Single-Event Latchup Test Summary for the RT2378 Analog-Digital Converter

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I. Introduction

This document presents a summary of the single-event latchup (SEL) test results for the RT2378 analog-to-digital converter (ADC).

II. Experimental

The RT2378 is a low noise, low power, high speed 20-bit SAR ADC. The part features a 2.5 V supply, 21 mW of power consumption, and achieves ±2 ppm integrated non-linearity (INL) [1]. The part is built on a CMOS process. Table I shows the part and test information.

We carried out heavy ion irradiation at the Lawrence Berkeley National Laboratory (LBNL) Berkeley Accelerator Space Effects (BASE) facility [2] with 10 MeV/n beam in vacuum. Table II shows the ion specie, LET, range and energy used at LBNL. The SEE testing was performed in accordance with JESD57 test procedures [3].

Table I
Part information.

Generic Part Number	RT2378
Manufacturer	Analog Devices, Inc.
Quantity tested	17
Part Function	20-Bit, 1 Msps, Low Power SAR ADC with 0.5 ppm INL
Part Technology	CMOS
Package Style	16-lead MSOP
Test Equipment	Power supply, oscilloscope, multimeter, and PC

Table II
Heavy-ion specie, LET, range, and energy.

Ion	**Initial LET in air ($MeV \cdot cm^2/mg$)**	**Range in Si (μm)**	**Energy (MeV)**
Kr	30.9	110	886
Ag	48.2	90	1039
Xe	58.8	90	1956

Figure 3 shows a schematic diagram of the SEE test circuit. The Vdd was maintained at 2.5 V. We varied the OVdd from 2.5 V to 5 V during the test. We experimented with the power supply current threshold limits during the test, varying the limit level from 10 mA to 2 A. The current limit affected the vulnerability of the part to SEL as will be discussed in more detail below. The testing was carried out either at ambient or elevated temperature. The ambient temperature represented the temperature in vacuum without active cooling/heating. The elevated temperature at the part was approximately 70ºC to 75ºC.

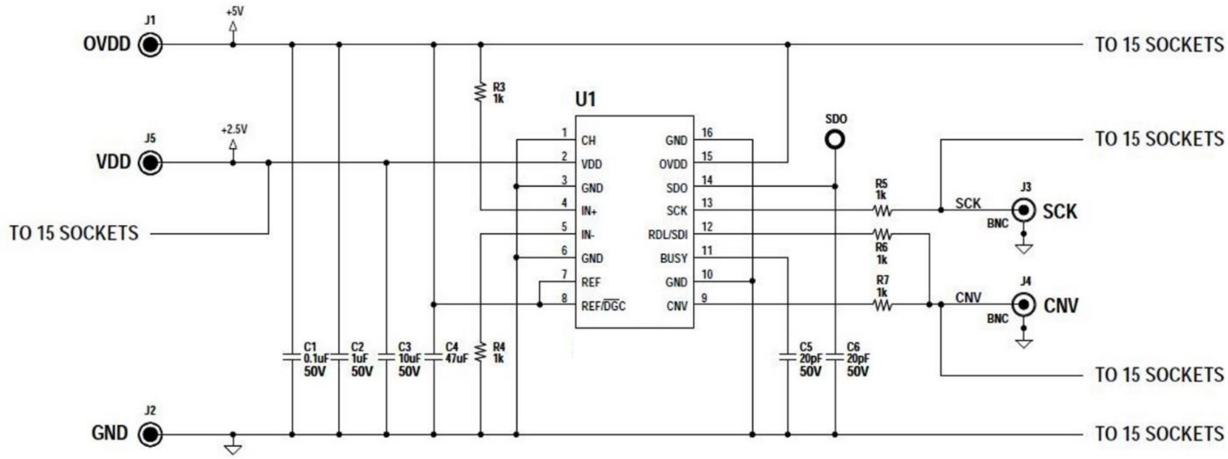

Figure 1. Circuit diagram of the SEE test circuit.

III. Results/Discussion

The part showed sensitivity to SEL. Figure 2 shows the SEL cross section as a function of LET at room temperature, for various OVdd bias levels. The error bars represent the Poisson error at the upper bound 95% confidence level. As shown, the SEL sensitivity is visibly higher at 5 V than at lower values. We note here that the current limit during the 2.5 V run was set to 10 mA. Although no SEL was observed at 2.5 V, we observed two current spikes during the run. Events from later runs showed that the current spikes could reach 200 mA or higher. In some cases, those current spikes led to SEL. So, it is possible that the lower current limit of 10 mA prevented SEL from triggering. Subsequently, the test was resumed with higher current limit thresholds to study the SEL sensitivity.

Figure 3 compares the room temperature and elevated temperature data at 2.75 V and 3.65 V. The SEL cross sections at elevated temperature increased in magnitude relative to the cross sections at room temperature with increasing LET. So, elevated temperature appeared to impact the limiting cross section more so than the threshold LET.

In most cases the SEL was not immediately destructive, although we did not perform a post-latchup life test to examine for latent damage. In cases of nondestructive SEL, a power cycle recovered normal functionality. There were also cases of destructive effects following SEL. A separate third-party study concluded that a combination of high beam flux and inadequate heat dissipation contributed to the destructive failures. The high flux may have triggered multiple SELs from different transistor structures on the die – i.e. micro-latchups. The supply current increased with subsequent SELs. This process continued until the heat buildup exceeded the heat dissipation capacity of the existing packaging and setup, leading to thermal damage. We have not independently studied the failures and verified the proposed mechanism. However, if the hypothesis is true, then the destructive effects would not occur in a space environment with relatively lower flux levels than the cyclotron environment. Further, based on the experimental results, it appears that limiting the SEL current can possibly eliminate physical damage.

Figure 3 also includes Weibull fits of the cross sections for 3.65 V at room and elevated temperature. Table III below shows the Weibull parameters for the average fits. We used the Cosmic Ray Effects on Micro-Electronics Code (CREME96) tool to calculate the on-orbit event rate [4]. The event rate for background galactic cosmic ray heavy ions in the international space station (ISS) orbit behind 100 mil spherical aluminum shielding is approximately 7.28×10^{-9} per day at room temperature and 3.74×10^{-8} per day at elevated temperature. These rates also correspond to failure-in-time (FIT) metrics of 0.30 and 1.56 failures per billion hours.

Table III
Weibull fit parameters for OVdd of 3.65 V.

Parameter	Room Temperature	Elevated Temperature	Unit
LET_0	27	27	*MeV·cm²/mg*
Sigma	3.5×10^{-6}	1.15×10^{-5}	*cm²*
Shape	4.9	4.7	*NA*
Width	48	48	*MeV·cm²/mg*

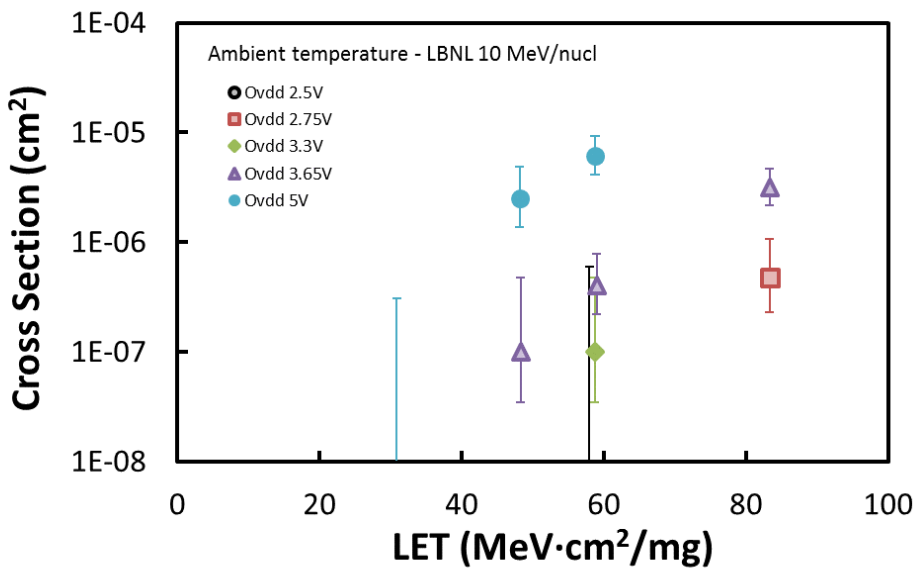

Figure 4. SEL cross section vs. LET for the RT2378 irradiated with 10 MeV/amu heavy ions.

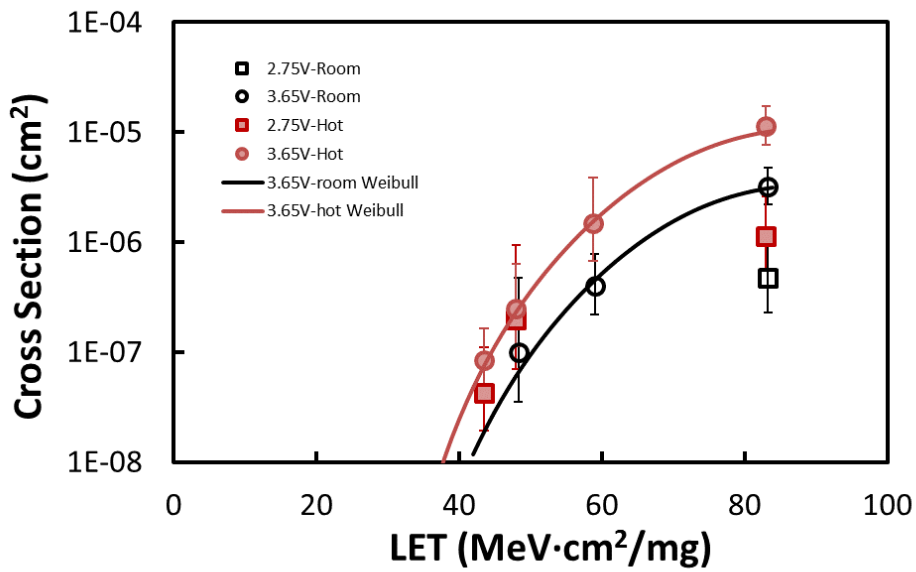

Figure 5. SEL cross section vs. LET for the RT2378 irradiated with 10 MeV/amu heavy ions.

IV. Conclusion

This report summarizes the SEL sensitivity of the RT2378 from heavy ion irradiation carried out by Analog Devices, Inc. We determined that SEL cross section increased with increasing OVdd voltage and with increasing temperature. The SEL cross section was measurably higher for 5 V than for a range of 2.75 to 3.65 V. The SEL sensitivity was enhanced at elevated temperature. Particularly, the limiting cross section was higher at elevated temperature than at room temperature. Most observed events were nondestructive, and recoverable with a power cycle. We also observed destructive events. The destructive failures may be due to specific test conditions of accelerator testing – e.g. high beam flux. Properly limiting the supply current may eliminate or reduce the probability of destructive failures. The average occurrence rate in the ISS orbit is approximately one SEL in 3.77×10^5 years at room temperature and 7.32×10^4 years at elevated temperature.

V. Reference

[1] Analog Devices, Inc. (2018) “RT2378-20 – Radiation Tolerant 20-bit, 1 Msps, Low Power Plastic Package SAR ADC” [Online]. Available: http://www.linear.com/product/RT2378-20 Accessed on: January 16, 2018.

[2] Michael B. Johnson, Berkeley Lawrence Berkeley National Laboratory (LBNL), 88-Inch Cyclotron Accelerator, Accelerator Space Effects (BASE) Facility http://cyclotron.lbl.gov.

[3] JEDEC Government Liaison Committee, Test Procedure for the Management of Single-Event Effects in Semiconductor Devices from Heavy Ion Irradiation," JESD57, http://www.jedec.org/ standards-documents/docs/jesd-57, Dec. 1996.

[4] J. Adams, Jr., A. Barghouty, M. Mendenhall, R. Reed, B. Sierawski, K. Warren, J. Watts, and R. Weller, “CRÈME: The 2011 Revision of the Cosmic Ray Effects on Micro-Electronics Code,” IEEE Trans. Nucl. Sci., vol. 59, no. 6, pp. 3141-3147, Dec. 2012.