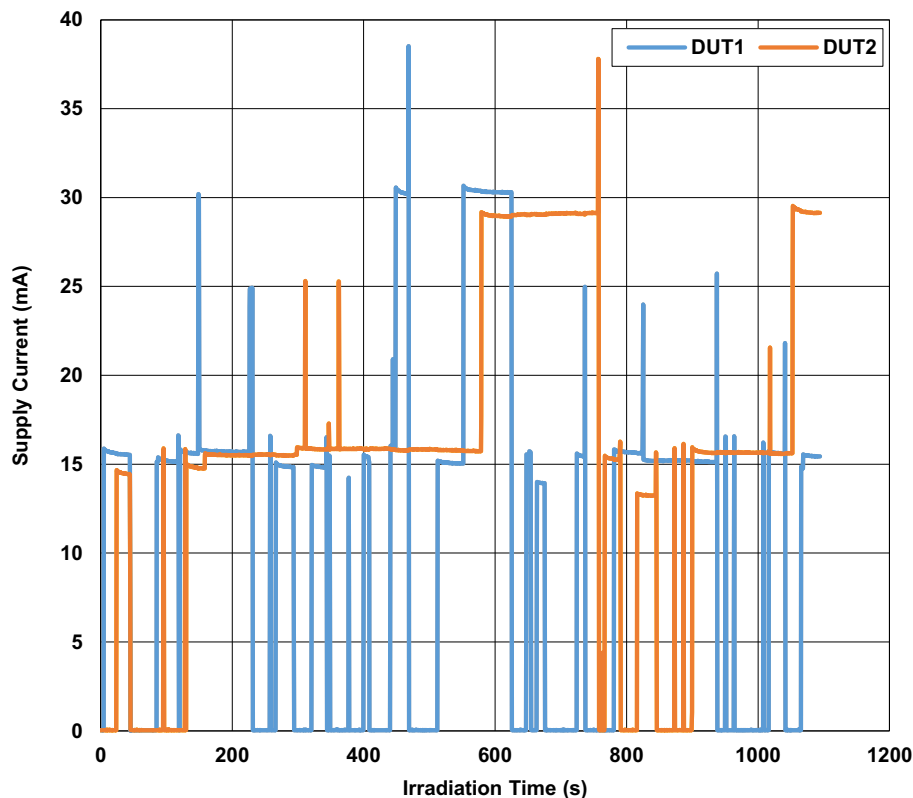


Figure 3. Supply current during irradiation run 408 of the ISL70061SEH FOK material with a supply voltage of 6.9V, a case temperature of +125°C, and normal incidence gold for 86MeV•cm²/mg to 1x10⁷ions/cm² at approximately 1x10⁴ions/(cm²•s).

Destructive SEE testing done on the final product design (a metal variant from FOK to mitigate SET) was limited to supply voltages of 6.5V and 6.7V to avoid the SEL events observed on the FOK material. This resulted in no SEL events being recorded. However, since the silicon design was not changed from the FOK it is fully expected that SEL would still occur at a supply of 6.9V as originally found.

The destructive SEE testing was done on two parts at a time to minimize beam time. The parts were mounted so that both were inside the beam diameter. The parts were biased and monitored separately during the testing.

Destructive SEE (to include SEL) testing of the ISL70061SEH proceeded with monitoring five currents before and after irradiation. In addition, for SEL testing, the supply current during irradiation was monitored and logged for the case of an unloaded output with the switch in an on condition. The logged currents only showed transitions below

100 μ A as cited earlier. The summary of the before and after irradiation currents is presented in [Table 1](#) for the SEL testing. The monitored currents did not show changes to indicate any damaging events during the irradiations.

Table 1. SEB Monitor Current Readings for the case of irradiation with $V_{ON} = V_{DON} = V_{SWI}$ and unloaded SWO with normal incidence gold for 86MeV $\cdot$ cm²/mg to 1x10⁷ions/cm² per irradiation at +125°C case temperature.

DUT	V_{SWI} Test (V)	I_{SWI} (Switch Off) $V_{SWI} = 5V$ $V_{SWO} = 0V$ $V_{ON} = \text{Open}$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWI} (Switch On) $V_{SWI} = 5V$ $V_{SWO} = \text{Open}$ $V_{ON} = 5V$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWO} (DON Off) $V_{SWI} = 0V$ $V_{SWO} = 5V$ $V_{ON} = \text{Open}$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWO} (DON On) $V_{SWI} = 5V$ $V_{SWO} = 4V$ $V_{ON} = \text{Open}$ $V_{DON} = 5V$ (mA) $\pm 10\%$		I_{DON} (I_{IH}) $V_{SWI} = 5V$ $V_{SWO} = 4V$ $V_{ON} = \text{Open}$ $V_{DON} = 5V$ (μA) $\pm 20\%$	
		Pre	Delta	Pre	Delta	Pre	Delta	Pre	Delta	Pre	Delta
1	6.5	33.0	-2%	29.7	-4%	7.6	1%	37.2	0%	1.9	-5%
	6.7	32.3	-2%	28.5	-1%	7.7	-1%	37.3	0%	1.8	0%
2	6.5	31.8	0%	29.6	7%	7.5	7%	36.7	0%	1.7	6%
	6.7	31.8	-2%	31.8	-10%	8.0	0%	36.7	0%	1.8	-6%
3	6.5	33.2	-2%	29.6	-2%	7.6	0%	36.9	0%	1.7	6%
	6.7	32.5	-1%	28.9	-2%	7.6	0%	37.0	0%	1.8	0%
4	6.5	32.4	-2%	28.7	0%	8.1	-1%	37.0	0%	1.8	-6%
	6.7	31.9	1%	28.8	-1%	8.0	1%	37.1	0%	1.7	6%

Another group of four parts was irradiated at input voltages of 6.5V and 6.7V with dynamic conditions created by applying a 100Hz signal between 0V and 5V to the ON input. The DON input was set to the test voltage and the output was loaded with a 1k Ω resistor. The results for these irradiations appear in [Table 2](#). Again, there was no indication of any damage.

Table 2. SEB monitor current readings for the case of irradiations with $V_{ON} = 0V$ to 5V at 100Hz, $V_{DON} = V_{SWI}$, and V_{SWO} loaded at 1k Ω . Irradiations were with normal incidence gold for 86MeV $\cdot$ cm²/mg to 1x10⁷ions/cm² per irradiation at +125°C case temperature.

DUT	V_{SWI} Test (V)	I_{SWI} (Switch Off) $V_{SWI} = 5V$ $V_{SWO} = 0V$ $V_{ON} = \text{Open}$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWI} (Switch On) $V_{SWI} = 5V$ $V_{SWO} = \text{Open}$ $V_{ON} = 5V$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWO} (DON Off) $V_{SWI} = 0V$ $V_{SWO} = 5V$ $V_{ON} = \text{Open}$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWO} (DON On) $V_{SWI} = 5V$ $V_{SWO} = 4V$ $V_{ON} = \text{Open}$ $V_{DON} = 5V$ (mA) $\pm 10\%$		I_{DON} (I_{IH}) $V_{SWI} = 5V$ $V_{SWO} = 4V$ $V_{ON} = \text{Open}$ $V_{DON} = 5V$ (μA) $\pm 20\%$	
		Pre	Delta	Pre	Delta	Pre	Delta	Pre	Delta	Pre	Delta
5	6.5	32.5	-1%	28.7	2%	7.6	7%	37.0	0%	2.1	-10%
	6.7	32.1	4%	29.3	-1%	8.1	-5%	36.9	0%	1.9	-5%
6	6.5	32.2	0%	29.0	-1%	10.5	-13%	37.4	0%	2.2	-9%
	6.7	32.2	1%	28.6	0%	9.1	-1%	37.4	0%	2.0	5%
7	6.5	33.8	6%	29.6	4%	8.1	1%	36.7	0%	1.7	6%
	6.7	35.8	-8%	30.7	-4%	8.2	-1%	36.6	1%	1.8	0%
8	6.5	33.6	-1%	31.5	-5%	7.9	1%	36.9	0%	1.7	0%
	6.7	33.2	-1%	29.0	2%	8.0	-1%	36.9	0%	1.7	6%

Finally, another four parts were irradiated with the switch in the on state and the output loaded with a 12A electronic current load. This tested the part in a high current state. The results for this testing are presented in [Table 3 on page 5](#). Once again there was no indication of any damage in the current measurements.

Table 3. SEB monitor current readings for the case of irradiations with $V_{ON} = V_{SWI}$, V_{DON} = open, and V_{SWO} loaded at 12A. Irradiations were with normal incidence gold for 86MeV•cm²/mg to 1×10^7 ions/cm² per irradiation at +125°C case temperature.

DUT	V_{SWI} Test (V)	I_{SWI} (Switch Off) $V_{SWI} = 5V$ $V_{SWO} = 0V$ $V_{ON} = \text{Open}$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWI} (Switch On) $V_{SWI} = 5V$ $V_{SWO} = \text{Open}$ $V_{ON} = 5V$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWO} (DON Off) $V_{SWI} = 0V$ $V_{SWO} = 5V$ $V_{ON} = \text{Open}$ $V_{DON} = \text{Open}$ (μA) $\pm 20\%$		I_{SWO} (DON On) $V_{SWI} = 5V$ $V_{SWO} = 4V$ $V_{ON} = \text{Open}$ $V_{DON} = 5V$ (mA) $\pm 10\%$		I_{DON} (I_{IH}) $V_{SWI} = 5V$ $V_{SWO} = 4V$ $V_{ON} = \text{Open}$ $V_{DON} = 5V$ (μA) $\pm 20\%$	
		Pre	Delta	Pre	Delta	Pre	Delta	Pre	Delta	Pre	Delta
9	6.5	33.5	1%	31.5	0%	8.3	-1%	37.1	0%	1.8	0%
	6.7	33.8	0%	31.4	0%	8.2	0%	37.1	0%	1.8	0%
10	6.5	32.9	0%	30.5	0%	7.9	0%	39.2	-3%	1.7	6%
	6.7	32.9	0%	30.6	0%	7.9	1%	39.2	-1%	1.8	0%
11	6.5	32.9	0%	29.3	0%	8.1	-2%	38.5	0%	1.9	-5%
	6.7	32.8	0%	29.3	0%	7.9	0%	38.4	0%	1.8	0%
12	6.5	33.4	0%	30.2	0%	8.0	1%	38.4	0%	1.8	-6%
	6.7	33.4	0%	30.1	1%	8.1	0%	38.3	0%	1.7	6%

From the testing cited above it was concluded that the ISL70061SEH did not suffer any SEL or any damaging effects (SEB) from irradiation with normal incidence gold (86MeV•cm²/mg) while operating at supply voltages of 6.7V and at case temperature of +125°C.

2. ISL70061SEH Single Event Transient (SET) Testing

The SET testing of the ISL70061SEH was done under four biasing conditions. Testing was done with the supply voltage at both 3.0V and 5.5V to span the operating range. At each voltage the part was tested in the off condition with both ON and DON biased at 0.4V, the maximum voltage for a logic low on those inputs. For the off condition, the output was loaded with only 1k Ω and 1 μF . The parts were also tested in the on condition with both ON and DON at 1.2V, the minimum voltage for a logic high on those inputs. An additional load was imposed with an electronic load at a current consistent with a 1 Ω load, 3.0A at 3.0V, and 5.5A at 5.5V.

During SET testing of the on switch, two kinds of V_{SWO} SET were noted. These types are represented in [Figure 4](#). The small events registered a drop in V_{SWO} of about 1V and then recovered. The large events registered a complete collapse of V_{SWO} followed by a spontaneous restart with the controlled soft turn-on.

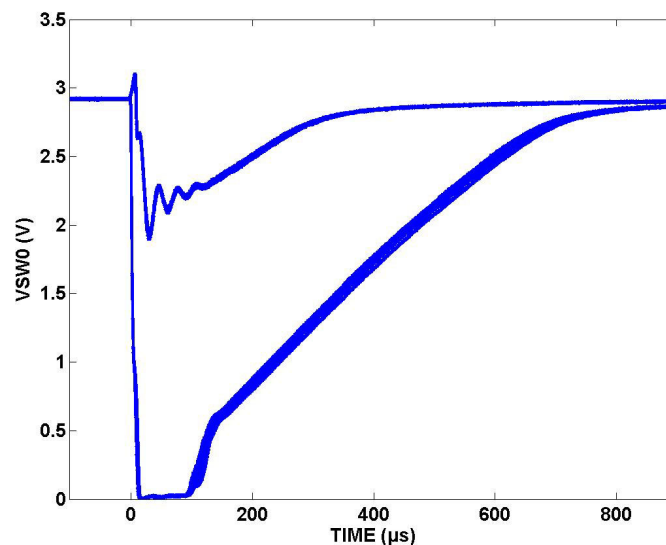


Figure 4. Composite plot of V_{SWO} SET for 16 large and 12 small events (total of 28 SET) recorded for a run of 1×10^7 ions/cm² at normal incidence gold (86MeV•cm²/mg) with $V_{SWI} = 3.0V$ and a load of 1 Ω .

During the SET testing the V_{SWO} of the parts were monitored with oscilloscopes set to trigger and store a trace on a $\pm 1\%$ deviation ($\pm 30\text{mV}$ at 3.0V and $\pm 55\text{mV}$ at 5.5V). Other oscilloscopes were set to trigger and store events when V_{SWO} fell below 0.5V . The two oscilloscopes allowed real time counting of complete shutdown events, and the calculation of small events by the difference in the counts.

The SET counts for irradiation of parts with normal incidence gold ($86\text{MeV}\cdot\text{cm}^2/\text{mg}$) are presented in [Table 4](#). The total counts are for the 1% deviation trigger, so they include the large transient counts. The large counts are only those events that dropped below 0.5V on V_{SWO} . The difference between the counts yields just the small SET count. Therefore, DUT15 at 3.0V yielded the highest small count of 15 events (26-11).

Table 4. SET counts for irradiation with normal gold ($86\text{MeV}\cdot\text{cm}^2/\text{mg}$) to $1\times 10^7\text{ions}/\text{cm}^2$ at $+25^\circ\text{C}$. Total SET counts were captured with a trigger on V_{SWO} deviation of $\pm 30\text{mV}$ for V_{SWI} at 3.0V or $\pm 55\text{mV}$ for V_{SWI} of 5.5V . Large SET counts were captured with a trigger on V_{SWO} falling below 0.5V .

Inputs	V_{SWI}	Load	DUT13		DUT14		DUT15		DUT16	
			Total	Large	Total	Large	Total	Large	Total	Large
0.4V	3.0V	Open	0		0		0		0	
0.4V	5.5V	Open	0		0		0		0	
1.2V	5.5V	5.5A	8	3	8	4	4	2	5	1
1.2V	3.0V	3.0A	13	5	15	8	26	11	26	14

Because there were no off-state SET captured at $86\text{MeV}\cdot\text{cm}^2/\text{mg}$ only the on condition tests were dropped to lower LET levels. The results for the lower LET levels appear in [Tables 5](#) and [6](#).

Table 5. SET counts for irradiation with normal silver ($43\text{MeV}\cdot\text{cm}^2/\text{mg}$) to $1\times 10^7\text{ions}/\text{cm}^2$ at $+25^\circ\text{C}$. Small SET were captured with a trigger on V_{SWO} deviation of $\pm 30\text{mV}$ for V_{SWI} at 3.0V or $\pm 55\text{mV}$ for V_{SWI} of 5.5V . Large SET were captured with a trigger on V_{SWO} falling through 0.5V .

Inputs	V_{SWI}	Load	DUT17		DUT18		DUT19		DUT20	
			Total	Large	Total	Large	Total	Large	Total	Large
1.2V	5.5V	5.5A	8	6	9	2	4	2	4	2
1.2V	3.0V	3.0A	26	13	26	12	11	6	11	5

Table 6. SET counts for irradiation with normal copper ($20\text{MeV}\cdot\text{cm}^2/\text{mg}$) to $1\times 10^7\text{ions}/\text{cm}^2$ at $+25^\circ\text{C}$. Total SET counts were captured with a trigger on V_{SWO} deviation of $\pm 30\text{mV}$ for V_{SWI} at 3.0V or $\pm 55\text{mV}$ for V_{SWI} of 5.5V . Large SET were captured with a trigger on V_{SWO} falling through 0.5V .

Inputs	V_{SWI}	Load	DUT17		DUT18		DUT19		DUT20	
			Total	Large	Total	Large	Total	Large	Total	Large
1.2V	5.5V	5.5A	2	0	2	2	3	1	3	1
1.2V	3.0V	3.0A	9	4	9	5	13	8	13	4

The SET counts for the same fluence of $1\times 10^7\text{ions}/\text{cm}^2$ decreased with reduced flux indicating the events were likely multiple ion events. Flux experiments on two parts are summarized in [Table 7 on page 7](#). The tenfold reduction in flux would be expected to yield at least a tenfold reduction in the SET count of multiple ion events. This is approximately the case for the total SET events with the lower flux yielding 7.0% ($4/57$) of the events at the higher flux. At the lower flux the large events produced 7.1% ($2/28$) of the events at the higher flux. Similarly, the small SET produced lower flux events at 6.9% ($2/29$) compared to the count at the higher flux. The data is consistent with the assertion that the events at the higher flux are the result of multiple ion occurrences.

Table 7. SET counts for irradiation with normal gold (86MeV•cm²/mg) to 1x10⁷ions/cm² at +25°C. V_{SWI} was set to 3.0V and the load was 1Ω and 1μF. Total SET were captured with a trigger on V_{SWO} deviation of ±30mV. Large SET were captured with a trigger on V_{SWO} falling through 0.5V.

Flux (ions/(cm ² •s))	SET Counts for DUT1		SET Counts for DUT2	
	Total	Large	Total	Large
5x10 ⁴	28	16	29	12
5x10 ³	2	0	2	2

Ion shield testing on the FOK material confirmed that the large SET were in fact double ion events. The large events were isolated by shielding one of the redundant Undervoltage Lockout (UVLO) circuits. Shielding just one of these two redundant circuits eliminated the large events entirely. It was concluded that the large events were near simultaneous (to within the SET persistence time) ion strikes on the two redundant UVLO circuits.

Shielding to isolate the residual small SET occurrences was not possible. However, the comparable counts and behavior with flux suggest a multiple ion origin for the residual small SET.

A worst case interpretation of the data is to ascribe all the events captured at the lower flux to single ion events. This puts the maximum small SET cross section at 20μm² as measured at the lower flux and LET of 86MeV•cm²/mg. In earth's orbit, the flux of such high LET ions is so small (about one ion every 4500 years per cm²) that the cross section might as well be zero.

3. Discussion and Conclusions

The ISL70061SEH proved to be immune to SEL and destructive SEE when tested with a supply voltage at 6.7V, at a case temperature of +125°C, and irradiated with normal incidence gold for an LET of 86MeV•cm²/mg to a fluence of 1x10⁷ions/cm². A total of twelve parts were tested, four each under three different biasing circumstances. The first configuration looked specifically for signs of SEL in the operating current of an unloaded part. The second configuration looked at a switching case with a lightly loaded output (1kΩ). The third configuration was a high current case with the output supplying 12A. None of this testing resulted in any sign of SEL or damage in the five monitored currents.

SET testing yielded two forms of SET for the on switch ([Figure 4 on page 5](#)), large and small events. Large events that showed a complete shutdown of the output, were demonstrated by shielding experiments to be double ion events impacting the redundant UVLO circuits. Near simultaneous events in the two UVLO circuits defeat the redundancy and result in a false UVLO condition and a momentary shutdown of the switch. Shielding one of the two redundant UVLO circuits eliminated the larger events. Recovery was spontaneous and immediate. These large events are clearly not single ion events. The small SET where the output drops by about 1V and then recovers exhibited roughly the same statistics and flux dependence as the large events ([Table 7](#)). This implies, but does not conclusively prove, the small events to be double ion events. Interpreting the residual small events at low flux (5x10³ions/(cm²•s)) as valid single ion events yields a very small cross section of 20μm² worst case, or 10μm² average. This makes the chance of such an event in orbit vanishingly small, even if it is a single ion SET.

4. Revision History

Rev.	Date	Description
1.00	Mar.26.19	Initial release

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Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

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