
ISL73148SEH

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 such as 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 [ISL73148SEH](#) product. The ISL73148SEH is offered with radiation assurance screening to 75krad(Si) at 10mrad(Si)/s.

SEE Summary

The ISL73148SEH proved to be free of Destructive Single Event Effects (DSEE) including SEL at supply voltages up to $V_{CC} = 6.4V$, $DV_{CC} = 4.6V$, and $V_{REF} = 3.6V$ with a die temperature of 125°C when irradiated with normal incidence gold for a Linear Energy Transfer (LET) of 86MeV·cm²/mg. **Note:** These voltages are above the operating condition maximum values to provide an additional margin for end applications.

The ISL73148SEH exhibited SET that primarily lasted for a single sample and recovered to normal operation thereafter without any user intervention required indicating the device had no SEFI. The number and magnitude of SET decreased as the LET decreased. No observed SET lasted for longer than two samples and out of all the observed SET during testing, 99.98% were single sample events and 81.92% were less than 100 codes in magnitude. Out of the total number of samples observed during testing, 0.0021% of samples exhibited a SET.

SEE testing was performed on two different test dates with a cumulative dose effect being observed on the first test date. This cumulative dose effect resulted in a reduction in the number of SETs as the effective total dose increased during testing. During all SET testing, the devices were exposed to a total fluence of 2x10⁶ion/cm² and a sufficient number of devices under test (DUTs) were used to keep the cumulative does to under 8.5krad.

Part Description

The ISL73148SEH is a radiation hardened 8-channel high precision 14-bit SAR ADC (analog-to-digital converter) operating up to 900ksps with the integrated PGA bypassed and up to 480ksps with the integrated PGA enabled.

The ADC core is preceded by eight analog input channels followed by a buffered 8-to-1 multiplexer and a PGA (Programmable Gain Amplifier). The device features a peak SNR of 82dBFS when operating at 900ksps. With the PGA enabled, sampling rates up to 480ksps are supported. The PGA may be bypassed to allow the sample rate to be increased to 900ksps.

The product features 900/480ksps throughput with no data latency and features excellent linearity and dynamic accuracy. The ISL73148SEH offers a high-speed SPI-compatible serial interface that supports logic ranging from 2.2V to 3.6V using a separate digital I/O supply pin.

The ISL73148SEH offers a separate low power mode (LPM) pin that reduces power dissipation at lower sample rates. The analog input signal range is determined by an external reference applied to the V_{REF} pin with a supported input range of 2.4V to 2.6V.

The ISL73148SEH operates across the military temperature range from -55°C to +125°C and is available in a 28 Ld hermetically sealed Ceramic Dual Flat-Pack (CDFP) package.

The SEE testing of the ISL73148SEH was completed on two silicon versions. During the first two test sessions in June and August of 2021, Revision A silicon was used. Revision B silicon (released production silicon version)

was used during the third (final) test session in November 2021. Lot information for the first two test sessions was not logged, but in the final test session, three lots were tested: V6C750, V6C751, and V6C752.

Because the production silicon version is Revision B, the results from that silicon version serves as the focus of this report. However, the results from Revision A can be cited as well because the silicon design is similar between the two revisions and the results from the versions provide some information on manufacturing variability. In addition, the SEE results from Revision A were used to guide the test efforts for Revision B.

The samples were packaged without lids to allow irradiation, and only room temperature testing of the parts was done. No burn-in stressing was done on the parts.

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1. SEE Testing

1.1 Objective

The testing was intended to find the limits for the supply voltages set by the onset of Destructive Single Event Effects (DSEE) at a LET of $86\text{MeV}\cdot\text{cm}^2/\text{mg}$ (normal incidence gold). Additional testing was intended to identify and quantify SETs and SEFIs occurring in the output sample codes of the ISL73148SEH. The SET studies included irradiation with normal incidence gold ($86\text{MeV}\cdot\text{cm}^2/\text{mg}$), silver ($43\text{MeV}\cdot\text{cm}^2/\text{mg}$), argon ($8.5\text{MeV}\cdot\text{cm}^2/\text{mg}$), and neon ($2.7\text{MeV}\cdot\text{cm}^2/\text{mg}$).

1.2 Facility

SEE testing was done at the Texas A&M University (TAMU) Radiation Effects Facility of the Cyclotron Institute in College Station Texas. This facility is coupled to a K500 superconducting cyclotron that can supply a wide range of ion species and flux. The testing referred to in this report was performed on June 27, 2021, August 3, 2021, and November 17-18, 2021.

1.3 Setup

The ISL73148SEH was SEE evaluated using a general-purpose engineering evaluation board that allowed various application configurations to be used. The specific configurations changed with the type of testing. For destructive SEE testing (collectively called DSEE herein), the individual supply voltages and analog input were driven directly from an external power supply with currents monitored using an ammeter. For the SET testing, external power supplies supplied $\pm 10\text{V}$ to the evaluation board and the ISL73148SEH supply voltages were generated by onboard LDOs while an onboard amplifier circuit connected to the analog input set the ADC input to midscale. The onboard LDOs kept noise to a minimum and allow for fine resolution of SET detection.

For the DSEE testing, the ADC input clock (CSB) was set to 483.092ksp/s sampling rate with the PGA enabled with a gain of 2, AV_{CC} varied up to 6.5V, DV_{CC} set to 4.6V, and V_{REF} set to 3.6V. The maximum sampling rate (with the PGA enabled) and the maximum voltages were used for AV_{CC} , DV_{CC} , and V_{REF} to achieve the worst-case conditions. The monitored parameters for the ADC are listed in [Table 1](#).

Table 1. Monitored Parameters and Failure Criteria for the ISL73148SEH DSEE Testing

| Parameter Monitored | Failure Criteria |
|--------------------------|------------------|
| AV_{CC} Supply Current | $\pm 10\%$ |
| DV_{CC} Supply Current | $\pm 10\%$ |
| V_{REF} Supply Current | $\pm 10\%$ |

For DSEE testing, the DV_{CC} (4.6V), and V_{REF} (3.6V) input voltages were held constant during both test dates. For all DSEE testing, the AV_{CC} voltage was started at 5.8V and increased in 0.1V steps until DSEE was observed or 6.5V was reached. During all test dates, the sample rate was set to 483.092ksp/s with the PGA enabled.

For SET testing, the ISL73148SEH was tested under five conditions as given in [Table 5](#). The ISL73148SEH has a normal operation mode and a low power operation mode. In each operational mode, the PGA can be enabled or bypassed. For each mode of operation, the order of testing with the PGA enabled or bypassed was reversed from one DUT and/or LET to the next (for example, normal mode with the PGA bypassed followed by normal mode with the PGA enabled followed by normal mode with the PGA bypassed and so on). These configurations result in four possible test modes. The fifth test mode is achieved by enabling the SCAN function of the ISL73148SEH. The SCAN function sequences through the selection of the eight input channels beginning with channel 0 and ending with channel 7. As long as the ISL73148SEH SCAN function is enabled, it sequentially cycles through the selection of channels. When operating in the fifth test mode, the ISL73148SEH is in normal operation mode with the PGA bypassed to achieve the maximum sampling rate. Additional clocks on SDO were provided for the

information bits (info bits). For configurations where the PGA was bypassed, additional clocks were provided only for the channel info bits, but where the PGA was enabled, additional clocks were provided for the channel and gain info bits. For all test dates, the AV_{CC} supply was set to a voltage of 4.5V, the DV_{CC} supply was a voltage of 2.5V, and the V_{REF} input was set to a voltage of 2.5V. The AV_{CC} voltage corresponds to the minimum voltage for the ISL73148SEH. For each given mode, the ISL73148SEH was operated at the maximum sampling rate for that mode.

For all five test configurations, an onboard DAC (digital to analog converter) was used to drive channels 0 and 2 through 7 to independent values across the range of the ISL73148SEH. The onboard amplifier driver circuit was used to provide a DC input of $V_{REF}/2$ to channel 1. In the first four configurations where SCAN is not enabled, channel 1 is the observed channel. For the ISL73148SEH operating with bipolar data format, this means that the expected output code should be approximately 0 (zero scale). All other channels are driven to independent values different than which channel 1 is driven. The input conditions for all eight channels are summarized in [Table 2](#) below.

Table 2. ISL73148SEH Channel Input Voltages and Input Sources for SET Testing

| ADC Channel | Input Voltage (V) | Input Source |
|-------------|-------------------|--------------------|
| 0 | 0.3 | DAC |
| 1 | 1.25 | Amp Driver Circuit |
| 2 | 0.6 | DAC |
| 3 | 0.9 | DAC |
| 4 | 1.5 | DAC |
| 5 | 1.8 | DAC |
| 6 | 2.1 | DAC |
| 7 | 2.4 | DAC |

[Figure 1](#) shows the SET detection threshold that is configured inside the logic analyzer. The threshold window was widened slightly for the ISL73148SEH compared to the ISL73141SEH because of slight shifts observed in the offset during the initial test dates in June 2021. The slight shift in offset was explored and confirmed during the test session in August 2021 to set the appropriate threshold window for the testing that was completed in November 2021. Setting the ADC analog input to channel 1 to a mid-scale value enables the observation of positive and negative excursions in the output codes of the ISL73148SEH. A test run without a beam is performed to find the median output code on a per-part basis, and then a ± 20 code threshold is applied around that value. If the output code of the ADC goes beyond this threshold it is counted as a SET. The ± 20 code threshold was found by operating the ISL73148SEH and observing no output code excursion beyond the threshold with no beam at the TAMU facility. When the test run and calibration exercise are completed for channel 1 as previously described, the other seven channels are also observed to record the output code values. For each operating mode, the median code value for each of the eight channels is logged to a file. The median code for channel 1 is used to set the threshold window while the other seven channels are logged so that they can be used when post processing the SET data. When post processing the SET data for each test run, it can be determined if a SET occurred where the wrong channel was selected. Because the median code value is recorded for each channel, it can be determined if/when a channel was improperly selected. In addition, the channel information bits are monitored during the test and can be used to help determine the channel selection if/when a SET occurs. In the case that a SET occurs resulting in the wrong channel selection, the improperly selected channel can be identified by the value of the output code.

The ISL73148SEH evaluation board contains a CPLD, which takes the serial output data from the ADC and converts it to parallel. This data is input to a logic analyzer where it is observed for any SET. [Figure 1](#) shows the SET detection threshold that is configured inside the logic analyzer (**Note:** the figure shows the threshold for channel 1 of the ISL73148SEH). The ADC input is set to approximately midscale using an amplifier circuit present

on the ISL73148SEH engineering evaluation board driving the ADC analog input. Setting the ADC analog input to a mid-scale value enables the observation of positive and negative excursions in the output codes of the ISL73148SEH. A test run without beam is performed to find the median output code on a per-part basis, and then a ± 20 code threshold is applied around that value. During the calibration run, the median codes from all eight ADC channels are recorded. If the output code of the ADC goes beyond the specified threshold, it is counted as a SET. The ± 20 code threshold was found by operating the ISL73148SEH and observing no output code excursion beyond the threshold with no beam at the TAMU facility. The threshold window was widened slightly for the ISL73148SEH compared to the ISL73141SEH because of slight shifts observed in the offset during the June 2021 and August 2021 test dates.

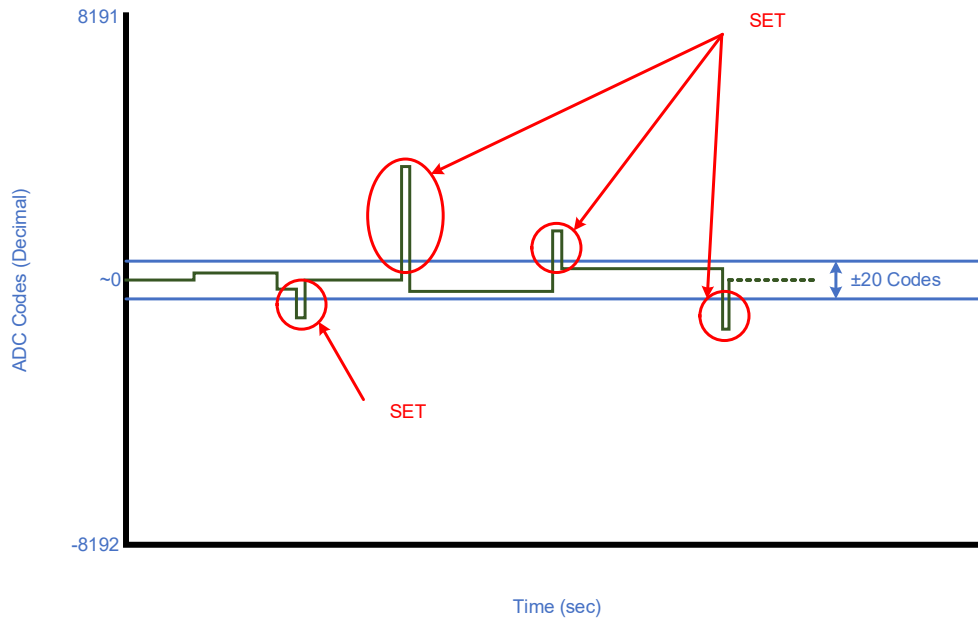


Figure 1. SET Detection Threshold

2. Results

2.1 DSEE Results

DSEE testing of the ISL73148SEH was performed on two parts from Revision A silicon on the June 2021 test date and on four parts from Revision B silicon during the November 2021 test dates.

Figure 2 shows the summary of the DSEE results for the ISL73148SEH Revision A devices tested on the June 2021 test date. One device passed at $AV_{CC} = 6.5V$ and one device failed at $AV_{CC} = 6.5V$ by violating the conditions in Table 1 for AV_{CC} current.

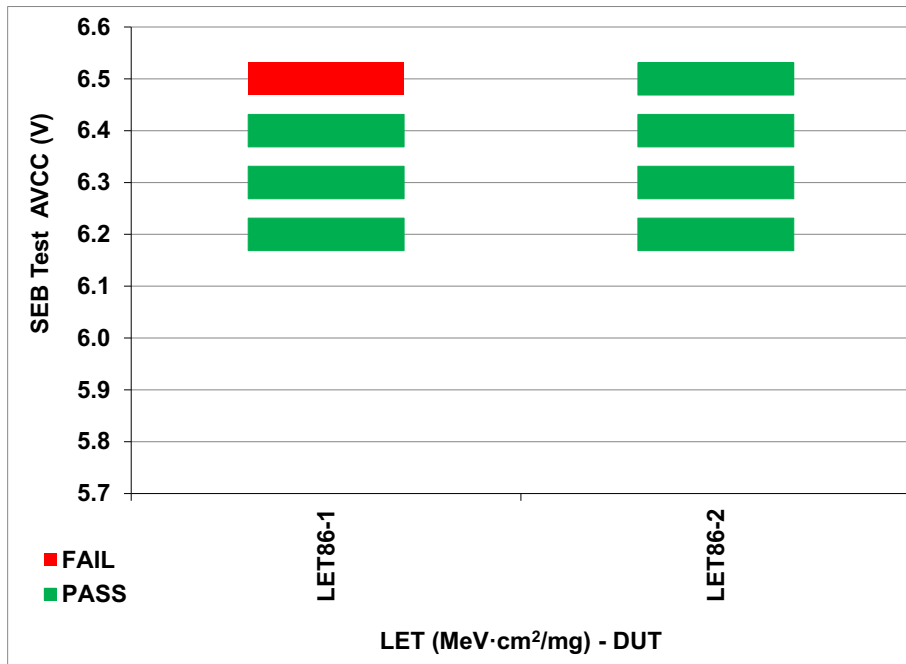


Figure 2. DSEE Testing Pass/Fail Summary - June 2021

Figure 3 shows the summary of the DSEE results for the ISL73148SEH Revision B devices (final released product) tested during the November 2021 test dates. All four devices passed at $AV_{CC} = 6.5V$ and were not tested at a higher supply voltage.

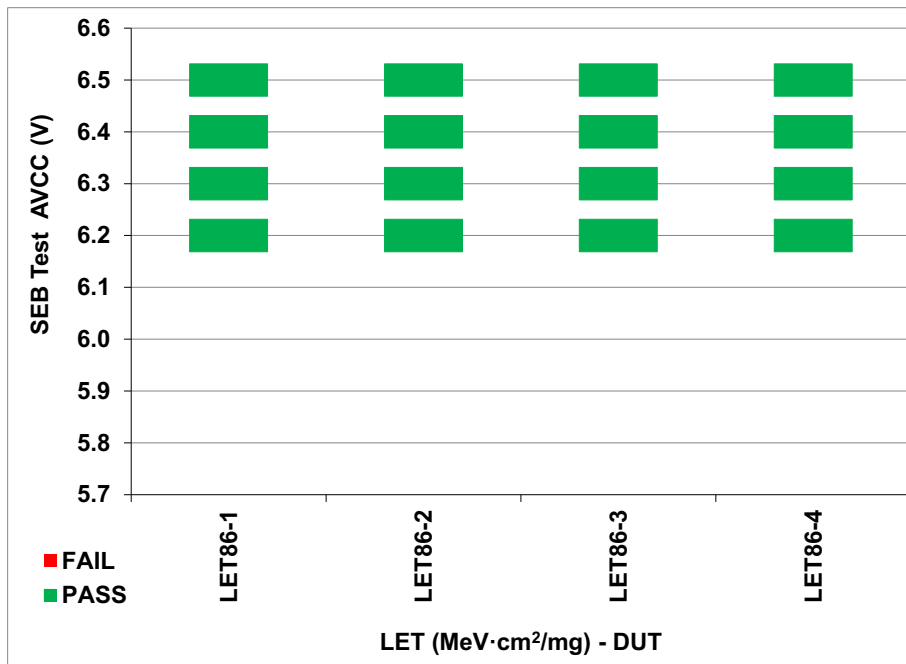


Figure 3. DSEE Testing Pass/Fail Summary - November 2021

DSEE of the ISL73148SEH was tested with normal incidence gold for 86MeV·cm²/mg at a die temperature of 125°C ±10°C with DV_{CC}, and V_{REF}, input voltages held constant at maximum values of 4.6V and 3.6V, respectively. During all test dates, the AV_{CC} voltage was started at 6.2V and increased in 0.1V steps until DSEE was observed or 6.2V was reached. During all test dates, the ISL73148SEH was set to normal operation mode with the PGA bypassed with the sample rate was set to 900ksps. Before, during, and after irradiation three parameters (Table 1) were monitored to look for signs of DSEE. The results of this testing for the ISL73148SEH part are presented for Revision A in Table 3 and Revision B (final) silicon in Table 4. Failures to the criteria in Table 1 are indicated with bold and red text.

Table 3. ISL73148SEH Revision A DSEE Testing Results for Normal Incidence Gold at LET = 86MeV·cm²/mg and 125°C ±10°C Die Temperature - June 2021^[1]

| Type- DUT | AV _{CC} (V) | I _{AVCC} | | | I _{DVCC} | | | I _{REF} | | |
|-----------|----------------------|-------------------|-----------|---------------|-------------------|-----------|-----------|------------------|-----------|-----------|
| | | Pre (mA) | Post (mA) | Delta (%) | Pre (mA) | Post (mA) | Delta (%) | Pre (µA) | Post (µA) | Delta (%) |
| Rev A-1 | 6.2 | 22.123 | 22.129 | 0.03 | 5.137 | 5.137 | 0.00 | 433 | 433 | 0.00 |
| | 6.3 | 22.496 | 22.434 | -0.28 | 4.807 | 4.810 | 0.06 | 436 | 434 | -0.46 |
| | 6.4 | 22.810 | 22.805 | -0.02 | 4.800 | 4.810 | 0.21 | 433 | 433 | 0.00 |
| | 6.5 | 23.191 | 63 | 171.66 | 4.811 | 4.790 | -0.44 | 432 | 436 | 0.93 |
| Rev A-2 | 6.2 | 21.890 | 21.937 | 0.21 | 4.85 | 4.85 | 0.00 | 433 | 433 | 0.00 |
| | 6.3 | 22.298 | 22.275 | -0.10 | 4.85 | 4.85 | 0.00 | 432 | 432 | 0.00 |
| | 6.4 | 22.642 | 22.628 | -0.06 | 4.85 | 4.85 | 0.00 | 431 | 431 | 0.00 |
| | 6.5 | 23.010 | 23.000 | -0.04 | 4.85 | 4.85 | 0.00 | 430 | 430 | 0.00 |

1. Each entry represents change across an irradiation of 5x10⁶ion/cm².

Table 4. ISL73148SEH Revision B DSEE Testing Results for Normal Incidence Gold at LET = 86MeV·cm²/mg and 125°C ±10°C Die Temperature - November 2021^[1]

| Type- DUT | AV _{CC} (V) | I _{AVCC} | | | I _{DVCC} | | | I _{REF} | | |
|-----------|----------------------|-------------------|-----------|-----------|-------------------|-----------|-----------|------------------|-----------|-----------|
| | | Pre (mA) | Post (mA) | Delta (%) | Pre (mA) | Post (mA) | Delta (%) | Pre (µA) | Post (µA) | Delta (%) |
| Rev B-1 | 6.2 | 20.282 | 20.210 | -0.35 | 1.218 | 1.179 | -3.20 | 338.2 | 338.2 | 0.00 |
| | 6.3 | 20.492 | 20.499 | 0.03 | 1.178 | 1.227 | 4.16 | 337.2 | 336.9 | -0.09 |
| | 6.4 | 20.796 | 20.796 | 0.00 | 1.242 | 1.213 | -2.33 | 336.1 | 336.1 | 0.00 |
| | 6.5 | 21.122 | 21.122 | 0.00 | 1.214 | 1.249 | 2.88 | 335.2 | 335.2 | 0.00 |
| Rev B-2 | 6.2 | 20.032 | 20.910 | 4.38 | 1.296 | 1.292 | -0.31 | 334.6 | 334.6 | 0.00 |
| | 6.3 | 20.414 | 20.414 | 0.00 | 1.306 | 1.283 | -1.76 | 333.6 | 333.4 | -0.06 |
| | 6.4 | 20.722 | 20.732 | 0.05 | 1.298 | 1.313 | 1.16 | 332.3 | 332.9 | 0.18 |
| | 6.5 | 21.063 | 21.088 | 0.12 | 1.311 | 1.293 | -1.37 | 331.3 | 331.3 | 0.00 |
| Rev B-3 | 6.2 | 20.278 | 20.259 | -0.09 | 1.201 | 1.246 | 3.75 | 340.6 | 340.6 | 0.00 |
| | 6.3 | 20.533 | 20.532 | 0.00 | 1.245 | 1.246 | 0.08 | 339.6 | 339.5 | -0.03 |
| | 6.4 | 20.831 | 20.861 | 0.14 | 1.247 | 1.256 | 0.72 | 338.6 | 338.8 | 0.06 |
| | 6.5 | 21.172 | 21.229 | 0.27 | 1.264 | 1.243 | -1.66 | 338.1 | 337.6 | -0.15 |

Table 4. ISL73148SEH Revision B DSEE Testing Results for Normal Incidence Gold at LET = 86MeV·cm²/mg and 125°C ±10°C Die Temperature - November 2021^[1] (Cont.)

| Type- DUT | AV _{CC} (V) | I _{AVCC} | | | I _{DVCC} | | | I _{REF} | | |
|-----------|----------------------|-------------------|-----------|-----------|-------------------|-----------|-----------|------------------|-----------|-----------|
| | | Pre (mA) | Post (mA) | Delta (%) | Pre (mA) | Post (mA) | Delta (%) | Pre (μA) | Post (μA) | Delta (%) |
| Rev B-4 | 6.2 | 20.086 | 20.075 | -0.05 | 1.221 | 1.199 | -1.80 | 338.7 | 338.6 | -0.03 |
| | 6.3 | 20.352 | 20.378 | 0.13 | 1.197 | 1.222 | 2.09 | 337.6 | 337.6 | 0.00 |
| | 6.4 | 20.667 | 20.676 | 0.04 | 1.212 | 1.221 | 0.74 | 336.5 | 336.4 | -0.03 |
| | 6.5 | 20.988 | 21.905 | 4.37 | 1.221 | 1.212 | -0.74 | 335.6 | 335.8 | -0.06 |

1. Each entry represents change across an irradiation of 5x10⁶ion/cm².

2.2 SET Results

Single event transient testing was performed on the ISL73148SEH under the conditions listed in [Table 5](#). The sequence in which these conditions were implemented was in alternating style from one DUT to the next in the order of 1-2, then 2-1 for normal mode tests and 3-4, then 4-3 for low power mode tests. Test condition #5 was specifically implemented to verify the channel sequencer of the ISL73148SEH, which is enabled by asserting the SCAN pin and was treated separately from modes 1 through 4. In SCAN mode, the ISL73148SEH sequences through all eight channels from 0 to 7 in repeating order. The alternating order of the tests in normal and low power modes was implemented to detect any potential dependency on cumulative dose effects. The sample rate of the ISL73148SEH changes depending on the operating mode and the state of the PGA. When the PGA is enabled for an additional 1μs of sampling time and when operating in low power mode, the CSB pulse width must be increased from the 150ns minimum in normal mode to 500ns. The sample rate for each operational mode is shown in [Table 5](#). To detect any potential AV_{CC} voltage-related or sample rate-related issues, the ISL73148SEH was tested at the minimum analog supply voltage of AV_{CC} = 4.5V.

Table 5. ISL73148SEH SET Test Conditions

| | Test Condition #1 | Test Condition #2 | Test Condition #3 | Test Condition #4 | Test Condition #5 |
|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| AV _{CC} | 4.5V | 4.5V | 4.5V | 4.5V | 4.5V |
| DV _{CC} | 2.5V | 2.5V | 2.5V | 2.5V | 2.5V |
| V _{REF} | 3.6V | 3.6V | 3.6V | 3.6V | 3.6V |
| Operating Mode | Normal | Normal | Low Power | Low Power | Normal |
| PGA Mode | Enabled | Bypassed | Enabled | Bypassed | Bypassed |
| SCAN | Disabled | Disabled | Disabled | Disabled | Enabled |
| Sample Rate | 462.963ksps | 900.091ksps | 393.701ksps | 684.932ksps | 900.091ksps |

SET cross-sections were produced for each of these conditions. The results from previous testing with the ISL73141SEH indicated a cumulative dose effect on the SET events when the total dose began to exceed 8.88krad. Therefore, during all SET testing performed in the June 2021, August 2021, and November 2021 test sessions, the cumulative dose was limited to less than 8.5krad to ensure a maximum number of observable SET.

The values shown in [Table 6](#) represent the maximum amount of cumulative dose seen by any device for each given test condition.

Table 6. ISL73148SEH Maximum Cumulative Dose During SET Testing

| Test Condition | LET = 2.7MeV·cm ² /mg (krad) | LET = 8.6MeV·cm ² /mg (krad) | LET = 43MeV·cm ² /mg (krad) | LET = 86MeV·cm ² /mg (krad) |
|----------------|--|--|---|---|
| | November 2021 | November 2021 | November 2021 | November 2021 |
| 1 | 3.469 | 3.296 | 2.752 | 5.504 |
| 2 | 3.671 | 3.598 | 2.958 | 5.504 |
| 3 | 3.469 | 3.296 | 2.752 | 5.504 |
| 4 | 3.469 | 3.296 | 2.752 | 8.256 |
| 5 | 4.486 | 4.400 | 4.128 | 2.752 |

The cross-sections from the November 2021 test dates are shown in [Figure 4](#), [Figure 5](#), [Figure 6](#), [Figure 7](#), [Figure 8](#), and [Figure 9](#). The cross-sections show a range of saturation values from $3.50 \times 10^2 \text{ ion}/\mu\text{m}^2$ to $4.86 \times 10^5 \text{ ion}/\mu\text{m}^2$. These cross-sections correspond to all five of the test conditions. For test condition #5, there are two cross-sections plotted. One cross-section ([Figure 8](#)) for test condition #5 is for data errors indicating that the data on the reported channel has violated the ± 20 code threshold for the expected value on that channel. Recall that each channel has a specific input value applied to result in a particular output code. The other cross-section for test condition #5 is for info bit errors ([Figure 9](#)). The operational mode in test condition #5 is very similar to test condition #2 in terms of operating mode with the major difference being the enabling of the SCAN mode for test condition #5. Therefore, the cross-section plots show similar behavior between these modes. This illustrates that not only the number of SET are similar because of the similar operational mode, but also that the number of SET is independent of channel selection.

The implementation of the test was slightly different for test condition #5 compared to the other four test conditions. Unlike test conditions #1 through #4, the ADC data was not observed using a logic analyzer for test condition #5. Instead, all ADC sample data was collected and stored in memory during the radiation exposure. The stored data was subsequently post-processed using software on a PC using an algorithm similar to what is illustrated in [Figure 1](#). In this case, however, the median code for each channel was input to the software on the PC where the ± 20 code threshold around each median code value was applied to determine if a SET was present. In addition, this software performed a check on the info bits to determine if a SET had occurred with respect to the sequencing of the ADC channels. It was found that while SET occurred in the info bits, all of the SETs were a single sample where the info bits reported a different channel than was expected in the sequence. After such a SET occurred, the following sample indicated the next correct channel in the sequence. For example, a sequence with a SET in the info bits might look like this: 0-1-2-6-4-5-6-7. This shows that the info bits were out of sequence for one sample, but that the overall sequence would still rotate through all eight channels correctly outside of the one sample where the info bits were incorrect. The cross-section plot for the info bits shows a very low number of this type of SET because there were very few of these SET observed. The data was analyzed to find SET, where the info bits and channel data were in error, and out of all the SET, observed that there were only five occurrences using gold ions (86MeV·cm²/mg) and four occurrences using silver ions (43MeV·cm²/mg) where there was both an info bit SET and simultaneously an ADC data SET.

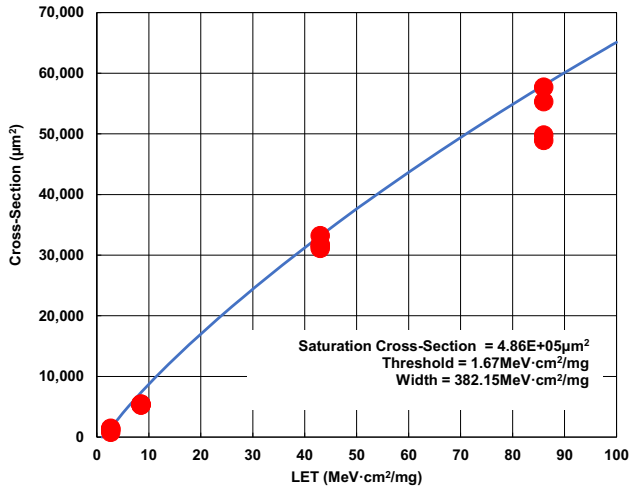


Figure 4. SET Cross-Section Test Condition #1

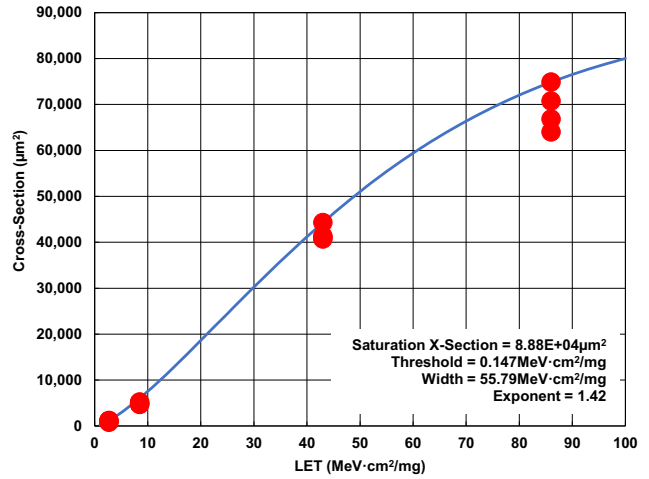


Figure 5. SET Cross-Section Test Condition #2

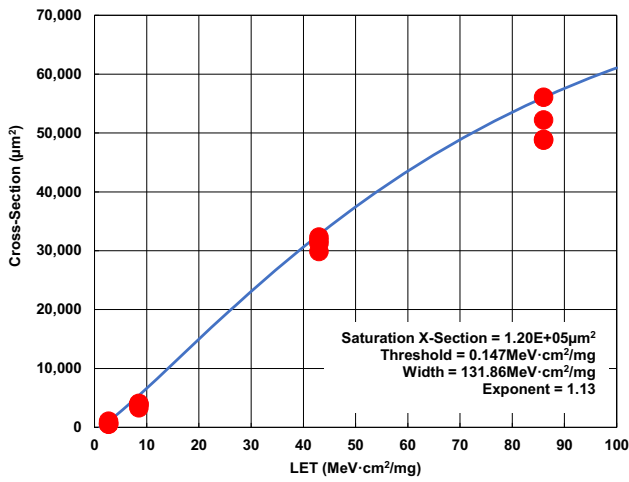


Figure 6. SET Cross-Section Test Condition #3

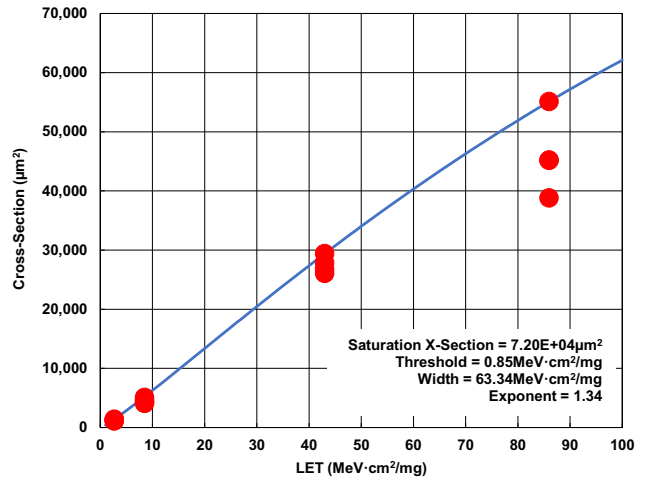


Figure 7. SET Cross-Section Test Condition #4

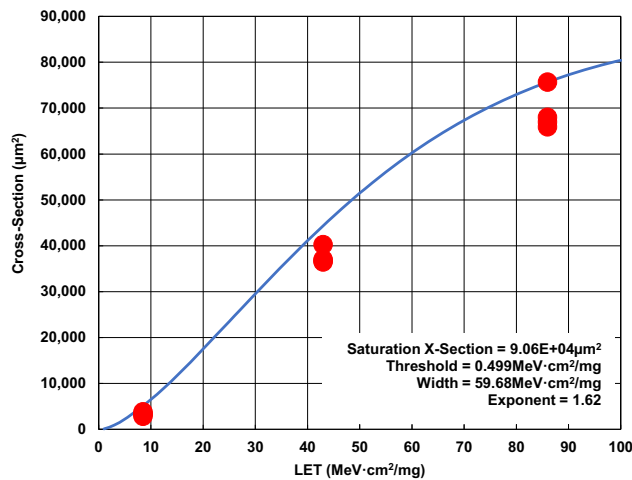


Figure 8. SET Cross-Section Test Condition #5 - Data

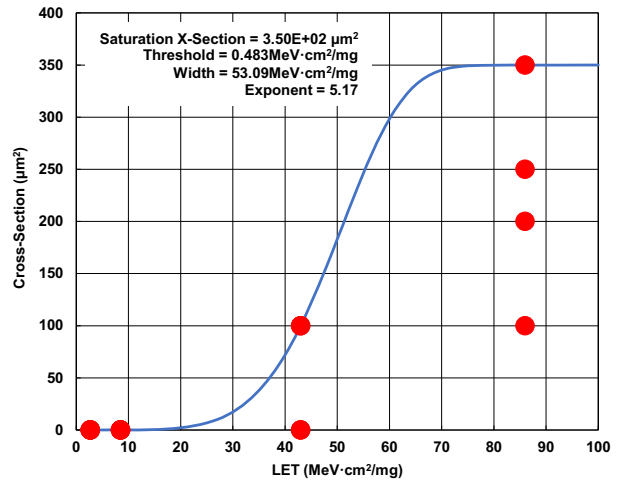


Figure 9. SET Cross-Section Test Condition #5 - Info Bits

The test data indicates that a majority of SET exhibited by the ISL73148SEH were under 100 codes in magnitude and lasted for a single sample. In fact, no SET observed lasted longer than two consecutive samples. The results show that out of all SET observed across all LET values that 81.93% were less than 100 codes in magnitude and 99.98% lasted for a single sample. The SET lasting two consecutive samples only occurred with LET values of 86MeV·cm²/mg and 43MeV·cm²/mg. There were no consecutive sample SETs observed at a LET value of 8.5MeV·cm²/mg and 2.7MeV·cm²/mg.

Figure 10, Figure 11, Figure 12, and Figure 13 show the magnitude versus time of a typical set of SET test runs at a LET of 2.7MeV·cm²/mg under test conditions #1 through #4. As can be seen, the delta between the expected code and the actual code for each SET is generally less than 64 codes. A typical set of SET test runs at a LET of 86MeV·cm²/mg is shown in Figure 14, Figure 15, Figure 16, and Figure 17. At this LET, there are a few SET that are near positive and negative full scale, but the majority are within 128 codes of the expected value near mid-scale. No SEFIs were observed and the ADC returned to the expected code value range after every SET at all LET values that were tested.

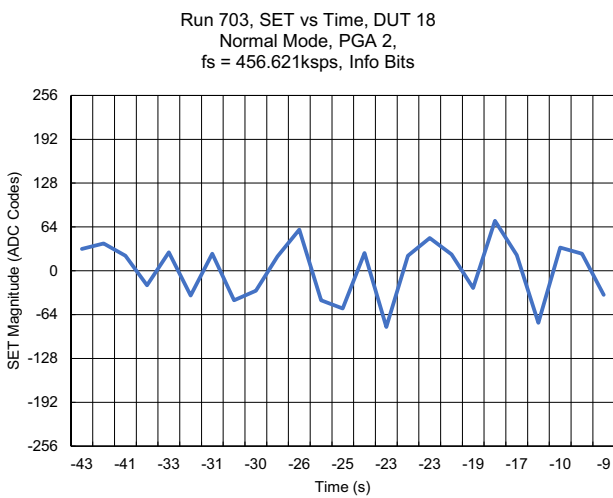


Figure 10. SET at LET = 2.7, Test Condition #1: Normal Mode, PGA Gain = 2

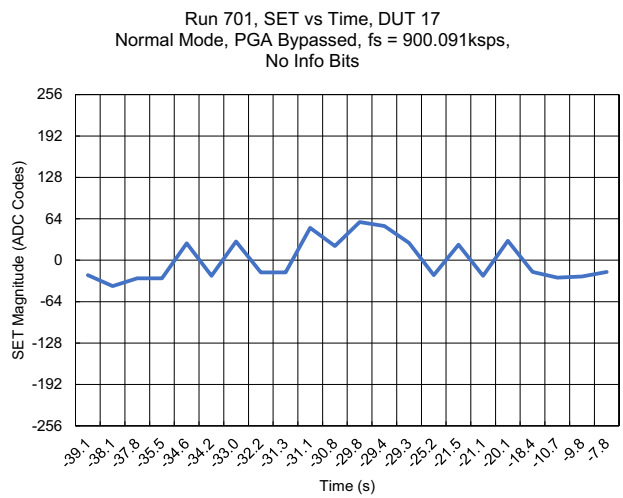


Figure 11. SET at LET = 2.7, Test Condition #2: Normal Mode, PGA Bypassed

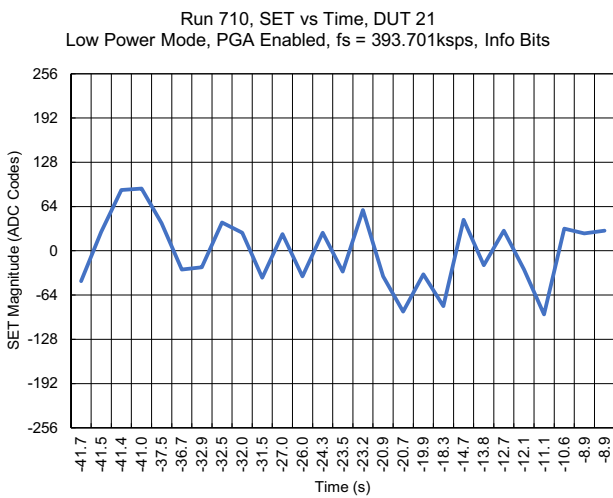


Figure 12. SET at LET = 2.7, Test Condition #3: Low Power Mode, PGA Gain = 2

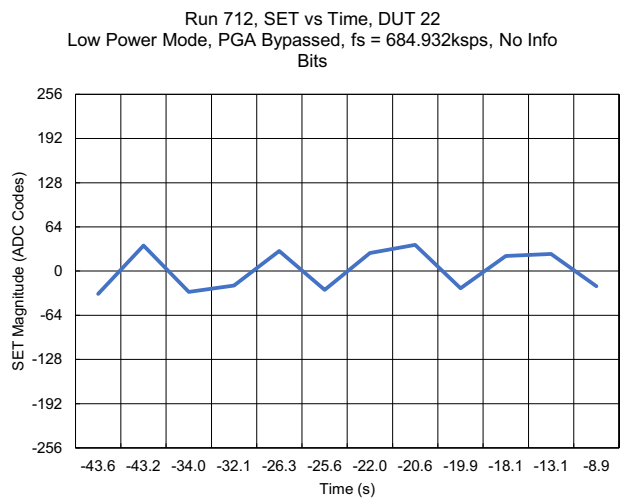


Figure 13. SET at LET = 2.7, Test Condition #4: Low Power Mode, PGA Bypassed

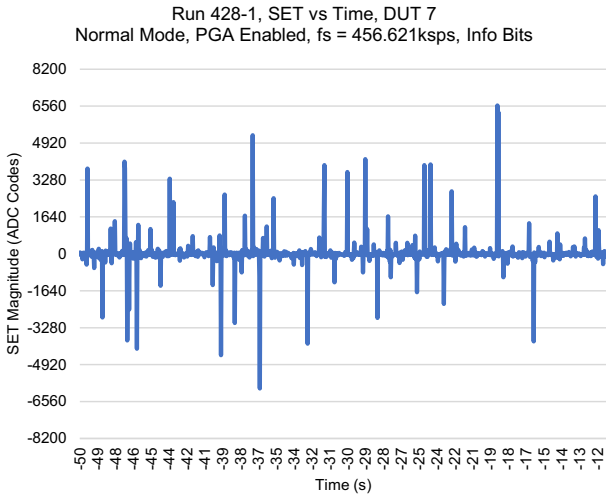


Figure 14. SET at LET = 86, Test Condition #1: Normal Mode, PGA Gain = 2

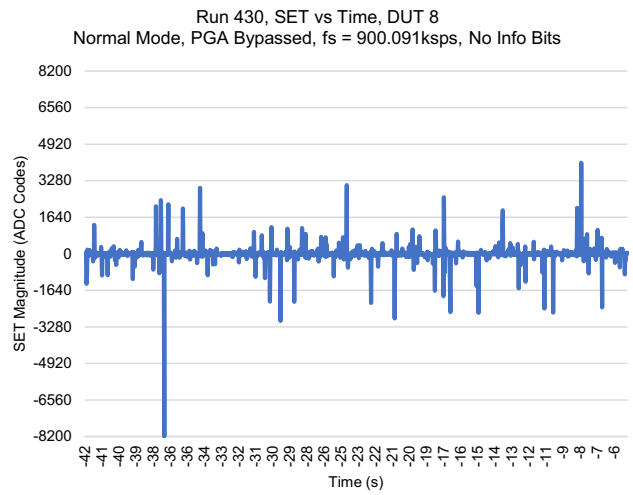


Figure 15. SET at LET = 86, Test Condition #2, Normal Mode, PGA Bypassed

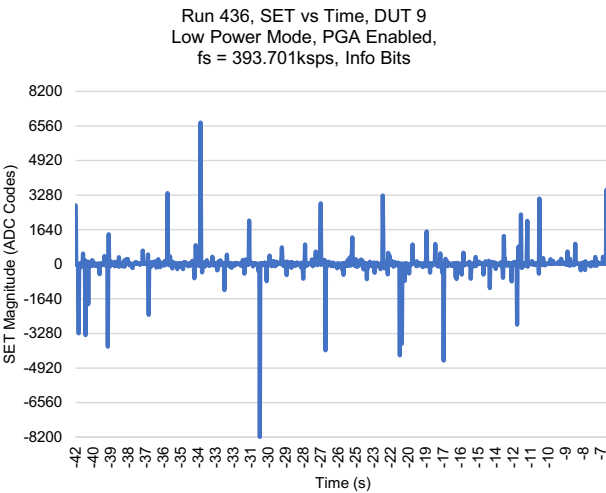


Figure 16. SET at LET = 86, Test Condition #3: Low Power Mode, PGA Gain = 2

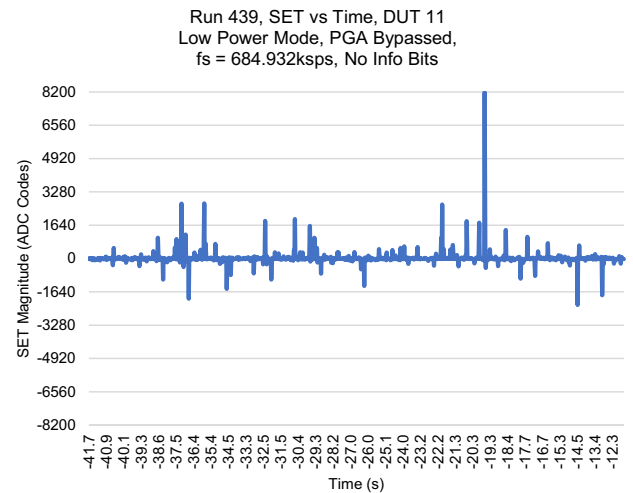


Figure 17. SET at LET = 86, Test Condition #4: Low Power Mode, PGA Bypassed

For the SET test runs shown in Figure 10 through Figure 17, a set of histograms were generated and are shown in Figure 18 through Figure 25. Even at the highest LET of 86MeV·cm²/mg most of the SET are within 128 codes or less of the expected value. The expected code value is in the range of code 0 (mid-scale value) so the max deviation should be less than 8500 codes even if the SET excursion is to either positive or negative full scale. The histogram plots show that distribution of the SET code deltas is reasonably Gaussian and primarily concentrated close to the expected mid-scale value.

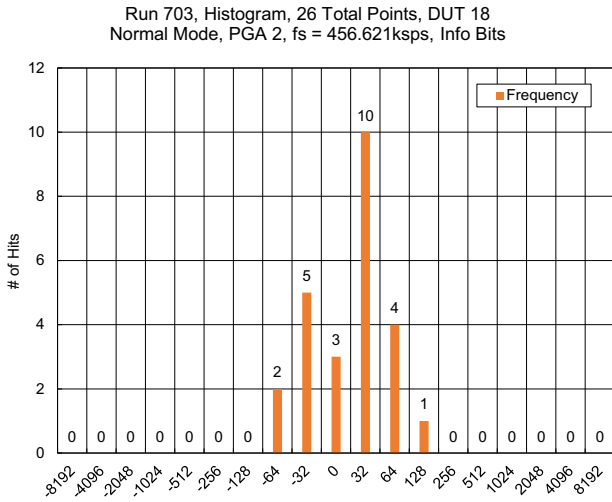


Figure 18. Histogram at LET = 2.7, Test Condition #1:
Normal Mode, PGA Gain = 2

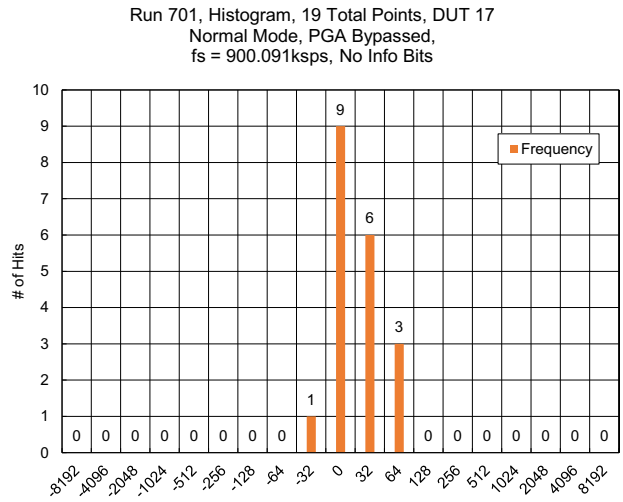


Figure 19. Histogram at LET = 2.7, Test Condition #2:
Normal Mode, PGA Bypassed

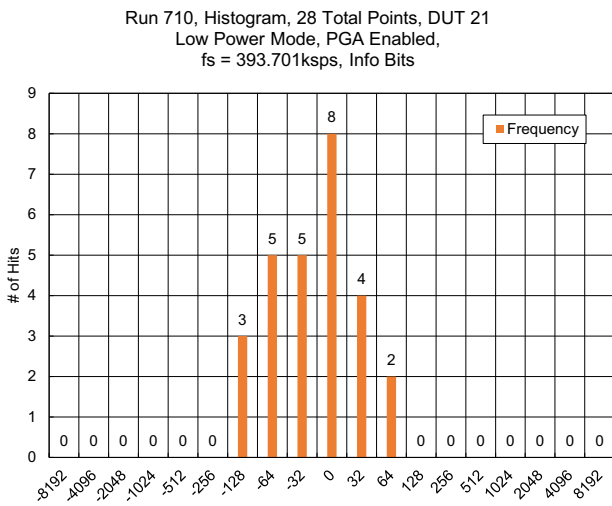


Figure 20. Histogram at LET = 2.7, Test Condition #3:
Low Power Mode, PGA Gain = 2

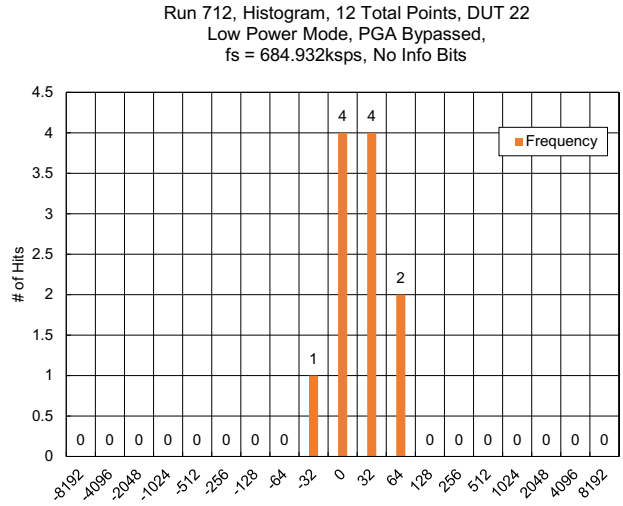
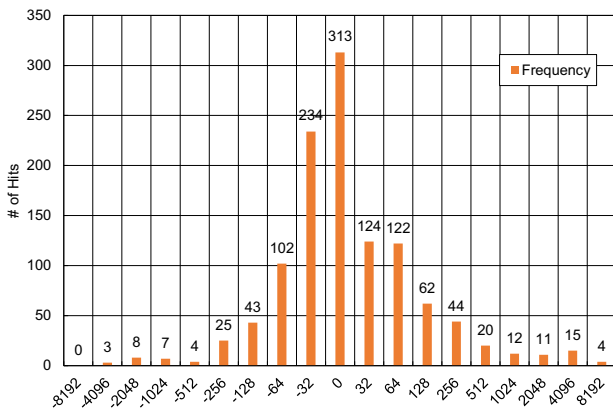


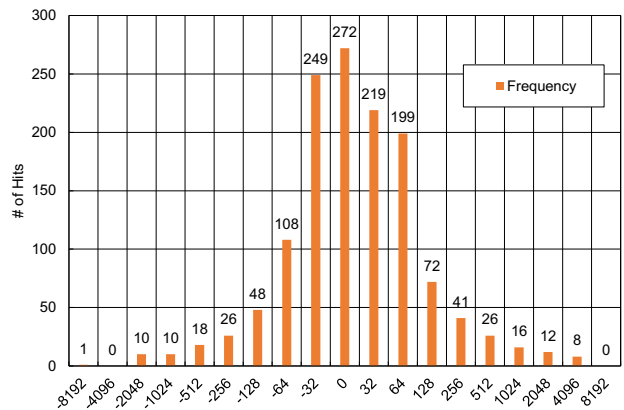
Figure 21. Histogram at LET = 2.7, Test Condition #4:
Low Power Mode, PGA Bypassed

Run 428-1, Histogram, 1154 Total Points, DUT 7
Normal Mode, PGA Enabled,
fs = 456.621ksps, Info Bits



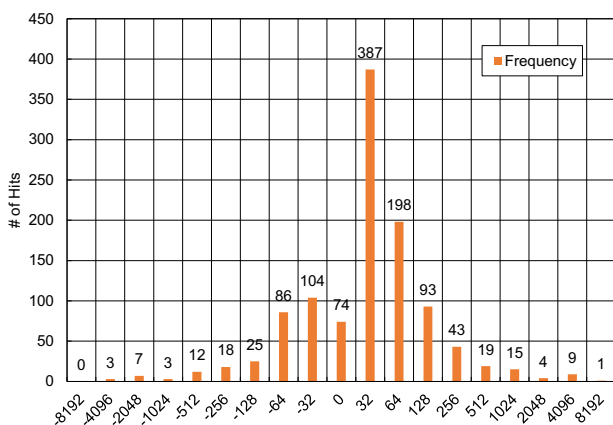
**Figure 22. Histogram at LET = 86, Test Configuration #1:
Normal Mode, PGA Gain = 2**

Run 430, Histogram, 1336 Total Points, DUT 8
Normal Mode, PGA Bypassed,
fs = 900.091ksps, No Info Bits



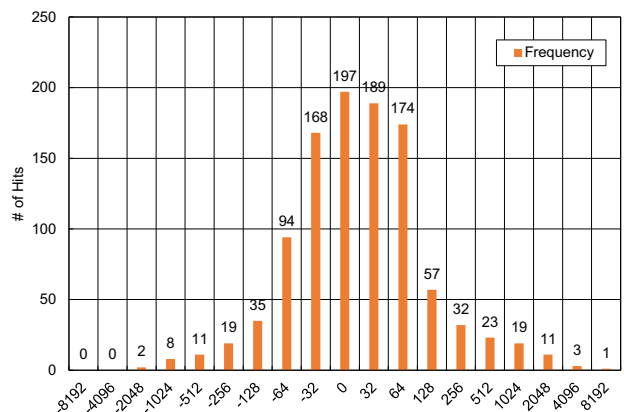
**Figure 23. Histogram at LET = 86, Test Configuration #2:
Normal Mode, PGA Bypassed**

Run 436, Histogram, 1102 Total Points, DUT 9
Low Power Mode, PGA Enabled,
fs = 393.701ksps, Info Bits



**Figure 24. Histogram at LET = 86, Test Configuration #3:
Low Power Mode, PGA Gain = 2**

Run 439, Histogram, 1044 Total Points, DUT 11
Low Power Mode, PGA Bypassed,
fs = 684.932ksps, No Info Bits



**Figure 25. Histogram at LET = 86, Test Configuration #4:
Low Power Mode, PGA Bypassed**

All SET test runs from the final qualification testing in November 2021 are given in [Table 7](#). Information is provided on the test conditions including DUT number, test number, LET, sample rate, operating mode, PGA condition, SCAN mode, total fluence, and approximate TID (total ionizing dose). The test results are given in terms of total SET, two consecutive sample SET, percentage of SET less than 100 codes in magnitude, and percentage of single sample SET.

During all testing dates for the ISL73148SEH, the total fluence was limited to 2×10^6 for all test runs. The ISL73148SEH devices were tested with a range of LET values from $86 \text{ MeV} \cdot \text{cm}^2/\text{mg}$ (gold) down to $2.7 \text{ MeV} \cdot \text{cm}^2/\text{mg}$ (neon) including $8.5 \text{ MeV} \cdot \text{cm}^2/\text{mg}$ (argon) and $43 \text{ MeV} \cdot \text{cm}^2/\text{mg}$ (silver) all at normal incidence. By keeping the total fluence low during the test, the cumulative dose was maintained below 8.88krad, allowing for a higher number of SETs to be observed. Because previous results showed that the SET decreased with a higher cumulative dose, keeping the exposure of each DUT limited allows for the highest number of SET to be observed. This resulted in a condition where a worst-case cross-section of SET could be achieved. Overall, the data shows that the number of SETs decrease as the LET decreases. In addition, the average magnitude of the SET observed stays relatively small (less than 128 LSB deviation) across all LET even at the highest LET tested at

ISL73148SEH SEE Test Report

86MeV·cm²/mg. The ISL73148SEH returned to normal operation after every SET observed and no SEFIs were observed during any test run.

Table 7. ISL73148SEH Revision B SET Testing Results - November 2021

| Run | DUT | LET (cm ² /mg) | Sample Rate (ksps) | Operating Mode | PGA ^[1] | Info Bits ^[1] | SCAN | Approx. TID (krad) | Total SET | 2 Sample SET | % SET <100 Codes | % SET Single Sample |
|-------|-----|---------------------------|--------------------|----------------|--------------------|--------------------------|------|--------------------|-----------|--------------|------------------|---------------------|
| 427 | 7 | 86 | 900.091 | Normal | By. | Dis. | No | 2.752 | 1415 | 0 | 82.12 | 100.00 |
| 428-1 | 7 | 86 | 462.963 | Normal | EN | EN | No | 5.504 | 1154 | 0 | 77.99 | 100.00 |
| 429 | 8 | 86 | 462.963 | Normal | EN | Dis. | No | 2.752 | 1106 | 0 | 79.11 | 100.00 |
| 430 | 8 | 86 | 900.091 | Normal | Dis. | Dis. | No | 5.504 | 1336 | 0 | 80.39 | 100.00 |
| 431 | 28 | 86 | 900.091 | Normal | By. | Dis. | No | 2.752 | 1497 | 0 | 81.03 | 100.00 |
| 432 | 28 | 86 | 462.963 | Normal | EN | EN | No | 5.504 | 978 | 1 | 70.76 | 99.90 |
| 433 | 29 | 86 | 462.963 | Normal | EN | EN | No | 2.752 | 996 | 0 | 76.31 | 100.00 |
| 434 | 29 | 86 | 900.091 | Normal | By. | Dis. | No | 5.504 | 1280 | 0 | 83.20 | 100.00 |
| 435 | 9 | 86 | 684.932 | LPM | By. | Dis. | No | 2.752 | 1121 | 0 | 84.66 | 100.00 |
| 436 | 9 | 86 | 393.701 | LPM | EN | EN | No | 5.504 | 1102 | 0 | 79.67 | 100.00 |
| 437 | 10 | 86 | 393.701 | LPM | EN | EN | No | 2.752 | 904 | 0 | 79.54 | 100.00 |
| 438 | 10 | 86 | 684.932 | LPM | By. | Dis. | No | 5.504 | 975 | 0 | 84.00 | 100.00 |
| 439 | 11 | 86 | 684.932 | LPM | By. | Dis. | No | 2.752 | 1044 | 0 | 81.51 | 100.00 |
| 440 | 11 | 86 | 393.701 | LPM | EN | EN | No | 5.504 | 903 | 2 | 78.18 | 99.78 |
| 441-1 | 12 | 86 | 393.701 | LPM | EN | EN | No | 5.504 | 776 | 1 | 58.76 | 99.87 |
| 442 | 12 | 86 | 684.932 | LPM | By. | Dis. | No | 8.256 | 978 | 1 | 78.83 | 99.90 |
| 443 | 13 | 86 | 900.091 | Normal | By. | EN | Yes | 2.752 | 1339 | - | 84.62 | - |
| 444 | 14 | 86 | 900.091 | Normal | By. | EN | Yes | 2.752 | 1318 | - | 83.31 | - |
| 445 | 15 | 86 | 900.091 | Normal | By. | EN | Yes | 2.752 | 1513 | - | 82.68 | - |
| 446-1 | 27 | 86 | 900.091 | Normal | By. | EN | Yes | 2.752 | 1360 | - | 82.06 | - |
| 301 | 17 | 43 | 900.091 | Normal | By. | Dis. | No | 1.376 | 886 | 1 | 84.65 | 99.89 |
| 302 | 17 | 43 | 462.963 | Normal | EN | EN | No | 2.752 | 622 | 0 | 76.53 | 100.00 |
| 303 | 18 | 43 | 462.963 | Normal | EN | EN | No | 1.376 | 664 | 0 | 82.83 | 100.00 |
| 304-1 | 18 | 43 | 900.091 | Normal | By. | Dis. | No | 2.958 | 814 | 0 | 88.08 | 100.00 |
| 305 | 19 | 43 | 900.091 | Normal | By. | Dis. | No | 1.376 | 822 | 0 | 86.74 | 100.00 |
| 306 | 19 | 43 | 462.963 | Normal | EN | EN | No | 2.752 | 630 | 0 | 80.63 | 100.00 |
| 307 | 20 | 43 | 462.963 | Normal | EN | EN | No | 1.376 | 635 | 1 | 80.63 | 99.84 |
| 308-1 | 20 | 43 | 900.091 | Normal | By. | Dis. | No | 2.958 | 826 | 0 | 87.05 | 100.00 |
| 309 | 21 | 43 | 684.932 | LPM | By. | Dis. | No | 1.376 | 597 | 0 | 87.10 | 100.00 |
| 310 | 21 | 43 | 393.701 | LPM | EN | EN | No | 2.752 | 557 | 0 | 81.33 | 100.00 |
| 311 | 22 | 43 | 393.701 | LPM | EN | EN | No | 1.376 | 588 | 0 | 81.97 | 100.00 |
| 312 | 22 | 43 | 684.932 | LPM | By. | Dis. | No | 2.752 | 624 | 0 | 84.13 | 100.00 |
| 313 | 23 | 43 | 684.932 | LPM | By. | Dis. | No | 1.376 | 646 | 0 | 89.16 | 100.00 |

Table 7. ISL73148SEH Revision B SET Testing Results - November 2021 (Cont.)

| Run | DUT | LET (cm ² /mg) | Sample Rate (ksps) | Operating Mode | PGA ^[1] | Info Bits ^[1] | SCAN | Approx. TID (krad) | Total SET | 2 Sample SET | % SET <100 Codes | % SET Single Sample |
|-------|-----|------------------------------|--------------------------|-------------------|--------------------|-----------------------------|------|--------------------------|--------------|--------------------|---------------------------|------------------------------|
| 314 | 23 | 43 | 393.701 | LPM | EN | EN | No | 2.752 | 535 | 0 | 78.13 | 100.00 |
| 315 | 24 | 43 | 393.701 | LPM | EN | EN | No | 1.376 | 521 | 0 | 81.96 | 100.00 |
| 316 | 24 | 43 | 684.932 | LPM | Byp. | Dis. | No | 2.752 | 635 | 0 | 86.30 | 100.00 |
| 317 | 13 | 43 | 900.091 | Normal | Byp. | EN | Yes | 4.128 | 729 | - | 85.87 | - |
| 318 | 14 | 43 | 900.091 | Normal | Byp. | EN | Yes | 4.128 | 735 | - | 81.63 | - |
| 319 | 15 | 43 | 900.091 | Normal | Byp. | EN | Yes | 4.128 | 805 | - | 87.20 | - |
| 320 | 27 | 43 | 900.091 | Normal | Byp. | EN | Yes | 4.128 | 741 | - | 85.70 | - |
| 101 | 17 | 8.6 | 900.091 | Normal | Byp. | Dis. | No | 3.024 | 99 | 0 | 90.91 | 100.00 |
| 102 | 17 | 8.6 | 462.963 | Normal | EN | EN | No | 3.296 | 105 | 0 | 80.00 | 100.00 |
| 103 | 18 | 8.6 | 462.963 | Normal | EN | EN | No | 1.854 | 107 | 0 | 83.18 | 100.00 |
| 104 | 18 | 8.6 | 900.091 | Normal | Byp. | Dis. | No | 2.126 | 104 | 0 | 90.38 | 100.00 |
| 105 | 19 | 8.6 | 900.091 | Normal | Byp. | Dis. | No | 3.024 | 93 | 0 | 94.62 | 100.00 |
| 106 | 19 | 8.6 | 462.963 | Normal | EN | EN | No | 3.296 | 109 | 0 | 82.57 | 100.00 |
| 107-1 | 20 | 8.6 | 462.963 | Normal | EN | EN | No | 3.230 | 107 | 0 | 73.83 | 100.00 |
| 108-1 | 20 | 8.6 | 900.091 | Normal | Byp. | Dis. | No | 3.598 | 95 | 0 | 92.63 | 100.00 |
| 109 | 21 | 8.6 | 684.932 | LPM | Byp. | Dis. | No | 3.024 | 77 | 0 | 92.21 | 100.00 |
| 110 | 21 | 8.6 | 393.701 | LPM | EN | EN | No | 3.296 | 92 | 0 | 81.52 | 100.00 |
| 111 | 22 | 8.6 | 393.701 | LPM | EN | EN | No | 3.024 | 87 | 0 | 79.31 | 100.00 |
| 112 | 22 | 8.6 | 684.932 | LPM | Byp. | Dis. | No | 3.296 | 66 | 0 | 89.39 | 100.00 |
| 113 | 23 | 8.6 | 684.932 | LPM | Byp. | Dis. | No | 3.024 | 81 | 0 | 91.36 | 100.00 |
| 114 | 23 | 8.6 | 393.701 | LPM | EN | EN | No | 3.296 | 81 | 0 | 81.48 | 100.00 |
| 115 | 24 | 8.6 | 393.701 | LPM | EN | EN | No | 3.024 | 102 | 0 | 84.31 | 100.00 |
| 116 | 24 | 8.6 | 684.932 | LPM | Byp. | Dis. | No | 3.296 | 78 | 0 | 91.03 | 100.00 |
| 117 | 13 | 8.6 | 900.091 | Normal | Byp. | EN | Yes | 4.4 | 65 | - | 96.92 | - |
| 118 | 14 | 8.6 | 900.091 | Normal | Byp. | EN | Yes | 4.4 | 56 | - | 91.07 | - |
| 119 | 15 | 8.6 | 900.091 | Normal | Byp. | EN | Yes | 4.4 | 76 | - | 93.42 | - |
| 120 | 27 | 8.6 | 900.091 | Normal | Byp. | EN | Yes | 4.4 | 67 | - | 91.04 | - |
| 701 | 17 | 2.7 | 900.091 | Normal | Byp. | Dis. | No | 3.382 | 23 | 0 | 82.61 | 100.00 |
| 702 | 17 | 2.7 | 462.963 | Normal | EN | EN | No | 3.469 | 16 | 0 | 87.50 | 100.00 |
| 703 | 18 | 2.7 | 462.963 | Normal | EN | EN | No | 2.213 | 26 | 0 | 100.00 | 100.00 |
| 704 | 18 | 2.7 | 900.091 | Normal | Byp. | Dis. | No | 2.299 | 19 | 0 | 100.00 | 100.00 |
| 705 | 19 | 2.7 | 900.091 | Normal | Byp. | Dis. | No | 3.382 | 24 | 0 | 100.00 | 100.00 |
| 706 | 19 | 2.7 | 462.963 | Normal | EN | EN | No | 3.469 | 29 | 0 | 82.76 | 100.00 |
| 707 | 20 | 2.7 | 462.963 | Normal | EN | EN | No | 3.412 | 24 | 0 | 95.83 | 100.00 |
| 7082 | 20 | 2.7 | 900.091 | Normal | Byp. | Dis. | No | 3.671 | 20 | 0 | 100.00 | 100.00 |

Table 7. ISL73148SEH Revision B SET Testing Results - November 2021 (Cont.)

| Run | DUT | LET (cm ² /mg) | Sample Rate (kpsps) | Operating Mode | PGA ^[1] | Info Bits ^[1] | SCAN | Approx. TID (krad) | Total SET | 2 Sample SET | % SET <100 Codes | % SET Single Sample |
|-----|-----|---------------------------|---------------------|----------------|--------------------|--------------------------|------|--------------------|-----------|--------------|------------------|---------------------|
| 709 | 21 | 2.7 | 684.932 | LPM | By. | Dis. | No | 3.382 | 21 | 0 | 100.00 | 100.00 |
| 710 | 21 | 2.7 | 393.701 | LPM | EN | EN | No | 3.469 | 28 | 0 | 92.86 | 100.00 |
| 711 | 22 | 2.7 | 393.701 | LPM | EN | EN | No | 3.382 | 24 | 0 | 91.67 | 100.00 |
| 712 | 22 | 2.7 | 684.932 | LPM | By. | Dis. | No | 3.469 | 12 | 0 | 100.00 | 100.00 |
| 713 | 23 | 2.7 | 684.932 | LPM | By. | Dis. | No | 3.382 | 12 | 0 | 100.00 | 100.00 |
| 714 | 23 | 2.7 | 393.701 | LPM | EN | EN | No | 3.469 | 26 | 0 | 80.77 | 100.00 |
| 715 | 24 | 2.7 | 393.701 | LPM | EN | EN | No | 3.382 | 22 | 0 | 100.00 | 100.00 |
| 716 | 24 | 2.7 | 684.932 | LPM | By. | Dis. | No | 3.469 | 10 | 0 | 100.00 | 100.00 |
| 717 | 13 | 2.7 | 900.091 | Normal | By. | EN | Yes | 4.486 | - | - | - | - |
| 718 | 14 | 2.7 | 900.091 | Normal | By. | EN | Yes | 4.486 | - | - | - | - |
| 719 | 15 | 2.7 | 900.091 | Normal | By. | EN | Yes | 4.486 | - | - | - | - |
| 720 | 27 | 2.7 | 900.091 | Normal | By. | EN | Yes | 4.486 | - | - | - | - |

1. EN = Enabled, Byp. = Bypassed, and Dis. = Disabled.

3. SET Mitigation Options

The ISL73148SEH experiences SET when exposed to irradiation. These SET are low in magnitude on average with most below 128 LSBs of deviation from the expected value. Overwhelmingly most SET last for a single sample with less than 10 observed SET lasting for two consecutive samples. No observed SET lasted longer than two consecutive samples. To mitigate these events, some possible options are presented in this report.

One option is to collect a large number of samples (such as 10000 or larger) and average the samples collected to reduce the effects of a SET within those samples. Averaging a large number of samples lowers the impact of any SET that may be present in the collected data. The application would dictate the number of samples required to reduce the effects and a potential SET below any appreciable system-level effect.

In an application where a known range of values are expected, a second option is to discount a set of samples if the sample(s) within a given acquisition of data is outside a defined window. This method is similar to the detection of SET presented herein. In this case, if samples are collected outside the expected range, it is disregarded and another acquisition of data occurs. In the unlikely event that repeated data acquisitions show a SET then another option can be used.

In this third option, a combination of the first two options is a potential solution. This option collects a large number of samples (such as 10000) and throws away any sample beyond an application based threshold window, and averages the remaining samples. If a set of sample data is collected with an expected value of 8200 and an expected range of 8150 to 8250, any code outside of this range is thrown out while the remaining samples are recorded.

4. Discussion and Conclusions

The ISL73148SEH proved to be DSEE immune up to an AV_{CC} supply voltage of 6.4V for irradiation with normal incidence Au for $86\text{MeV}\cdot\text{cm}^2/\text{mg}$. The testing was completed with a die temperature of $125^\circ\text{C} \pm 10^\circ\text{C}$. A DSEE event was only observed on one DUT at $AV_{CC} = 6.5\text{V}$ during the June 2021 testing where the AV_{CC} domain experienced a destructive latch-up with the current on AV_{CC} increasing by 171.66%. During the November 2021 testing, no DSEE events were observed on either of the four DUTs up to $AV_{CC} = 6.5\text{V}$. This results in a maximum allowable AV_{CC} voltage of 6.4V.

The ISL73148SEH exhibited no SEFIs and had mostly single sample low magnitude SETs. A cumulative dose effect exists with the device that results in a reduction of the number of SETs as the total ionizing dose increases above 8.88krad. The saturation cross-sections ranged from $3.50 \times 10^2 \text{ion}/\mu\text{m}^2$ to $4.86 \times 10^5 \text{ion}/\mu\text{m}^2$. The highest saturation cross-section was for test condition #1 where the ISL73148SEH was operated in normal mode with the PGA gain set to a value of 2. The next highest cross-section was for test condition #3, which was similar to test condition #1 and had the PGA gain set to a value of 2 with the operating mode in low power mode. The saturation cross-section values were also similar between test conditions #2 and #5 where the PGA was bypassed in both cases and the difference was in the operating mode, normal versus low power. The saturation cross-section for data errors in test condition #5 was nearly identical to that of test condition #2, which indicates that the channel sequencer has little to no impact at all on the SET. Finally, the lowest saturation cross-section was for the info bit SET in test condition #5. This shows that few SETs were observed with the channel sequencer operation.

Only a small number of SETs lasting two consecutive samples were observed with most lasting for a single sample and none lasting longer than two consecutive samples. The SET remains at a relatively low average magnitude up to a LET of $86\text{MeV}\cdot\text{cm}^2/\text{mg}$ (less than 128 LSBs deviation). The data shows out of all SET observed 81.93% were less than 128 codes in magnitude and 99.92% lasted for a single sample. The SET data exhibits that the ISL73148SEH does not experience large magnitude SET on average and that when a SET occurs, the device recovers after one sample the majority of the time with no event lasting longer than two consecutive samples. In addition, no device SEFIs were observed. Overall, the SEE data illustrates the ISL73148SEH is well-suited for space applications offering robust DSEE performance and SET with minimal impact to the end application.

5. Revision History

| Rev. | Date | Description |
|------|--------------|---|
| 1.01 | Sep 19, 2022 | Changed radiation tolerant to radiation hardened throughout the document. |
| 1.00 | Jun 22, 2022 | initial release |

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