Heavy Ion Test Report for the LTC6268-10 Operational Amplifier

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I. Introduction

The purpose of this test is to determine the heavy ion-induced single-event effect (SEE) susceptibility of the LTC6268-10 from Linear Technology Corp.

II. Test Goals

The primary goals of the heavy ion test are summarized below.

1. Determine single-event transient (SET) characteristics
    a. Determine SET linear energy transfer (LET) threshold
    b. Obtain worst case SET waveform for applicable operating condition
    c. Map out SET cross section for rate prediction
2. Determine other SEE characteristics
    a. Evaluate potential susceptibility to single-event latchup (SEL), burnout (SEB), and/or dielectric rupture (SEDR).
    b. Evaluate potential susceptibility to dropout

III. Device Under Test

The LTC6268-10 is a single/dual 4 GHz FET-input operational amplifier. It operates on 3.1 V to 5.25 V supply and consumes 16.5 mA per amplifier. There is a shutdown feature that can be used to lower power consumption when the amplifier is not in use.

Figure 1 shows a functional schematic diagram of the device. Table I shows the basic part and test details. Detailed device parameters and functional descriptions can be found in the datasheet [1].

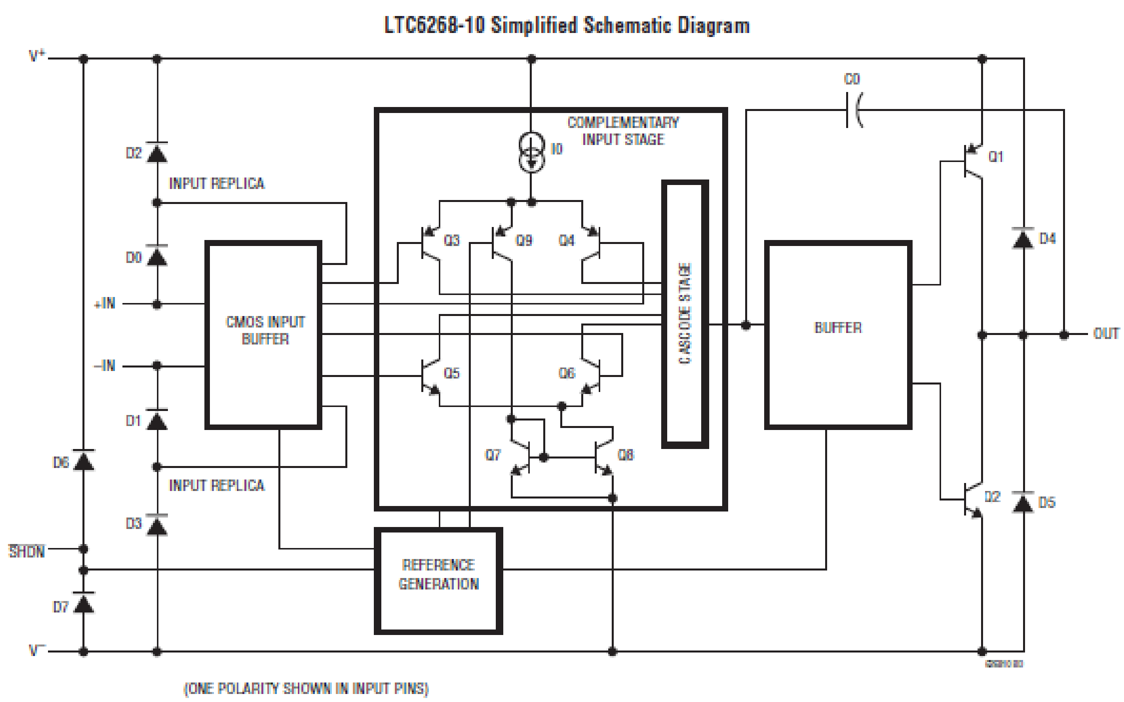

Figure 1. Schematic block diagram.

Table I
Part and test information.

Generic Part Number:	LTC6268-10
Procured Part Number:	LTC6268HS8-10PBF
Lot Date Code (LDC):	1433
Quantity Tested:	7
Serial Numbers of Control Sample:	1, 2
Serial Numbers of Radiation Samples:	3, 4, 5, 6, 7, 8, 9, 10
Part Function:	Operational amplifier
Part Technology:	BiCMOS
Package Style:	8-Lead Plastic Small Outline
Test Equipment:	Keithley 2400 current source Digital oscilloscope Power supply PC

IV. Test Facility

The heavy-ion testing was carried out at the Texas A&M University Cyclotron Facility with a K500 source. The irradiation was carried out in air. A second heavy ion test was carried out at the Lawrence Berkeley National Laboratory (LBNL) Berkeley Accelerator Space Effects (BASE) Facility utilizing an 88-inch cyclotron. The irradiation was carried out in vacuum at LBNL.

Facility: TAMU and LBNL
Cocktail: 15 MeV/amu (TAMU) 10 MeV/amu (LBNL)
Flux: $< 1 \times 10^5$ ions/(cm^2·s)
Fluence: $\leq 1 \times 10^7$ ions/cm^2
Ions: Shown in Table II

Table II
Heavy-ion specie, linear energy transfer (LET) value, range, and energy.

Ion	Initial LET in air (MeV·cm^2/mg)	Range in Si (µm)	Energy (MeV)
Ne	2.5	316	300
Ar	7.7	229	599
Kr	25.4	170	1259
Au	80.2	155	2955
Au (LBNL)	85.8	90	1956

V. Test Method

A. Test Setup

Figure 2 shows the schematic diagram of the test circuit. Four parts were mounted on each board. The input and output signals for each part were accessed via BNC connectors. Also, the parts on a board shared common supply voltages. However, jumper connectors allowed for isolation of the supply voltage to each part.

We supplied the input with a current source (10 or 100 nA). The output was monitored using an oscilloscope. The output triggered when the signal exceeded the preset trigger level which was set above the noise floor. A LabView program interfaced with the current source and scope. The program allowed the user to remotely control the test setup. The program also captured and recorded each triggered event. Additionally, a separately LabView program controlled the power supply. The supply current levels were recorded for each run.

Figure 3 shows a schematic block diagram of the irradiation test setup. The PC is located in the control room, directly above the irradiation chamber. The power supply, oscilloscope, and current source were located inside the irradiation chamber. However, the equipment were out of the beam source. One part was irradiated at one time. The other parts on the same board were shielded from the beam. Figure 4 shows a photograph of a test board mounted with four delidded parts.

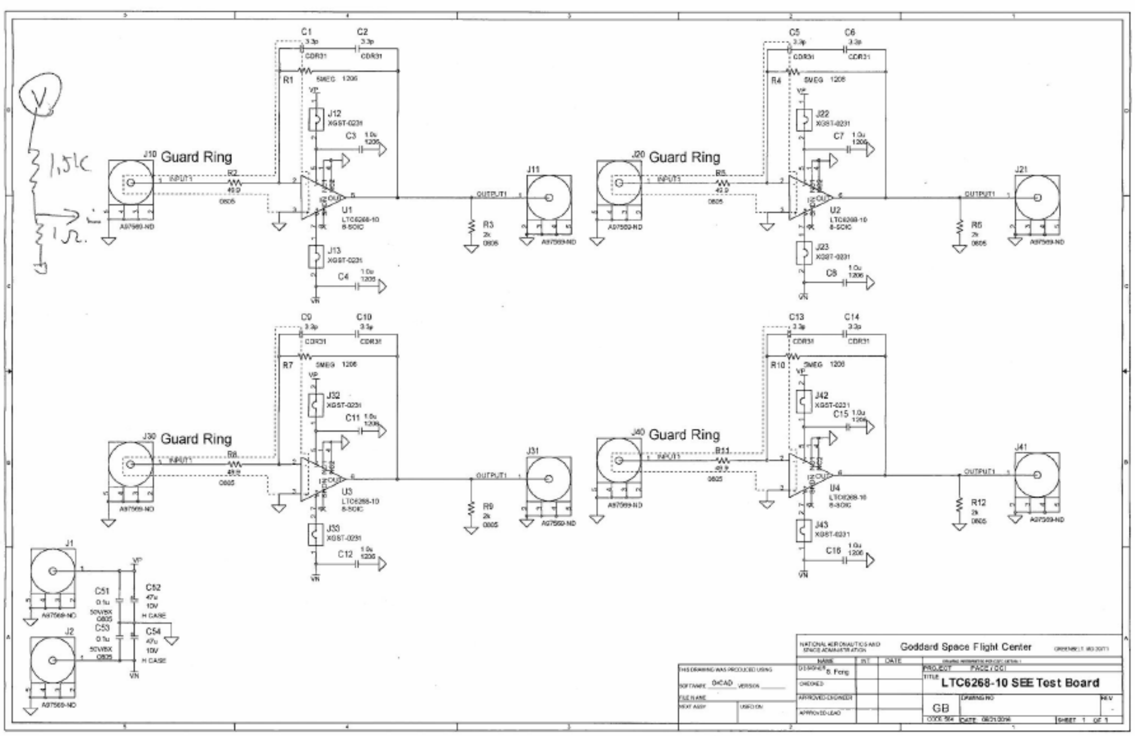

Figure 2. Circuit schematic diagram of the test board.

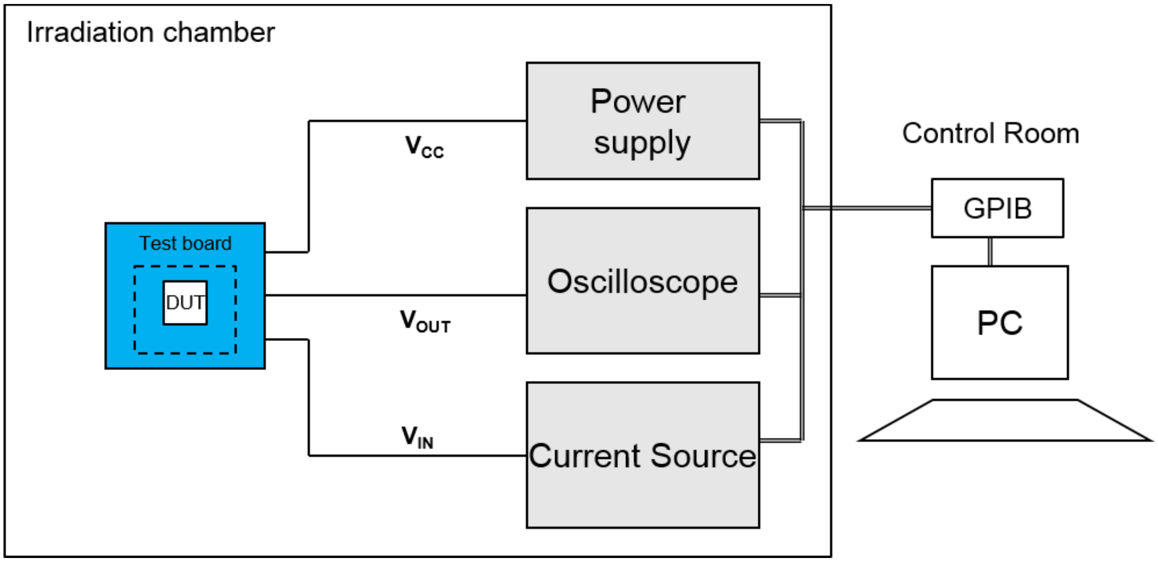

Figure 3. Schematic block diagram of the test setup.

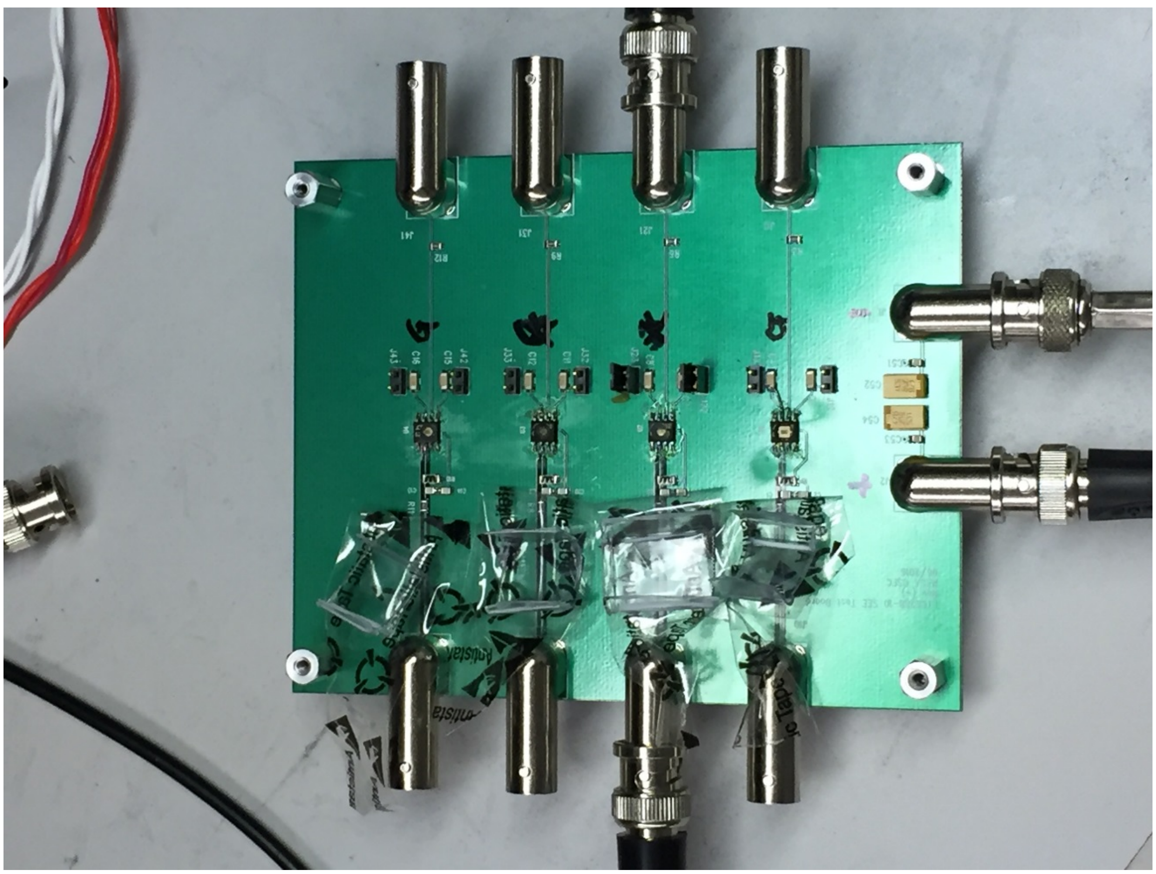
Figure 4. Photograph of a test board mounted with four delidded parts. Electrostatic discharge tape attached lids are located below the parts.

B. Irradiation procedure

The fluence for each run were set high enough to record a statistically meaningful number of upsets (≥ 100) up to a fluence of 2×10^6 cm^{-2}. The flux was maintained low enough to avoid multiple ion strikes which can lead to bus contention.

Beam dosimetry information was recorded for each run, including the beam energy, ion specie, ion energy, ion range in silicon, LET at Braggs peak, fluence, flux, and exposure time. Total-ionizing dose from the heavy ion irradiation was calculated from the LET and fluence.

i. Single-event transient

A list of the irradiation procedure is as follows.

1. Set up DUT. Position board to ensure that the stage has full movement capability. Ensure proper functionality of DUT
2. Note the effect of background noise on the signal integrity. Set trigger level slightly higher than the noise level to avoid false triggering
3. Close the irradiation cave
4. Once again ensure functionality including
5. Select appropriate ion specie
6. Set run conditions including the fluence and flux
7. Start irradiation
8. Irradiation can be stopped once adequate number of SEU (typically ≥ 100 events) is captured or up to a fluence of approximately 1×10^6 cm^{-2} to 2×10^6 cm^{-2} for statistical confidence
9. Change the device operating condition (i.e. input current level, etc.), and repeat irradiation
10. Change the beam characteristics and repeat irradiation for each set of device operating condition
11. Map out a cross section vs. LET plot

ii. Single-event latchup

For single-event latchup evaluation, the DUT was irradiated to 1×10^7 cm^{-2} at room temperature. The supply current was monitored *in-situ* during the irradiation. An exponential increase in the supply current can potentially signal the onset of SEL. In the event of a SEL, the procedures are as follows.

1. Shut off the beam immediately, and record the fluence
2. If the current is in a stable state, allow the DUT to dwell in the latched condition for at least 5 minutes
3. Attempt to recover operation by first reset then power cycle
4. After the device recovers functionality, the operator should perform parametric characterization to examine for degradation (i.e. input bias current, etc.)
5. If the part shows no degradation, then irradiation can continue
6. Determine the SEL LET threshold, and map out a cross section

C. *Test Conditions*

Test Temperature:	Ambient temperature
Operating Frequency:	DC
Input Current:	10, 100, and 200 nA
Output impedance:	1 kΩ
Gain:	100 dB
Supply Voltage:	$V^+ = 2.5$ V, $V^- = -2.5$ V
Angles of Incidence:	0^o (normal) to 60^o (or maximum allowable)
Parameters:	1) Output voltage 2) Supply current 3) Supply voltage 4) Input Bias Current

VI. Results

We found that the LTC6268-10 is susceptible to heavy ion-induced SET. We did not observe any other type of SEE up to a LET of 85.6 MeV·cm^2/mg. Figure 5 shows the SET cross section vs. effective LET for various input currents. Note that we did not include the cross section for a LET of 85.6 MeV·cm^2/mg in Figure 5, since some transients were not captured or counted, given the higher than normal flux level required for a higher fluence (1×10^7 cm^{-2}). We performed the irradiation at that LET to primarily examine the hardness to potentially destructive events, which we did not observe. The output trigger was set to 200 mV$_{pp}$ to compensate for the level of facility background noise. Figure 6 shows a SET amplitude vs. duration distribution plot. The figure shows that the SETs can be generally divided into two categories: 1) SETs with a short duration on the order of microseconds, and 2) SETs with long duration on the order of milliseconds. The majority of SETs have duration less than 7 µsec.

While the cross section did not vary significantly with the input level, the distribution of the SET magnitude showed a clear dependence on the input current. Figure 7 shows a column bar chart of the SET count for small and large events at input currents of 10, 100, and 200 nA. The SET count generally increases with decreasing input current for both small (< 1 msec) and large (≥ 1 msec) events. Furthermore, the number of small events increases exponentially with decreasing input current. The SET count for small events is significantly higher at 10 nA input current, and the proportion of small to large events is enhanced at 10 nA relative to 100 and 200 nA.

Table III shows the Weibull fit parameters at 95% CL. Table IV shows the PACE mission on-orbit upset rates derived from the Weibull fit. The last row in Table IV is the solar event rate scaled according to a probabilistic model estimating the likelihood of seeing an event of similar magnitude as the October 1989 solar event [2]. Figures 8 – 11 show examples of SETs.

Table III
SET cross section Weibull parameters at 95% CL.

Parameter	95% CL	Unit
LET_0	1	$MeV \cdot cm^2/mg$
Sigma	1.50E-03	cm^2
Exponent	0.8	*NA*
Width	14	$MeV \cdot cm^2/mg$

Table IV
SET event rate at 95% CL for background GCR and solar event.
The solar flare rate is also given in events per active year using a probabilistic model [2].

Environment 1000 mils Al	95% CL	Unit
Background GCR	2.79	Per device-year
Solar event	1.02×10^{-1}	Per device-week
Solar flare rate scaled by event per active year [2]	3.57×10^{-3}	Per device-year

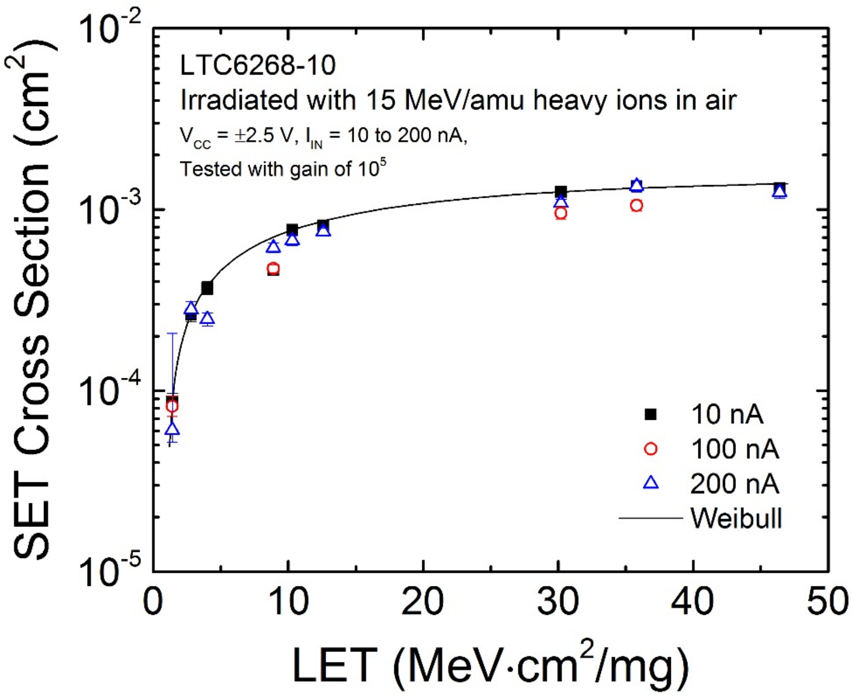

Figure 5. SET cross section vs. effective LET for the LTC6268-10 irradiated with 15 MeV/amu heavy ions in air.

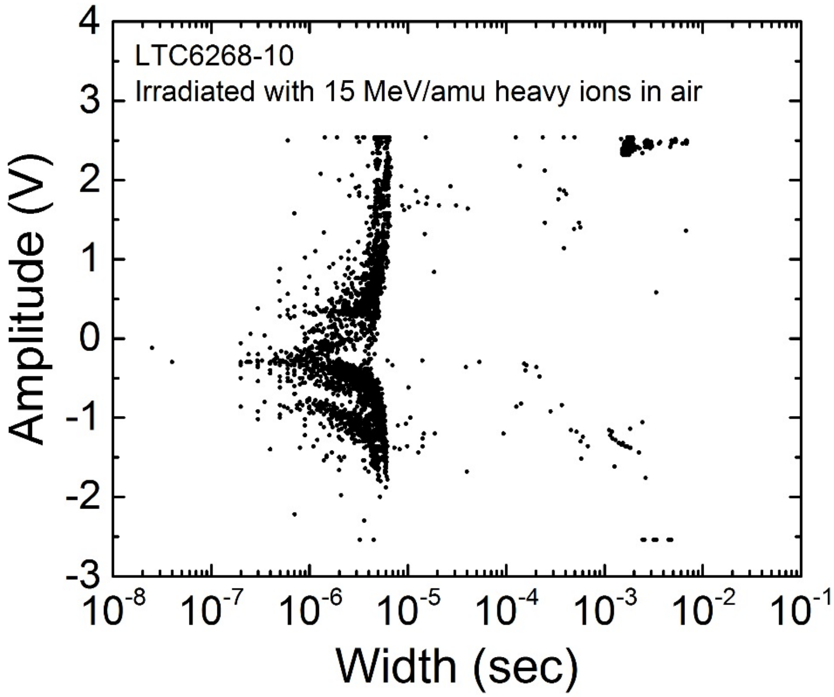

Figure 6. SET amplitude vs. width plot for the LTC6268-10 irradiated with 15 MeV/amu heavy ions in air.

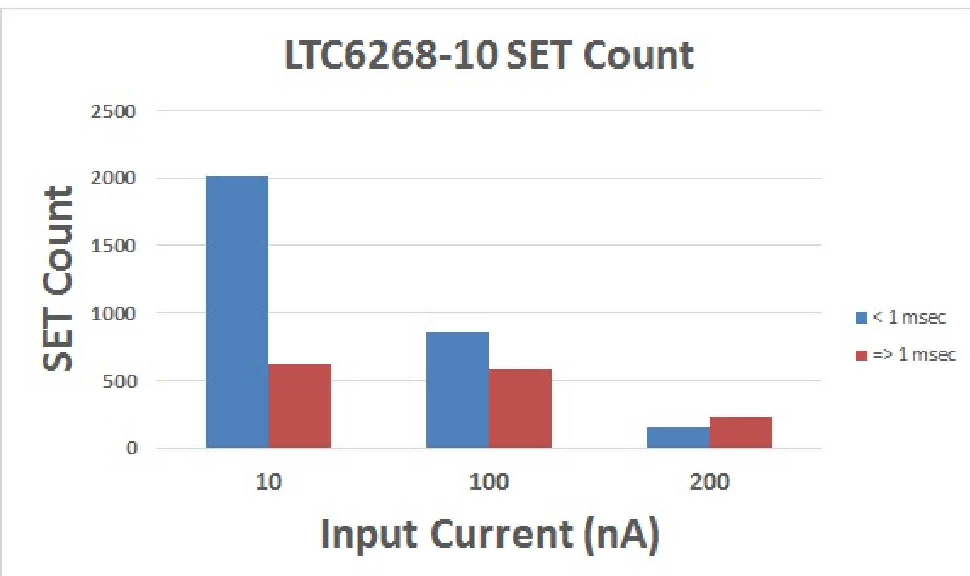

Figure 7. SET count vs. input current for the LTC6268-10 irradiated with 15 MeV/amu heavy ions in air. The SETs are divided into two categories with respect to its duration: < 1 msec, and ≥ 1 msec.

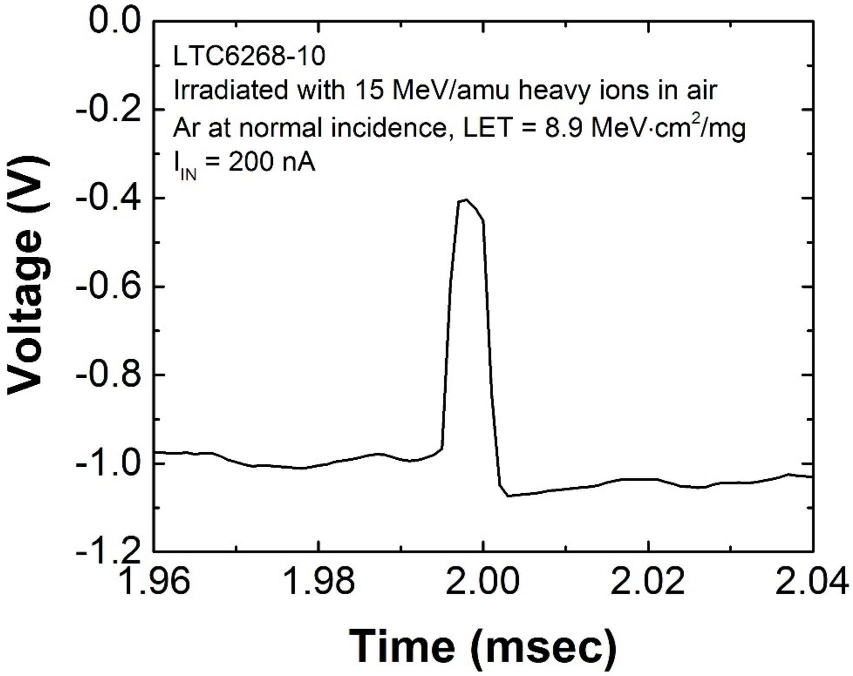

Figure 8. SET characteristics for the LTC6268-10 irradiated with 15 MeV/amu heavy ions in air.

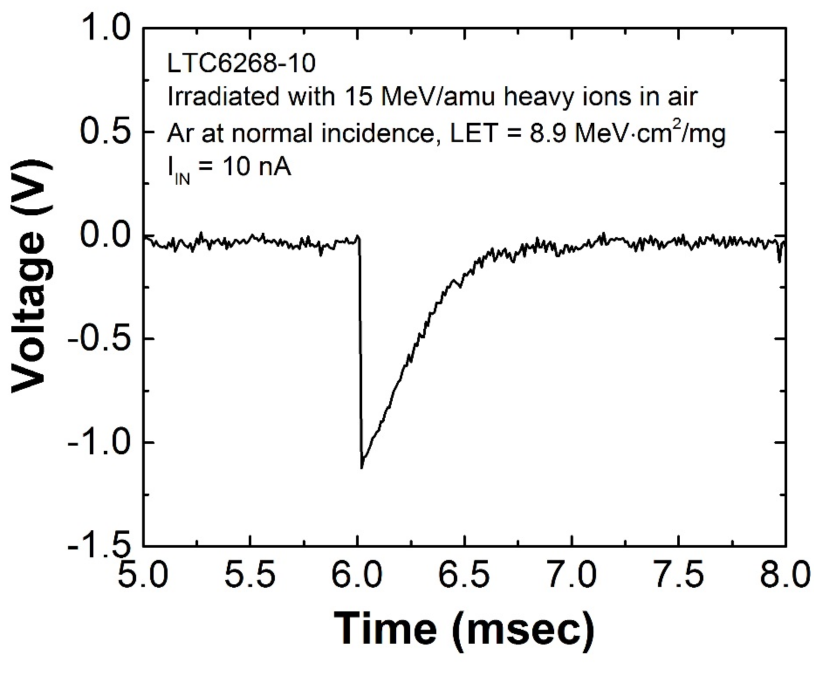

Figure 9. SET characteristics for the LTC6268-10 irradiated with 15 MeV/amu heavy ions in air.

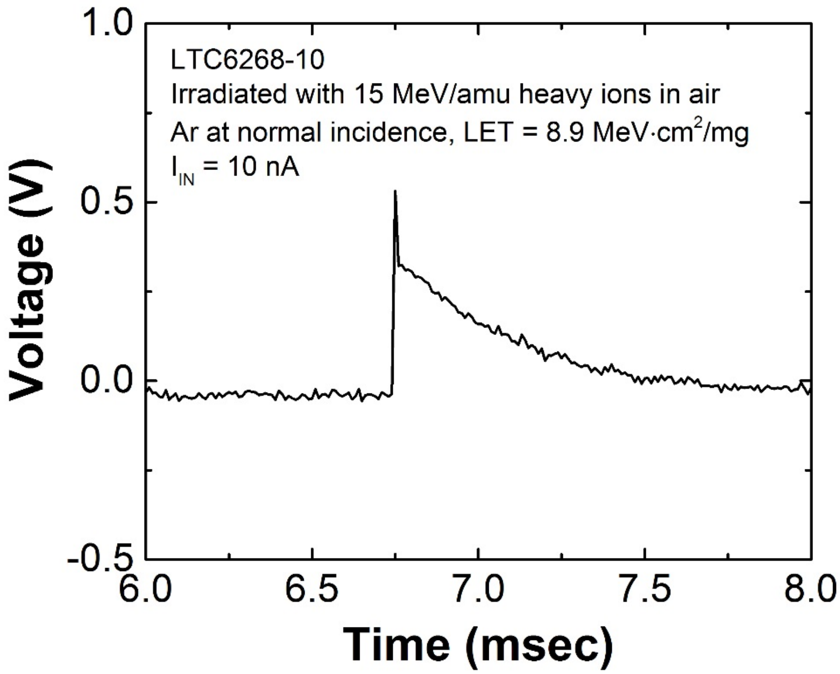

Figure 10. SET characteristics for the LTC6268-10 irradiated with 15 MeV/amu heavy ions in air.

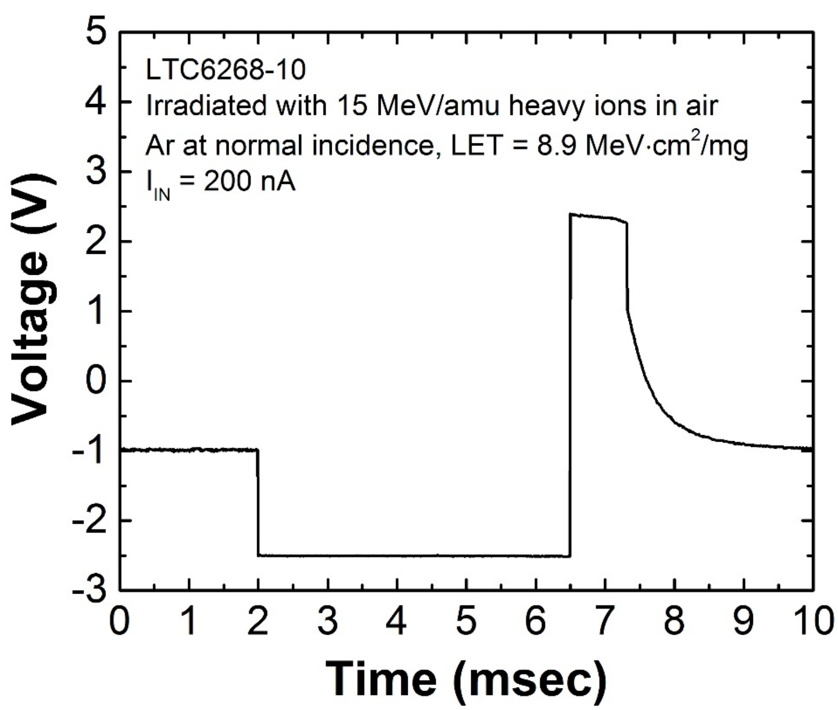

Figure 11. SET characteristics for the LTC6268-10 irradiated with 15 MeV/amu heavy ions in air.

VII. Reference

[1] Linear Technology Corp. (2016, Jul), "*LTC6268-10: 4GHz Ultra-low bias current FET input Op Amp*" [Online]. Available: http://www.linear.com/docs/46371 Accessed on: Jul 18, 2016.

[2] M. A. Xapsos, G. P. Summers, J. L. Barth, E. G. Stassinopoulos, and E. A. Burke, "Probability model for worst case solar proton event fluences," *IEEE Trans. Nucl. Sci*., vol. 46, pp. 1481-1485, Dec. 1999.