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Single-Event Effect Test Report Analog Devices LTC1604AIG#90117 ADC

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1. Introduction

This study is to characterize the destructive single-event latchup (SEL) susceptibility of the Analog Devices LTC1604AIG#90117 (LTC1604) analog/digital converter (ADC). The device was monitored for SEL current events on the power supplies during exposure to a heavy ion beam at Lawrence Berkeley National Laboratory (LBNL) 88-inch Cyclotron. Testing was performed on September 11, 2021.

2. Test Result Summary

The LTC1604 did not experience any destructive single-event effects (SEE) during heavy ion irradiation at a normal-incidence linear energy transfer (LET) of 49.3 $MeVcm^2mg^{-1}$ under elevated 85°C temperature conditions and a fluence to $1x10^7cm^{-2}$. SEL was observed upon additional testing at LET of 52.5 $MeVcm^2\ mg^{-1}$ under ambient operational temperature conditions (approximately 40°C) and nominal voltage conditions at a fluence of $1.8x10^6cm^{-2}$ on SN1. An effort was made to repeat this observation, but it was not observed a second time up to an additional fluence of $2x10^7cm^{-2}$. Testing continued to characterize the temperature dependence of SEL. Temperature dependence could not be confirmed in lot date code (LDC) #1537, the lot tested in this campaign. Significant lot-to-lot variation with past results – those collected by Irom and Miyahira in 2004 [2] – is confirmed.

3. Devices Under Test

The Analog Devices LTC1604 is a 16-bit ADC with +/-5 V supply [1]. It provides high performance with a high dynamic range sample-and-hold. It converts an input differential signal in the range +/-2.5 V within a 5 MHz bandwidth at a sample rate of up to 333 kilosamples per second to a digital signal. The lot date code of the devices under test is #1537. Six pieces were provided. Four devices were decapsulated. Three devices were tested with the heavy ion beam. REAG internal ID assignment is 21-025.

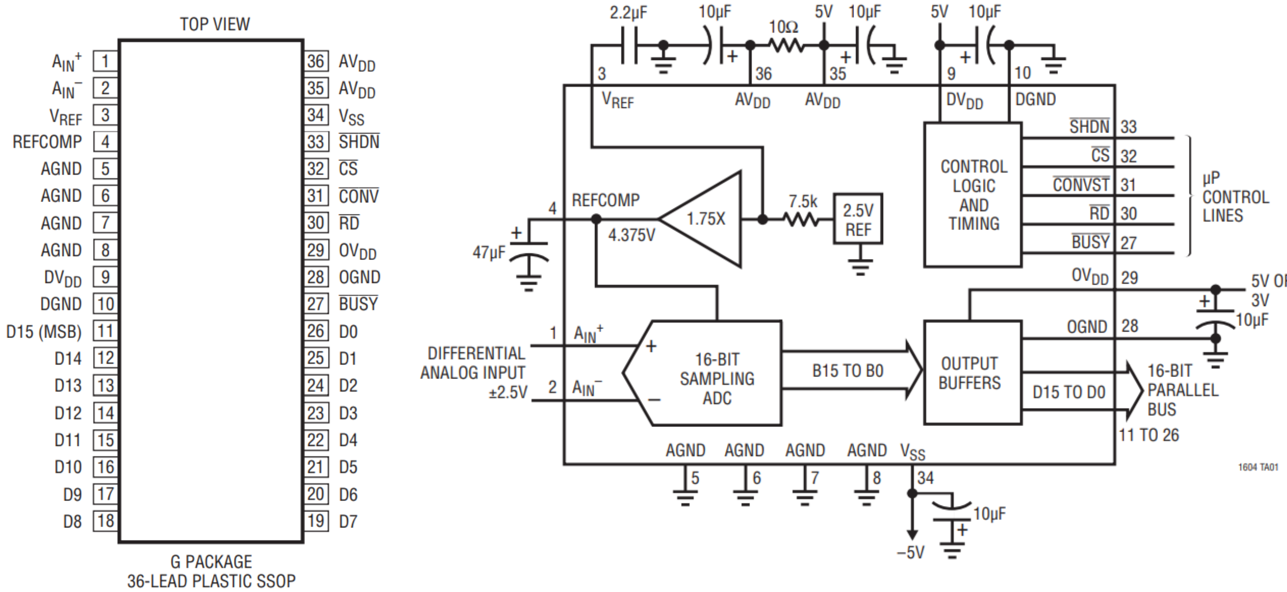

Figure 1 - LTC1604 functional diagram and package pinout

4. Test Facility

Facility: LBNL, 88-inch cyclotron, 16 MeV/amu tune in vacuum

Flux: Approximately $5x10^4$ $cm^{-2}s^{-1}$.

Fluence: Testing was conducted using 3 devices to cover at least $1x10^7 cm^{-2}$ at each test condition. A single device was tested to $1x10^7 cm^{-2}$ at the worst-case planned test condition. A second device was tested to an additional $5x10^6 cm^{-2}$ fluence at the worst-case planned test condition.

Ions / LET: A normal incidence LET of at least 37 MeV cm^2mg^{-1} was required for destructive SEL testing. Previous testing guidance referenced an LET onset of 52.3 MeV cm^2mg^{-1} for the LTC1604 but advised that lot-to-lot variability could be possible [2]. During this test, limited ions were necessary to cover needed LET. The highest nominal LET was 16 MeV/amu Xe, at 49.3 $MeVcm^2mg^{-1}$ in vacuum. Angle of incidence to the beamline was used to obtain higher LETs for additional experiments.

5. Test Conditions

Test Temperature: Ambient temperature (40°C), Maximum temperature (85°C).

Operating Frequency: Analog input voltage = 0 VDC. Outputs open.

Power Supply Voltage: AVDD = +5VDC, OVDD = +5VDC, DVDD = +5VDC, VSS = -5VDC.

Power Supply Current Limits: $I_{AVDD(MAX)}$ = 80mA, $I_{DVDD(MAX)}$= 160mA, $I_{OVDD(MAX)}$= 80mA, $I_{VSS(MIN)}$ = 80mA.

Parameters of Interest: Negative power supply current (I_{VSS}), positive analog power supply current (I_{AVDD}), positive digital power supply current (I_{DVDD}).

6. Test Methods

The test condition was static mode with grounded inputs and steady state power (not in Nap or Shutdown mode described in the datasheet [1]). Power supply currents were continually monitored for SEL. Current was logged to capture latchup events, and any precipitous increase would indicate latchup had occurred. From previous testing, it is known that unrestricted latchup is destructive to the device [2]. Due to the limited number of devices available for testing, the power supply currents were limited to prevent destructive latchup. Current limits are denoted in Test Conditions. When latchup occurred, currents were returned to normal after a power cycle was performed.

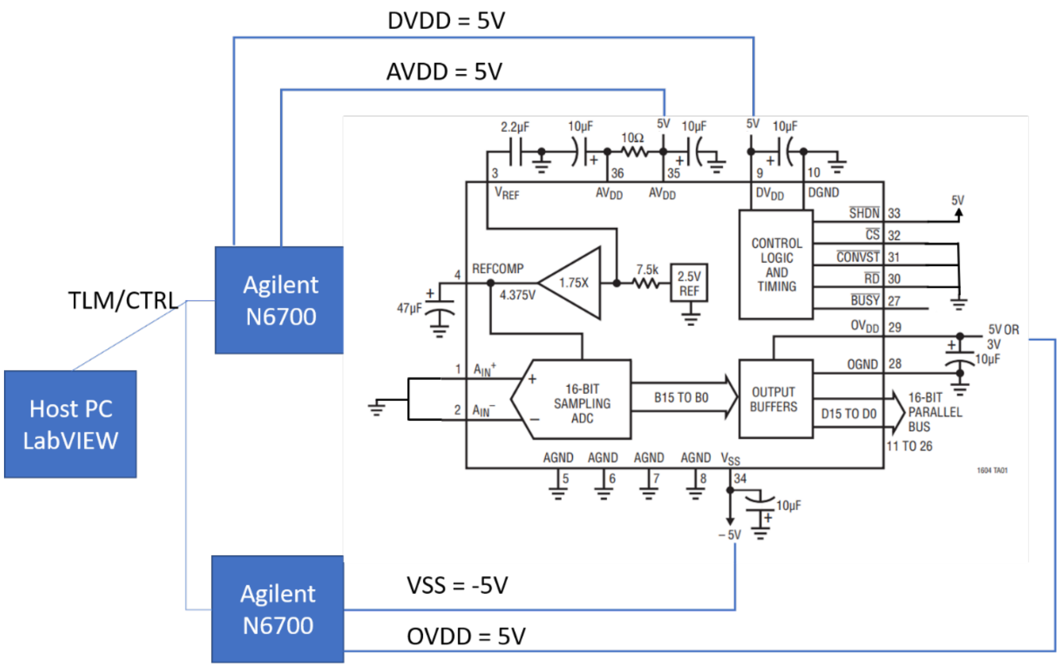

Figure 2 – Test circuit of LTC1604

Pre-test measurement of the power supply currents were taken to assure steady-state prior to beam exposures. Post-test notes were taken on SEL events including the final steady-state currents even though the devices were current limited.

Current was monitored in real time in order to observe SEL. The beam was stopped on a latchup event. After post-test notes were taken the part was power-cycled and allowed to return to steady state again. If nominal currents were observed after a power-cycle, then testing continued.

7. Test Performance

Personnel: Anthony Phan (SSAI), Matt Joplin (NASA) and Michael Campola (NASA)

The plan to test included repeating the tested LET and temperatures observed in [2] to investigate the possibility of lot-to-lot variation in the temperature effects on SEL cross section and SEL LET threshold. The LET spectrum of interest was 49-70 MeVcm^{2}mg^{-1}. Temperature conditions of interest were ambient and elevated temperature (85°C). Testing would establish LET threshold of the lot at ambient temperature first by starting at low LET, then the LET would be increased until cross-section saturation or LET = 70 MeVcm^{2}mg^{-1}.

8. Test Results

All tests were performed under vacuum with 16 MeV/amu cocktail. All angles to increase LET were along the X-axis, which is left-to-right with respect to the package in Figure 1, looking down the beamline at the exposed surface of LTC1604 die. Normal incidence was a 0-degree angle along the X-axis. The LTC1604 test conditions and results are below.

Table 1 – Run Log

DUT ID#	**Ion (Species)**	Angle (°)	LET (MeVcm^{2}mg^{-1})	**Range (um)**	Eff. LET (MeVcm^{2}mg^{-1})	Eff. Range (um)	Temp. (°C)	Fluence (cm^{-2})	SEL? (yes/no)
1	**Kr**	**0**	**25**	**136**	**25**	**136.1**	**25**	**1.00E+07**	**no**
1	**Xe**	**20**	**49.3**	**105**	**52.46**	**99**	**40**	**1.85E+06**	**yes**
1	**Xe**	**20**	**49.3**	**105**	**52.46**	**99**	**40**	**1.07E+07**	**no**
1	**Xe**	**20**	**49.3**	**105**	**52.46**	**99**	**41**	**1.07E+07**	**no**
1	**Xe**	**20**	**49.3**	**105**	**52.46**	**99**	**50**	**1.07E+07**	**no**
1	**Xe**	**20**	**49.3**	**105**	**52.46**	**99**	**85**	**1.07E+07**	**yes**
1	**Xe**	**20**	**49.3**	**105**	**52.46**	**99**	**85**	**1.07E+07**	**no**
1	**Xe**	**45**	**49.3**	**105**	**69.72**	**74**	**85**	**1.72E+06**	**yes**
1	**Xe**	**45**	**49.3**	**105**	**69.72**	**74**	**85**	**3.21E+06**	**yes**
2	**Xe**	**0**	**49.3**	**105**	**49.3**	**105.4**	**33**	**1.00E+07**	**no**
2	**Xe**	**0**	**49.3**	**105**	**49.3**	**105.4**	**40**	**1.01E+07**	**no**
2	**Xe**	**0**	**49.3**	**105**	**49.3**	**105.4**	**85**	**1.00E+07**	**no**
2	**Xe**	**0**	**49.3**	**105**	**49.3**	**105.4**	**85**	**1.01E+07**	**no**
2	**Xe**	**20**	**49.3**	**105**	**52.46**	**99**	**85**	**1.07E+07**	**no**
2	**Xe**	**45**	**49.3**	**105**	**69.72**	**74**	**85**	**6.80E+06**	**yes**
2	**Xe**	**45**	**49.3**	**105**	**69.72**	**74**	**85**	**9.17E+05**	**yes**
2	**Xe**	**45**	**49.3**	**105**	**69.72**	**74**	**85**	**2.12E+06**	**yes**
3	**Xe**	**45**	**49.3**	**105**	**69.72**	**74**	**38**	**4.72E+06**	**yes**
3	**Xe**	**45**	**49.3**	**105**	**69.72**	**74**	**38**	**6.67E+06**	**yes**
3	**Xe**	**45**	**49.3**	**105**	**69.72**	**74**	**40**	**7.65E+06**	**yes**
3	**Xe**	**35**	**49.3**	**105**	**60.18**	**86**	**40**	**1.00E+07**	**no**
3	**Xe**	**35**	**49.3**	**105**	**60.18**	**86**	**40**	**7.43E+06**	**yes**
3	**Xe**	**35**	**49.3**	**105**	**60.18**	**86**	**85**	**3.01E+06**	**yes**

The parts tested survived at least $1x10^7 cm^{-2}$ fluence at an LET of 49.3 $MeVcm^2mg^{-1}$ at elevated temperature.

The tests with LETs of 60 and 70 $MeVcm^2mg^{-1}$ were possible with use of on-angle testing as only a limited set of ions was made available during this test campaign.

Resultant Weibull plots of cross section versus LET are plotted in Figure 3 below in two families of temperature. Ambient data correspond to approximately 40 °C. Heated data correspond to approximately 85 °C.

Error bars cover a 95% confidence interval about the measured mean cross section. The error bars are calculated using the relationship of Poisson cumulative distribution function and the chi-square distribution corresponding to the number of observations.

At LETs when the number of observations is zero, the error bar is denoted by a downward arrow to indicate a lower bound of zero and an 'X' is plotted at the inverse of the fluence as if an event were just about to be observed. Weibull fit is by method of least squares.

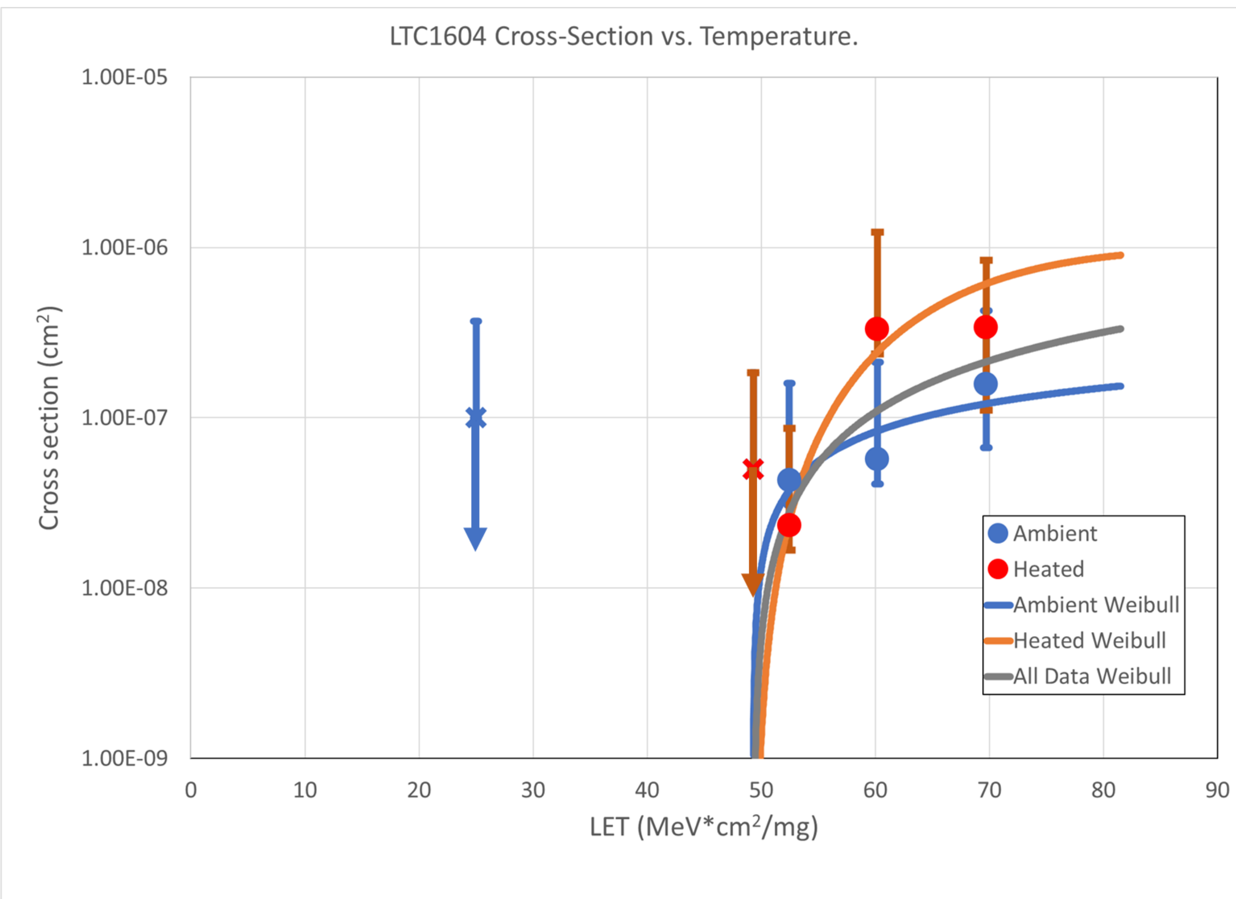

Figure 3 – Ambient and Heated LTC1604 LDC #1537 SEL data and Weibull plots

During analysis of the results it was noted that the ambient temperature threshold could be due to part-to-part variation, but the analysis of the data is inconclusive on this point. Additional testing could be performed to improve the statistics on the individual parts to enable part-to-part comparison with confidence. Weibull fit parameters are shown in Table 2.

Table 2 - Weibull Fit Parameters

Weibull fit parameter	Ambient	Heated	All Data
LET threshold	49.3	49.3	49.3
Sat. Cross-Section	3.E-07	1.E-06	1.E-06
Shape Factor	0.723	1.945	1.146
Width Factor	50.95	20.98	70.93

Previous data are shown for illustration in Figure 4 below.

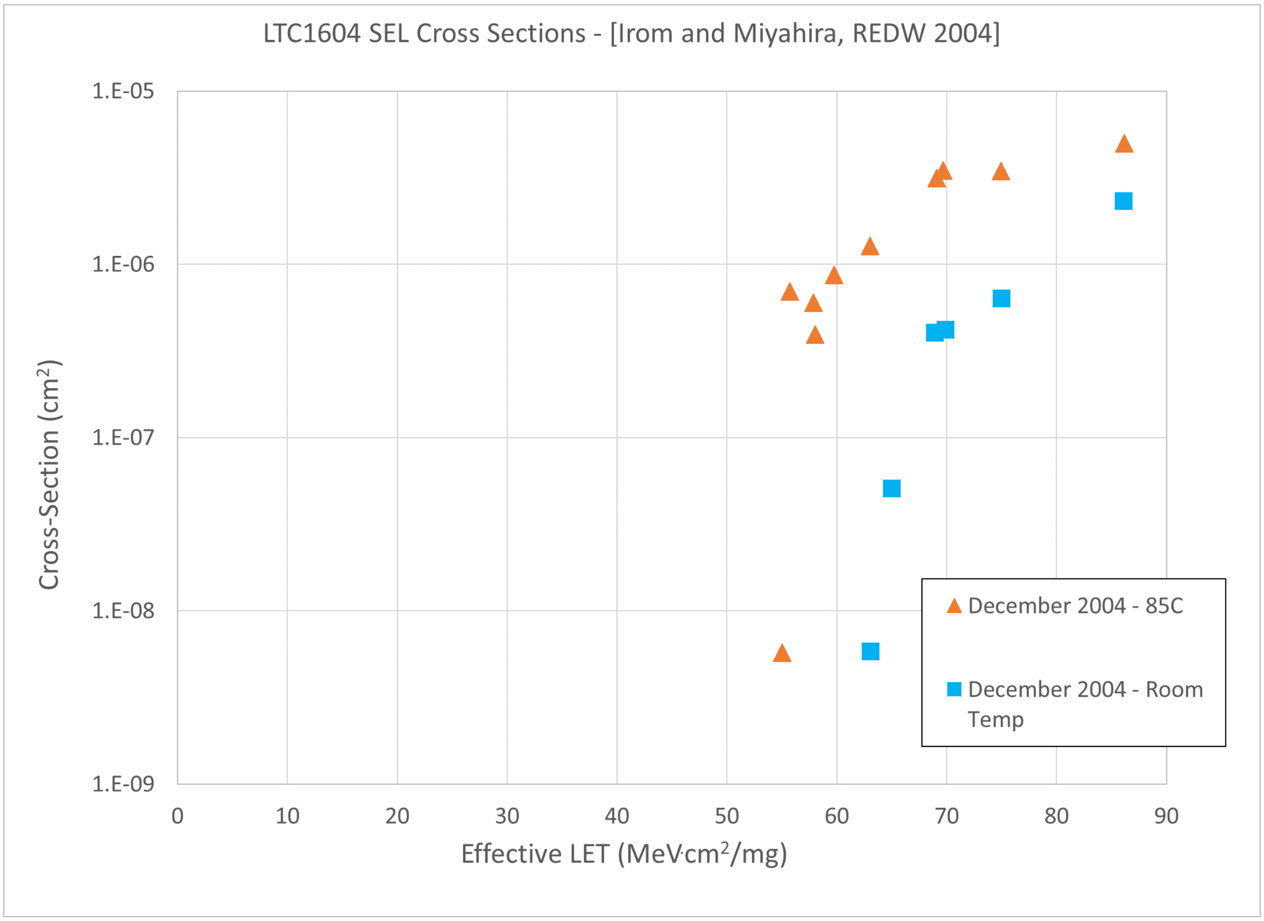

Figure 4 – LTC1604 SEL Cross Section, December 2004 [2]

A comparison between the 2004 data and LDC #1537 data to assess lot-to-lot variation showed a statistically significant difference between the lots in the aggregate. Student's 2-tailed t-test with a cumulative α =0.05 was applied to the natural log of the cross-section data. The t-test equation is as follows:

Equation 1 - calculation of Student's t-statistic

$$t = \frac{\bar{X}_1 - \bar{X}_2}{s_{\bar{\Delta}}}$$

where

Equation 2 - t-statistic variance

$$s_{\bar{\Delta}} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}.$$

In these equations, $\overline{X}_1$ and $\overline{X}_2$ are the mean values of each data set, s_1^2 and s_2^2 are the variance of each data set, n_1 and n_2 are the counts in each data set.

The mean values of the data are derived from the calculated cross section and evaluated as lognormal data. The variance is calculated by the absolute value of the product of the data set's upper and lower error bars set to a confidence level commensurate with probability contained within 1 standard deviation, or 0.68. The count is the sum of the number of observed latchups in the data set. The variation is across the aggregate of data taken from LET = 50-70 within which data of both lots is comparable. Table 3 summarizes the results of the analysis.

Table 3 – Student's t-Test Comparison of 2004 Data and 2021 Data

Comparison	t-value	d.f.	critical value (α =0.05)	H_0 rejected?
2004 data-#1537	11.06	168	2.364	YES

Because the t-value was greater than the critical value, the null hypothesis is rejected, and it can be inferred that lot-to-lot variation between the lots that produced SEL data in 2004 and lot #1537 (this study) is statistically significant according to the t-test.

The t-test was further applied to compare the effects of temperature on lot #1537 data. A summary of the analysis is shown in Table 4.

Table 4 – Student's t-Test LDC #1537 Comparison of Heated Data and Ambient Data

Comparison	t-value	d.f.	critical value (α =0.05)	H_0 rejected?
#1537 40°C –85°C	2.156	10	2.228	NO

In this case, because the t-value was not greater than the critical value, then we cannot conclude that temperature is a statistically significant variable.

9. Equipment List as Tested.

MFG and P/N	Function
Agilent 6700	Power supply
Agilent 6700	Power supply
LabView PC	Temp & Power Controller
Keysight 34970A	Thermocouple DAQ

10. References

1. Analog Devices LTC1604 Datasheet: https://www.analog.com/media/en/technical-documentation/data-sheets/1604fa.pdf
2. F. Irom and Tetsuo F. Miyahira, "Test Results of Single-Event Effects Conducted by the Jet Propulsion Laboratory", *2005 IEEE Radiation Effects Data Workshop Record*, pp. 36-41, 2005.