ADC Radiation Hardness Evaluation using Femtosecond Pulsed Laser for Space-COTS Applications

Jie-Seok Kim[1*], Seonguk Hwang[1], Hyeokjae Lee[1], Jae-Young Noh[1], and Young-Boo Kim[1]
QRT Inc [1]

Key Words: pulsed laser, COTS, radiation hardness, ADC, SEE, SEL, SEU, evaluation

I. Introduction

A pulsed–laser test is a good substitute for a heavy-ion radiation test. For its advantage in location and cost, it is well suited for space commercial off-the-shelf (COTS) applications.

The purpose of this test is to examine the pulse-laser induced single event effects (SEE) of the MAX153, 8–Bit ADC (analog to digital converter) from Analog Devices / Maxim Integrated. This evaluation was conducted at the QRT Laser Evaluation System. ADC is a semiconductor device that is used to receive analog signals and to read values from sensors. Even though for its popular usage, ADCs usually do not have multiple metal layers, allowing LASER to be irradiated on both the front–side and the back–side.

II. Device Description

MAX153 is a high–speed, microprocessor (μP)–compatible, 8–bit analog–to–digital converter (ADC) that uses a half–flash technique to achieve a 660ns conversion time, and digitizes at a rate of 1M samples per second (Msps). It operates with single +5V or dual ±5V supplies and accepts either unipolar or bipolar inputs. A POWERDN (power–down) pin reduces current consumption to a typical value of 1μA (with 5V supply). The part returns from power-down to normal operating mode in less than 200ns, providing large reductions in supply current in applications with burstmode input signals. [1]

The testing was conducted with the QRT Laser Evaluation System. LASER system was manufactured by RADTEST in the UK, a femto–second pulsed laser that can be used exclusively with single photon absorption (SPA) and two-photon absorption (TPA) owned by QRT Inc.

Table–1. QRT Laser Description

Item	Description
Wave length	650 nm – 1,700 nm
Beam diameter	~ 1 μm (FSWM)
Pulse duration	200 fs.
Laser Injection Energy	30 pJ – 30 nJ

III. Sample preparation and evaluation schematics

The sample was de–capsulated using chemical methods at QRT for laser injection on the chip. To enable laser injection into the semiconductor device, exposing the chip is necessary. The front–side analysis sample was prepared by chemically removing the epoxy molding compound (EMC), which is a packaging material. Meanwhile, for the back–side analysis, the bottom metal support of the chip was grinded to make the metal layer thinner and then it was physically removed to make it possible to irradiate the laser beam on the back–side substrate (not in this report). To perform laser evaluation on a prefabricated ADC, a circuit to drive the MAX153 ADC and a computer system to store and analyze it are required, and a laser suitable for the device conditions must be investigated (Fig. 1). Table–2 shows details the laser irradiation conditions, and a conceptual measurement block diagram of the laser evaluation system as shown in Fig. 1.

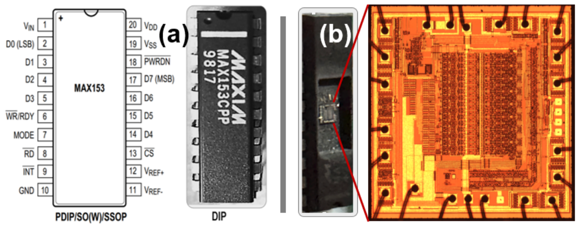


Fig.1. Pin configuration (a) & front de–capsulated MAX153ADC (b)

Fig. 1 describes the system structure for laser evaluation of MAX153 ADC. Fig 2 (a) shows a block diagram of the testing setup.

Tbale–2. LASER irradiation condition

Items	Detail information
Test Environment	Temperature and relative humidity (22°C, 34%)
Supply Voltage (V_{DD})	5V
Reference Voltage (V_{Ref})	5V
V_{in}	2.5V
Laser Energy (E_{LASER})	0.1nJ, 0.2nJ, 0.3nJ, 0.4nJ, 0.5nJ, 0.6nJ, 0.7nJ, 0.8nJ
Laser Wavelength / Mode	1064 nm / SPA
Laser Injection Frequency	500 Hz
Evaluation Parameter	Cross section of SEL and SEU

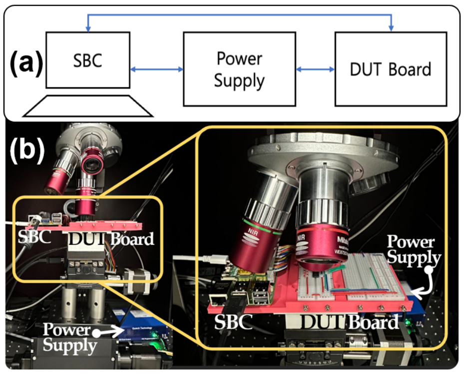


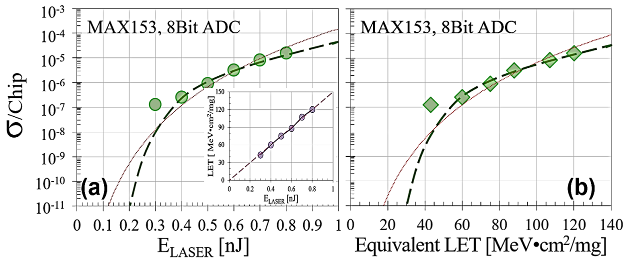
Fig. 2. LASER EVALUATION SETTING: (a) Block diagram of the testing setup, (b) Evaluation system based on (a).

Meanwhile, SBC also controls the device under test (DUT) board and reads values from the ADC. Fig.2 (b) shows a diagram configured to measure the block diagram in (a). A DUT board and an SBC were installed on the moving stage, the power supply was placed on an optical table, and the laser beam was configured to be irradiated to the ADC in the DUT through the objective lens of the microscope.

During the test, if an unusual status in operation or power consumption is held by neither the power supply nor DUT continuously, a power recycle of about 1 second is performed.

IV. Result and discussion

This section shows the result of laser SEE evaluation using the system shown in Fig. 2 after applying the laser beam energy condition and bias condition presented in Table–3 using the de–capsulated MAX153 ADC shown in Fig. 1 (b) [2], [3].



Fig, 3. (a) Cross−section (σ) of MAX153 evaluated by SPA LASER irradiated front−side chip with many laser−energy conditions and (b) Converted heavy ion cross−section (σ)

Fig 3 (a) shows a cross−section (σ) of conducted tests. Still, it has different charge-generating mechanisms with heavy−ions, laser σ will explain heavy−ion σ. σ is the number of error divided by the number of pulses injected, therefor unit (dimension) is cross−section per chip (σ /chip). However, when irradiating laser to the front side, it is important to note that the metal will block a certain amount of laser. Which will result in an under-estimating cross-section. Nevertheless, we can still perfectly extract one important value which is threshold energy. The thin red dotted line is the trend line obtained by the general approach, and the thick dotted line shown in Fig. 3 (a) is obtained by using Weibull fitting. It can be seen that the Weibull curve has a threshold energy value of approximately 0.2nJ, and it can be predicted with fairly high accuracy because no SEE is generated until 0.2nJ of laser energy. On the other hand, the generally provided trend line is approximated to 0.1nJ, confirming that the accuracy is relatively low. Through this analysis, the accuracy of the Weibull fitting method was reconfirmed.

Fig 3 (b) is the corresponding plot of Fig 3 (a) with equivalent linear energy transfer (LET). When we assume that the laser generates a certain amount of charge in the chip we can think about the corresponding heavy ion LET. However, in this case, we yet know the heavy ion measurement result. Therefore we used the correlation shown in Fig. 3 (Fig. 3 inset). Equivalent LET is difficult to estimate because there are a lot of factors that should be considered, such as the chip material, material thickness, degree of surface treatment, semiconductor technology, laser spot size, wavelength, etc. At QRT, we try to provide the best equivalent LET based on a database from multiple laser measurements and multiple heavy ion measurements. From this correlation, the threshold energy using the general trend line will be estimated to be 18−25 LET, and the Weibull trend line should be estimated to be approximately 30−40 LET.

Fig 4 (a) shows input current changes in the log scale. We can see the first current event happened at 0.3 nJ. We recycle the power when the device has not recovered to normal operating condition for a certain amount of time. The green vertical line indicates the event of power recycling. Fig. 4 (b) shows ADC values and the number of events during the test. The number of events is the sum of the number of single event latch−up (SEL) and single event upset (SEU).

Fig. 5. shows the error location of conducted tests. Light green dots represent where an error is most likely to happen. Red lines represent possible error locations due to uncertainty from the operation speed of the device and time logging errors in systems. Also, because this image is generated with comparably fast scanning, if the error did not occur immediately after laser injection, it may be drawn in a different location. Additionally, the error location is comparably very well−drawn due to its very fast operation speed.

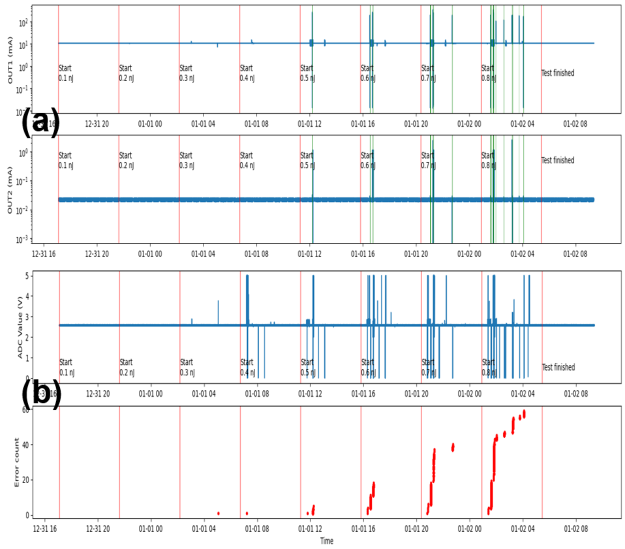


Fig.4. SEE visualization by error mapping on front side chip

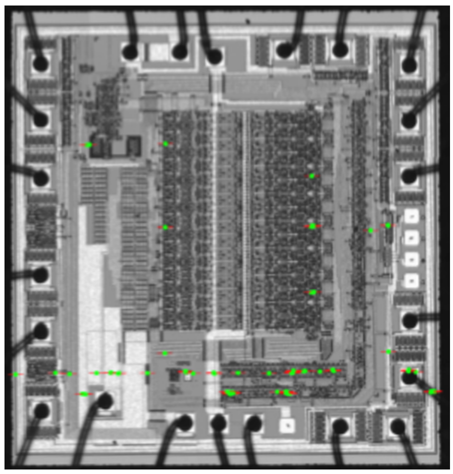


Fig. 5. Error location of MAX153 ADC

V. Summary and Conclusion

In this work, we have examined SEE for the MAX153 − 8bit ADC with a pulsed−laser. We have verified the laser energy threshold. During the pulsed laser SEE test, MAX153 showed output changes and latch−up events induced by laser injection. We confirmed the latch-up phenomenon in ADC by laser injection and secured the conditions for chip protection during SEE measurement to be applied to other ADCs. In addition, we plotted (1) the saturation curve according to laser energy and secured (2) the equivalent LET characteristics with the database (DB) of SRAMs in possession of QRT, and secured data that can be (3) predicted by applying other devices.

For Further work, we are planning to use other 6−7 ADC laser−tested results to improve the accuracy of our laser-heavy ion correlation. Also, we are focusing on ways to complement each other with the 6MeV KIST ion beam, which is currently improving for its usage in radiation tests for semiconductors.

Reference

[1] MAX153 ADC datasheet
[2] Heavy ion test report for GR718A(DC1411) TRAD Dec. 09. 2015
[3] Single event effect test report ADS 1278 (ADC) HIREX Oct. 2014