ISL72813SEH

Single-Event Effects (SEE) Testing

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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 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 ISL72813SEH product.

Product Description

The ISL72813SEH is a radiation hardened, high-voltage, high-current switch array fabricated using Intersil's proprietary complementary bipolar PR40 silicon-on-insulator process. This device integrates 32 switches that feature a 42V breakdown voltage. The maximum current rating for each switch is 530mA.

To reduce solution size and increase system density, the ISL72813SEH integrates a 5-bit to 32-line decoder (plus enable pin). This conveniently selects 1 of the 32 available switch channels. Level shifting circuitry allows reference of the output switch to a common negative voltage, V_{EE}. The inputs to the decoder are TTL/CMOS compatible.

The ISL72813SEH operates across the military temperature range from -55°C to +125°C and is available in a 44 Ld hermetically sealed Ceramic Lead-Less Chip Carrier (CLCC) package.

Two versions of the ISL72813SEH part, B01 and B02, were tested for SEB. These versions differed in that B01 had a 5Ω resistor in series with the GND pin, while B02 did not have the resistor. It was thought that the resistor might provide some incremental improvement in the protection for the VCC GND ESD clamp when the GND VEE clamp was triggered in an SEE event. Based on initial SEB results the B02 was selected as the production version and only it was tested for SET.

Related Literature

- For a full list of related documents, visit our website
  - ISL72813SEH product page

Test Objective

The testing was intended to find the limits of the V_{CC} and V_{EE} supply voltages for avoiding destructive Single-Event Burnout (SEB) at a Linear Energy Transfer (LET) of 86MeV•cm^2/mg. In addition, testing was carried out to look for significant Single-Event Transients (SET) impacting the switch channel activity at LET of 86MeV•cm^2/mg and 28MeV•cm^2/mg.

Test Facility

Single-event effects 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 which is capable of supplying a wide range of ion species and flux. The testing referred to here was done on June 25, 2016, August 27, 2016, and November 2, 2016.

Test Set-Up

The schematic for Single-Event Effects (SEE) testing is shown in Figure 1 on page 2. The ISL72813SEH samples tested were from lot X7C0J, wafer 04 (version B01) and wafer 09 (version B02).

For damaging single events (SEB) testing, the V_{CC} supply was set to 6.5V and the V_{EE} supply was set to the test voltage in the range of -32V to -38V. During damaging single-event testing R_{31} was 1kΩ. With the part disabled (EN = GND), the leakage currents into V_{CXX} (GND) and V_{C0} (GND) were measured along with the I_{CC} supply current. In the disabled state, all 32 switches are in the OFF condition. Then, the part was enabled (EN = V_{CC} to address Channel 0, C0) and a supply of 250mA was placed on V_{C0} and the voltage at V_{C0} was measured. This latter configuration was maintained during the irradiation. After the irradiation, the measurements were repeated and the resulting changes critiqued for indication of damage to the part.

For Single-Event Transient (SET) testing the irradiation configuration described above for SEB was used with V_{CC} = 4.5V and V_{EE} = -34V and V_{CXX} = GND. The voltages at V_{C31} = V_{OFF} (nominally GND) and V_{C0} = V_{ON} (nominally V_{EE}) were monitored with an oscilloscope adjusted to capture events on transients of ±2V on V_{OFF}. For SET, R_{31} was 100Ω to provide more insight into the current involved in the SET events.

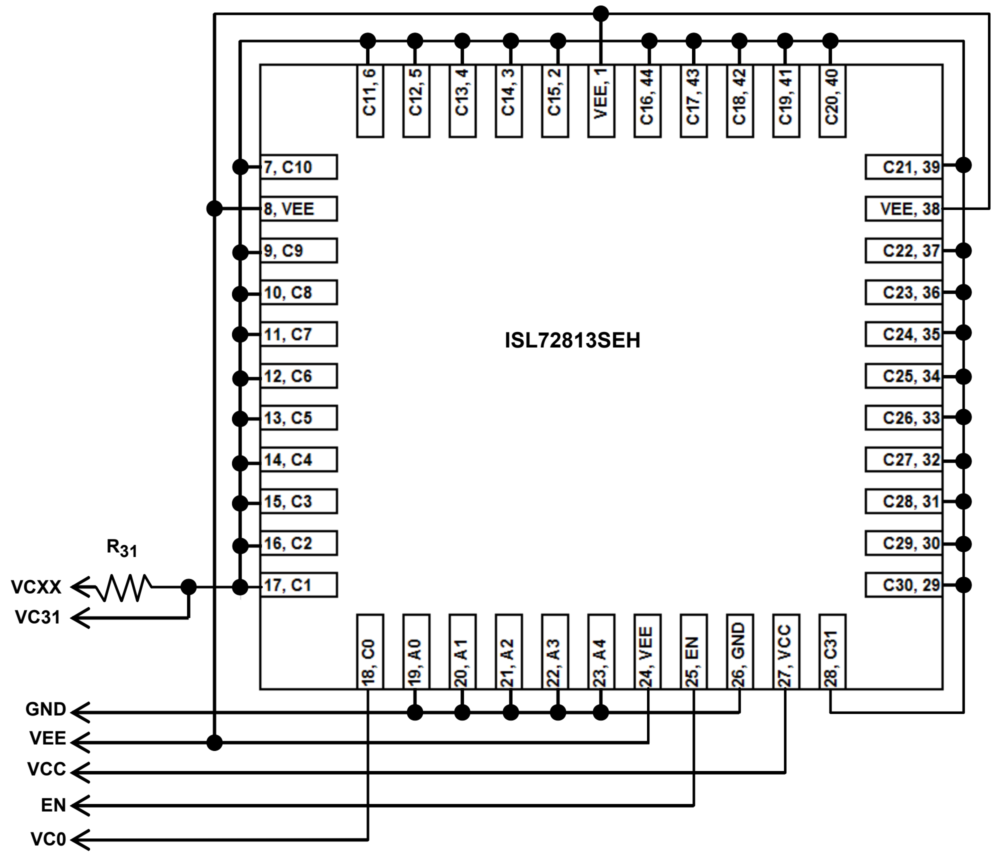

FIGURE 1. SCHEMATIC OF THE SEE TESTING ARRANGEMENT FOR THE ISL72813SEH

SEB Testing Results at 86MeV • cm^2/mg

Five B01 parts were tested for Single-Event Burnout (SEB) failures with V_{CC} = 6.5V and +125°C case temperature. Single-Event Latch-Up (SEL) was not an explicit consideration since the parts are manufactured in a dielectrically isolated process. Four parameters were monitored before and after irradiation: V_{C0} at 250mA, I_{CC} disabled, I_{C0} disabled, and I_{C31} (sum of current on all non-addressed channels) disabled. Any significant change in these parameters was taken as proof of SEB. Limits of ±25% change in the leakage currents were used to critique changes, while limits of 10% in the V_{C0} measurements were applied. The irradiations were carried out with gold for LET = 86MeV • cm^2/mg to 1x10^{7}ion/cm^2. The parts had Channel C0 enabled with 250mA of current during irradiation. The V_{EE} was varied to establish a failing voltage.

The first part, of B01 version, was started at V_{EE} = -34V, and it failed there. The next two parts passed at -37V and -35V respectively, failing at the next 1V increments in V_{EE}. The fourth part was tested up to -35V and it passed to that level. The fifth part passed through -34V but failed at -35V, though the failure was marginal with I_{C31} dropping from 75nA to 26nA. The common failure mode for the other parts was a catastrophic increase in the I_{C31} leakage current.

TABLE 1. SEB TESTING RESULTS FOR B01 VERSION WITH LET = 86MeV • cm^2/mg, +125°C CASE TEMPERATURE, AND V_{CC} = 6.5V. CHANNEL C0 WAS CONDUCTING 250mA DURING IRRADIATION.

V_{EE}	B01 DUT4	B01 DUT3	B01 DUT1	B01 DUT2	B01 DUT6
-33			PASS	PASS	PASS
-34	FAIL	PASS	PASS	PASS	PASS
-35		PASS	PASS	PASS	FAIL
-36		PASS	FAIL		
-37		PASS			
-38		FAIL			

Four B02 parts were tested for SEB with the same methodology as used for the B01 version. As mentioned previously the B02 version differs from the B01 version in that a 5Ω resistor in series with the GND pin present on the B01 part is shorted out on the B02 version. The first B02 part passed at V_{EE} = -35V. It then failed while out of beam during the V_{EE} change to -36V and so testing couldn't continue. The next two parts passed at -36V and failed at -37V. The final part passed at -34V and failed at -35V.

TABLE 2. SEB TESTING RESULTS FOR B02 VERSION WITH LET = 86MeV•cm^2/mg, +125°C CASE TEMPERATURE, AND V_{CC} = 6.5V. CHANNEL C0 WAS CONDUCTING 250mA DURING IRRADIATION.

V_{EE}	B02 DUT1	B02 DUT2	B02 DUT3	B02 DUT5
-34	PASS	PASS	PASS	PASS
-35	PASS	PASS	PASS	FAIL
-36	N/A	PASS	PASS	
-37		FAIL	FAIL	
-38				

The SEB testing results support the conclusion that the two versions of the ISL72813SEH are essentially equivalent for SEB and can survive irradiation with LET = 86MeV•cm^2/mg ions at a bias of V_{CC} = 6.5V and V_{EE} = -33V with a case temperature of +125°C.

Testing Results for SET on 31 OFF Channels

The SET testing done August 27, 2016 consisted of monitoring V_{C31} with all 31 of the OFF channels in parallel with R_{31} equal to 100Ω. Channel C0 was enabled and unloaded (open circuit). The nominal voltage without SET was 0V for V_{C31}. An oscilloscope monitored V_{C31}, and the oscilloscope was triggered on V_{C31} at -2V deviation. Testing for SET was done on the B02 version of the die, though it is expected that the two versions should have identical SET behavior, since the only difference is the 5Ω resistor in series with the GND pin on the B01 version. The B02 version has been selected as the production version on the basis of the marginally better SEB results. The parts were at ambient temperature (~+25°C) during the SET testing. Each part was run with gold ions for LET = 86MeV•cm^2/mg to 1x10^{6}ion/cm^2 at a flux of approximately 1x10^{4}ion/(cm^2-s). The summary of the event counts appears in Table 3. The only V_{C0} transients noted were small magnitude and coincided with a V_{C31} SET event indicating that they were noise from the larger V_{C31} SET.

TABLE 3. V_{C31} SET EVENT COUNTS FOR 31 OFF CHANNELS TRIGGERING AT V_{C31} < -2V WITH 100Ω R_{31} FOR 86MeV•cm^2/mg IN 1x10^{6}ion/cm^2 AT APPROXIMATELY 1x10^{4}ion/(cm^2-s).

V_{C31} SET COUNT AT -2V AND 100Ω			
DUT1	DUT2	DUT3	DUT4
3629	2810	2900	4123

The high counts and variability in the SET counts (from 2810 to 4123) appear to be the result of the flux being too high and did not allow capture of all the events that occurred during the irradiation time due to the capture time of the oscilloscope traces. Further testing at a lower flux and with only a single OFF channel monitored was suggested and was carried out October 31, 2016 and November 2, 2016 to establish cross section estimates and is reported later in this report.

The captured and stored V_{C31} SET traces were post processed using MATLAB routines to accomplish the following analysis. The V_{C31} SET magnitudes broke into essentially two major groupings with a small background distribution as shown in Figure 2 on page 4. One grouping constituting approximately 72% of the SET captures was in the range of 2V to 6V. The second grouping consisted of approximately 21% of the SET captures and represented SET magnitudes of 33V and more. The SET magnitudes achieving the 34V magnitude calculate to 340mA of SET current, while the 2V to 6V calculate to events on the order of 40mA. The -2V trigger threshold indicates at least 20mA of SET current.

The large number of captures did provide worst case events that were relatively rare. DUT4 provided the most peculiar of the events as depicted in Figure 3 on page 4. There is a temptation to consider the SET of Figure 3 as a multiple ion (4) event. However, the fact that there were ten SET captures that were essentially identical to Figure 3, argues for a single ion event and some device oscillation mechanism. In addition, for DUT4, there were five events with only three repetitions and two events with only two repetitions. This all points to a real single-event phenomenon. There was a smattering of clearly multiple ion events, but the timing between the events was random and generally the pairs were of different magnitudes and durations. DUT2 had three double pulse events that looked as the DUT4 events. DUT1 and DUT3 did not exhibit the multiple pulse events.

Just to provide another example of the 4-pulse events on DUT4, Figure 4 on page 5 shows such an event with some subtle difference from Figure 3. The last two false recovery times mimic the last false recovery time of Figure 3. This again brings home the improbability that the two events in question are actually the result of multiple ion strikes.

Further evidence against the multiple ion interpretation of Figures 3 and 4 is provided by Figure 5 on page 5. The three pulses in this latest figure look to be like the first, third, and fourth pulses in Figure 4. The regularly timed pulses and the rate of occurrence with fewer pulses (ten 4-pulse events, five 3-pulse events, and three 2-pulse events) make a multiple ion explanation very hard to support.

The majority of the large duration V_{OFF} SET are represented by the example of Figure 6 on page 6. For the single-pulse events such as in Figure 6 the duration is several microseconds. However, these events having such durations are actually rare. The rarity of these events is demonstrated in Figure 7 on page 6, which demonstrates that the majority of events are less than 1µs in duration and only rare events are at durations above 5µs. All the events beyond 10µs are from DUT4 and represent the multiple pulse events represented in Figures 3 through 5.

Another way to look at the V_{OFF} SET population is presented in Figure 8 on page 7. In this case, the V_{OFF} SET duration (V_{OFF} <-2V) is plotted against the SET magnitude. This loses some of the frequency clarity of the histograms of Figures 2 and 7, but it makes clearer the general correlation between duration and magnitude. The knee at the low magnitude end of Figure 8 accounts for most of the events with duration less than 1µs and correlate to the LESS bin in Figure 7. The knee at the high magnitudes in Figure 8 correlates to the bins of 1-5µs in Figure 7.

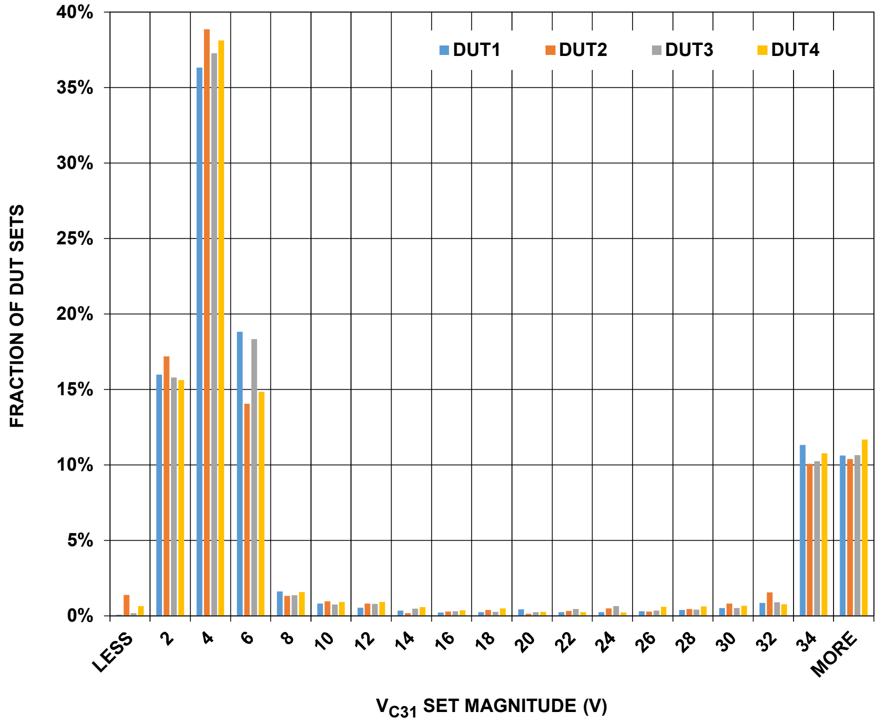

FIGURE 2. HISTOGRAM OF THE FRACTION OF DUT V_{C31} SET BY MAGNITUDE (>2V) WHEN IRRADIATED TO $1x10^6 ion/cm^2$ WITH $86MeV \cdot cm^2/mg$ GOLD IONS AND WITH R_{31} AT 100Ω.

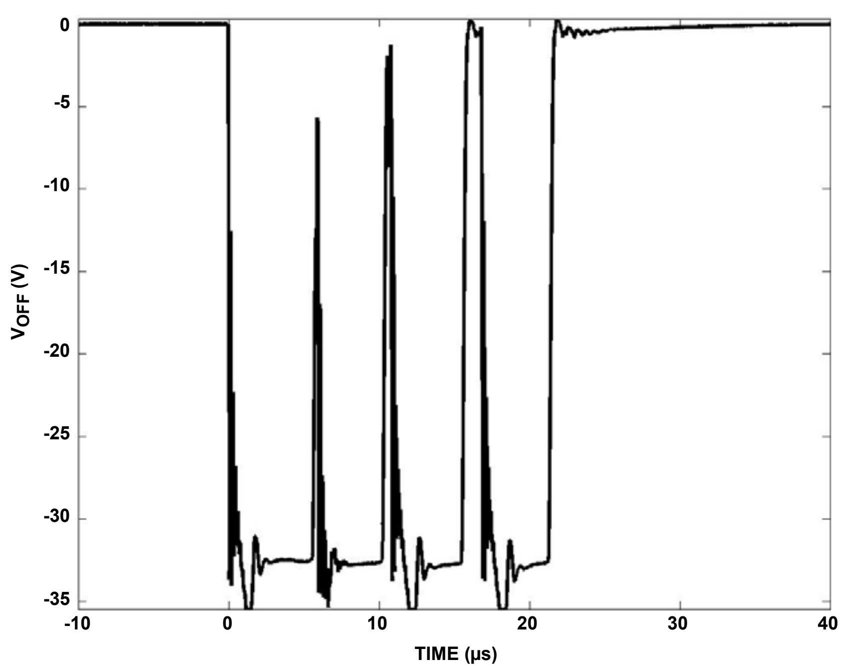

FIGURE 3. WORST CASE EXAMPLE FOR V_{C31} SET FROM DUT4 WHEN IRRADIATED TO $1x10^6 ion/cm^2$ WITH $86MeV \cdot cm^2/mg$ GOLD IONS AND WITH R_{31} AT 100Ω. $V_{OFF} = V_{C31}$.

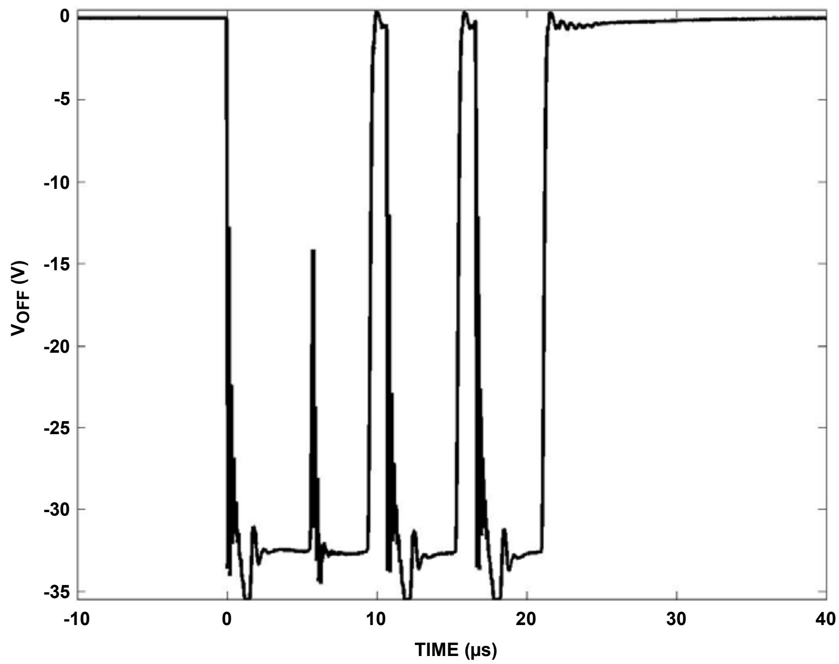

FIGURE 4. ANOTHER 4-PULSE EVENT FROM DUT4 WHEN IRRADIATED TO $1x10^6$ion/cm^2 WITH 86MeV • cm^2/mg GOLD IONS AND WITH R_{31} AT 100Ω. $V_{OFF} = V_{C31}$.

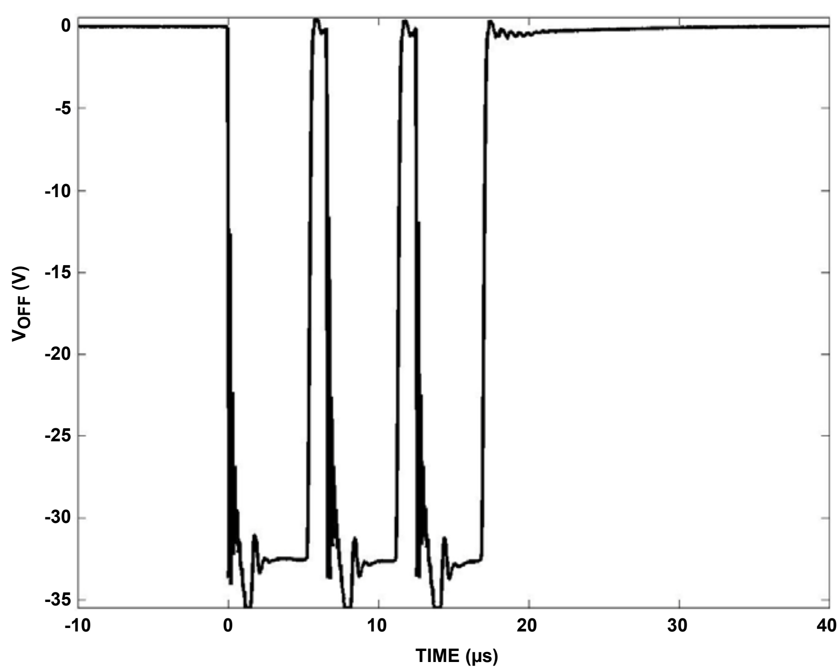

FIGURE 5. A 3-PULSE EVENT FROM DUT4 WHEN IRRADIATED TO $1x10^6$ion/cm^2 WITH 86MeV • cm^2/mg GOLD IONS AND WITH R_{31} AT 100Ω. $V_{OFF} = V_{C31}$.

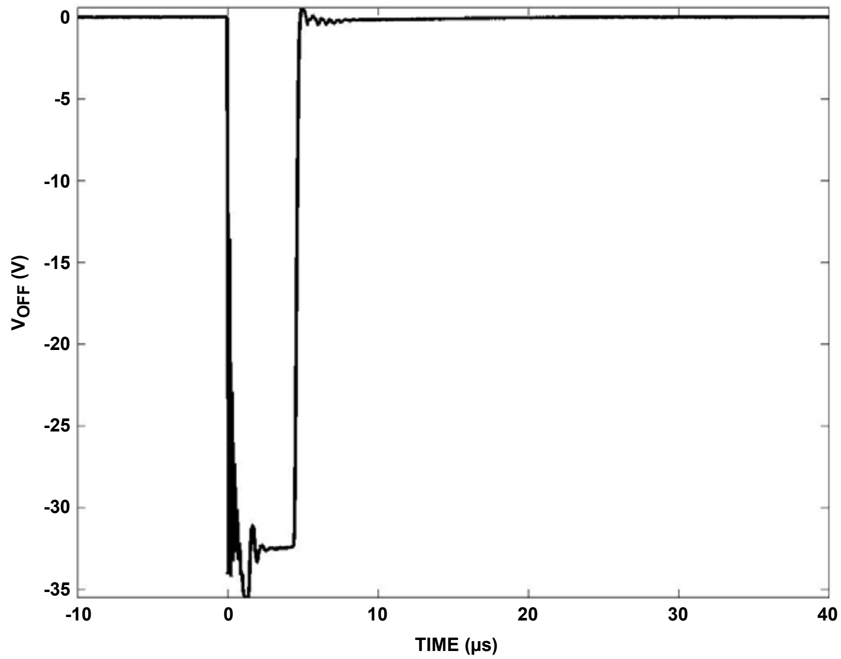

FIGURE 6. LONGEST V_{OFF} SET FOR DUT1 WHEN IRRADIATED TO $1x10^6 ion/cm^2$ WITH $86MeV \cdot cm^2/mg$ GOLD IONS AND WITH R_{31} AT 100Ω. $V_{OFF} = V_{C31}$.

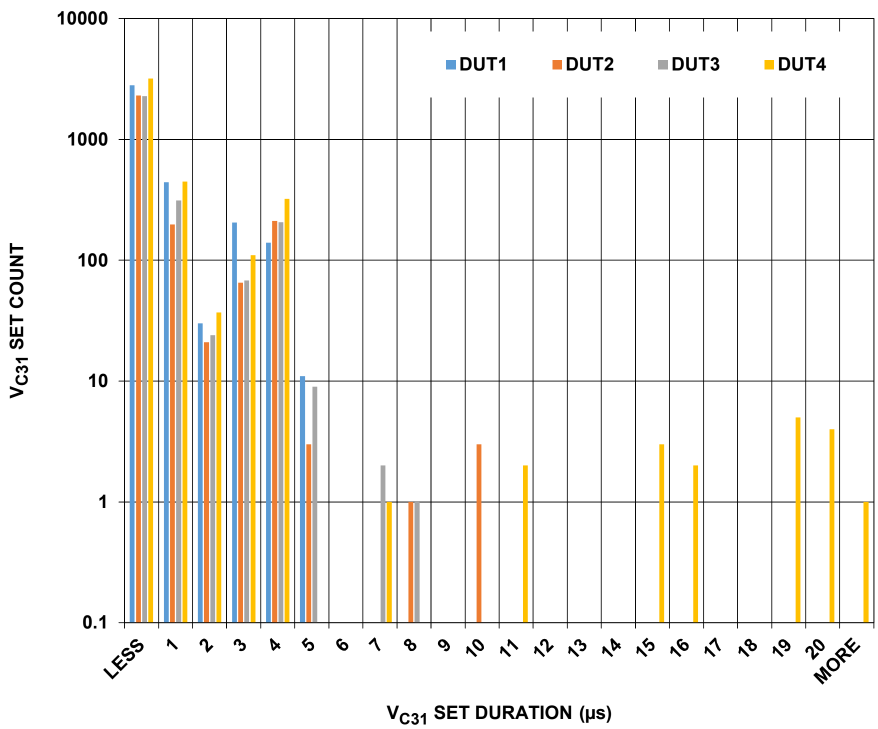

FIGURE 7. HISTOGRAM OF V_{OFF} SET COUNTS BINNED BY V_{C31} SET DURATIONS (<-2V) FOR $86MeV \cdot cm^2/mg$ GOLD IONS TO $1x10^6 ion/cm^2$.

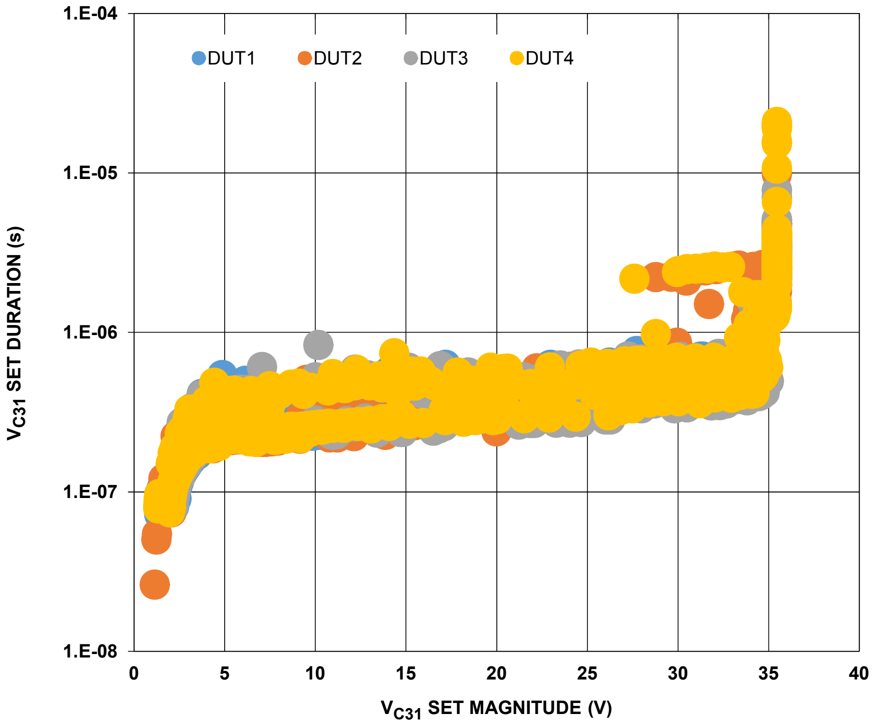

FIGURE 8. PLOT OF V_{OFF} SET DURATION V_{C31} <-2V VERSUS SET MAGNITUDE FOR IRRADIATION TO $1x10^6$ion/cm^2 WITH 86MeV•cm^2/mg GOLD IONS AND WITH R_{31} AT 100Ω.

Testing Results for SET on 1 OFF Channel

The testing of a single OFF channel (C1) for SET at a lower flux ($5x10^3$ion/(cm^2-s)) and to include a lower LET (28MeV•cm^2/mg) was carried out on October 31, 2016 and November 2, 2016. The same 100Ω resistor was used for R_{31} in Figure 1 on page 2, but only Channel 1 (Pin 17) was connected to it. The connection between Pin 17 and Pin 16 was removed to isolate Channel 1. The same 2V SET magnitude (20mA) was used to trigger SET captures. A summary of the SET counts captured is presented in Table 4. The same DUTs as used before were used again for this testing.

TABLE 4. V_{C31} SET EVENT COUNTS WITH ONLY CHANNEL C1 CONNECTED FOR TRIGGERING AT V_{C31} <-2V WITH 100Ω R_{31}.

LET (MeV•cm^2/mg) AND FLUENCE (ion/cm^2)	V_{C31} SET COUNT AT -2V				CROSS SECTION MAXIMUM (cm^2)
	DUT1	DUT2	DUT3	DUT4	
86 to $1x10^6$	NA	90	122	108	$1.22x10^{-4}$
28 to $2x10^6$	NA	102	89	96	$5.10x10^{-5}$

The NA entries in the first column of Table 4 are because the first unit failed to function at TAMU. The reason for the failure is not known. The SET counts in Table 4 are low enough to ensure that they represent a good basis for cross section estimation. The cross section estimate for LET = 86MeV•cm^2/mg is $1.22x10^{-4}$cm^2. The same parts yield about half that cross section, $5.1x10^{-5}$ cm^2, for the same capture criteria, V_{C31}<-2V at LET = 28MeV•cm^2/mg.

DUT4 when tested at LET = 86MeV•cm^2/mg again, produces some multi-pulse events, nine in all, ranging from a double pulse to events with five pulses (3). An example of the 5-pulse events is in Figure 9 on page 8.

Again, the multiple ion interpretation is hard to rationalize. The other interpretation, that a single ion causes a multiple pulses, is also hard to rationalize but it seems more justified. A total of 9 events out of 108 exhibited multiple pulses, but only on DUT4. The other two DUTs did not exhibit any multiple pulse events. There was no identifiable difference between the DUTs or their configurations to explain the difference. It should also be noted that no multiple pulse events were recorded at LET = 28MeV•cm^2/mg. So it would appear that the multiple pulse events are dependent on the LET of the incident ion.

Another characteristic of the SET that did not carry over the earlier testing to this last set of testing, is the distribution of SET magnitudes of Figure 2 on page 4. The distribution of small magnitude SET in the range of 2V to 6V did not reappear in the latest single channel testing. A representation of the distribution is shown in Figure 10 on page 8. When looking at Figure 10, keep in mind that the fluence used at 28MeV•cm^2/mg was twice that used at 86MeV•cm^2/mg. The distribution for 28MeV•cm^2/mg exhibits an almost singular peak in the 35V to 37V bin. The distribution for 86MeV•cm^2/mg is considerably more spread out. However, unlike the previous testing, the single channel testing shows the full magnitude SET to be dominant.

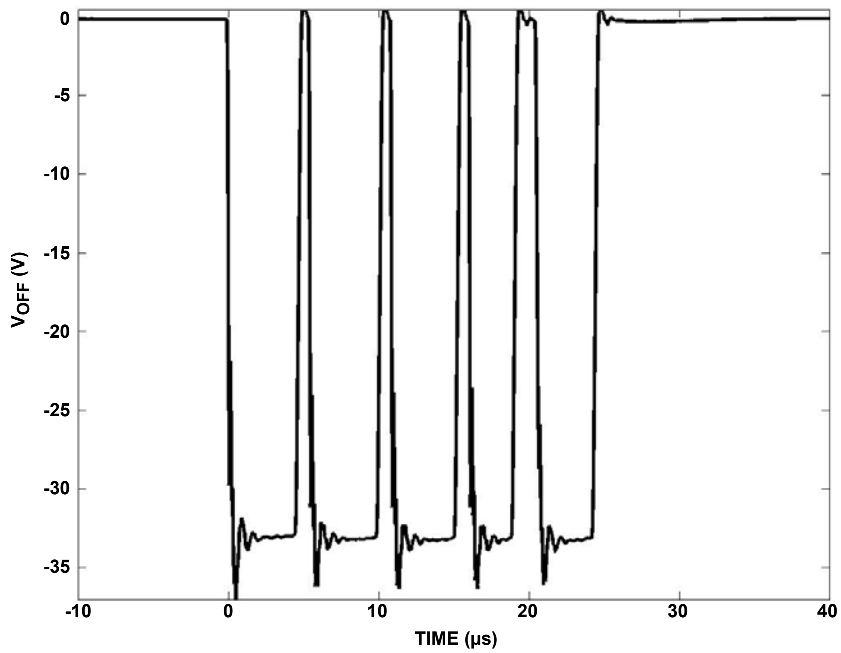

FIGURE 9. A 5-pulse event from DUT4 single channel when irradiated to $1x10^6$ion/cm^2 with 86MeV • cm^2/mg gold ions and with R_{31} at 100Ω. $V_{OFF} = V_{C31}$.

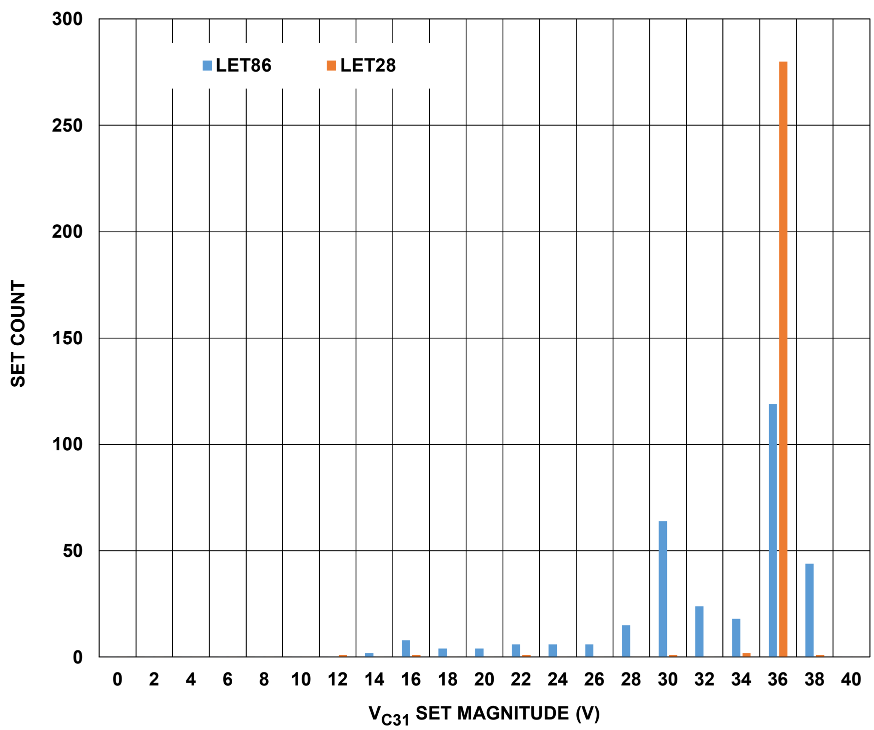

FIGURE 10. The SET magnitude distribution for single channel testing grouped by irradiation LET (86 or 28MeV • cm^2/mg) with the 3 DUTs combined for each case.

Discussion and Conclusions

Single-Event Burnout (SEB) testing supports the conclusion that the ISL72813SEH can survive environments with 86MeV•cm^2/mg ions to 1x10^{7}ion/cm^2 at biases of V_{CC} = 6.5V and V_{EE} = -33V while at +125°C case temperature. There was some variability in the V_{EE} failure voltage, from -34V up to -38V. Even so, four units of each version passed SEB testing at -34V, while one B01 unit failed at -34V. This supports a lower bound on SEB survival at V_{EE} = -33V.

Single-Event Transient (SET) testing revealed that ions of 86MeV•cm^2/mg induce off-channel conduction events up to at least 340mA (34V across the 100Ω resistor R_{31}). Rare events produced SET persisting up to 25µs with multiple pulse (up to 5) characteristics as seen in Figures 3 and 9. The majority of events were less than 5µs duration. No events that impacted V_{ON} (an on channel) were observed that did not originate with a V_{C31} event. A single channel test with 100Ω R_{31} led to SET of V_{C31} <-2V with cross section of 1.22x10^{-4}cm^2 with ions of LET 86MeV•cm^2/mg and cross section of 5.1x10^{-5}cm^2 for ions of LET 28MeV•cm^2/mg. The SET associated with these cross sections were primarily the full 340mA indicating that the output was briefly fully active. The form of the SET did not change with LET, only the cross section changed with LET.

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