An Improved SEL Test of the ADV212 Video Codec

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***Abstract*-- Single-event effect (SEE) test data is presented on the Analog Devices ADV212. Focus is given to the test setup used to improve data quality and validate single-event latchup (SEL) protection circuitry.**

I. Introduction

SINGLE-event effect (SEE) testing of microelectronic devices serves two sometimes-overlapping purposes: to determine if susceptibility to a specific destructive phenomena exists [1], and to estimate the rate at which a phenomena will occur during operation. As an example of the former, single-event latchup (SEL) testing is typically performed with the goal of verifying that the device does not latchup under heavy-ion irradiation, often by increasing voltage and temperature to create a worst-case condition. As an example of the latter, single-event upset (SEU) testing thoroughly characterizes sensitivity to a recoverable data upset such that, when combined with a mission profile, one can generate an error rate (for example, in bit-errors per device-day) [2].

Ideally, a part susceptible to destructive effects like SEL would be identified and replaced during the design stage. However, for cost, schedule, availability, or other practical reasons it may not be desirable to substitute an alternative part. This work describes a heavy-ion test of an ADV212 video codec that both characterized the rate of, and demonstrated repeated recovery from, single-event latchups.

II. Devices Under Test

The ADV212 is a single-chip JPEG2000 codec for video and image compression applications manufactured by Analog Devices. It is built on a 180-nm complementary metal-oxide semiconductor (CMOS) process [3]. The devices tested are packaged in a 144-ball Ball Grid Array (BGA) package with gold bond wires. Internally it is a complex device with multiple interconnected digital blocks, including a processor, random access memory (RAM), interconnecting data buses, and dedicated data processor circuitry [3], each potentially subject to numerous single-event effects. A summary of relevant device characteristics is provided in Table I.

TABLE I
DEVICE UNDER TEST

Part Number:	ADV212BBCZ
Manufacturer:	Analog Devices
Type:	Video Codec
Lot Date Code:	1216 & 1220
Process Node:	180 nm CMOS
Packaging:	144 BGA
Test Facility:	Texas A&M Cyclotron

A test apparatus using a Xilinx ML510 board was used to control and communicate with a pair of ADV212s – one under heavy-ion irradiation, and one protected (a so-called golden part). Acid etching was used to remove the plastic encapsulant and expose the entire silicon die of the target DUTs (Fig. 1).

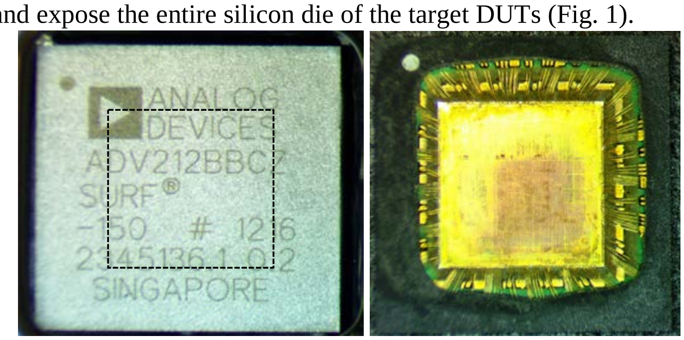

Fig. 1. Packaged ADV212 with superimposed die outline obtained via x-ray (left), and test-ready ADV212 after nitric acid decapsulation (right).

A pseudo-random bit sequence (PRBS) was fed into both devices to simulate a raw image frame, and a cyclic redundancy check (CRC) operation compared the output of the compressed images to each other. Any mismatch between the two outputs was logged as a “CRC Error” and, absent any other observed failure, categorized as a single-event upset (SEU).

The test image size was 1000x1000 pixels, the frame rate was approximately 30 frames per second, and the compression level was configured to 20. Any CRC discrepancy, failure of the device under test (DUT) to communicate with the FPGA, or power supply over-current condition was detected and logged by software operating on a host PC. The device was

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operated at nominal voltage levels (1.5 V_{core}, 2.5 V_{IO}) and at room temperature.

III. Previous Radiation Data

Prior testing [7] of a similar device, the Analog Devices ADV202, was limited to 63-MeV proton irradiation but showed a substantial sensitivity to single-event functional interrupts (SEFI), which presented as device hang-ups without a corresponding increase in power consumption. Based on that data, it was expected that the ADV212 would also be sensitive to single-event effects, and a heavy-ion test was conducted to characterize these effects and to evaluate the possibility of single-event latchup.

The first round of heavy-ion testing for this work was conducted at the Texas A&M Cyclotron Facility in 2013, where it was irradiated with a broad range of ions using the 15-MeV/amu tune. Testing quickly showed that the device is highly-sensitive to numerous single-event functional interrupts (SEFI), many of which were further classified as single-event latchups based on their high-current state and necessity of a power cycle to resume functionality. Other upsets, like bit errors in data frames were also noted.

Critically, the threshold for latchup events was determined to be a linear energy transfer (LET) of between 1.3 and 2.7 MeV-cm^2/mg, far below the typical mission radiation requirements. No parts were ever functionally-damaged or degraded during testing with LETs as high as 85.4 MeV-cm^2/mg. The data showing SEL sensitivity are graphed as cross-section versus LET in Fig. 2, and a least-squares Weibull curve has been overlaid. The best-fit Weibull parameters are shown on the plot for reference.

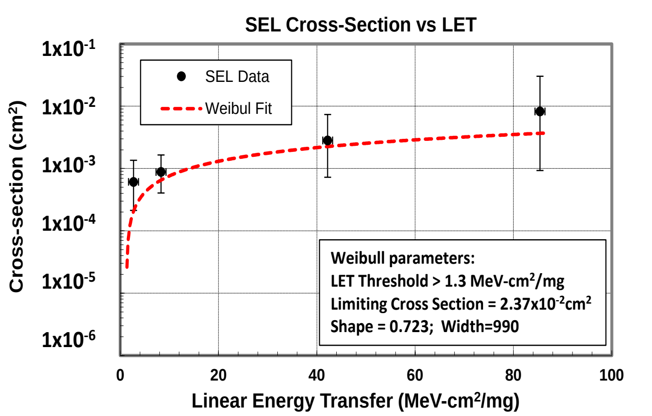

Figure 2. SEL cross-section with Weibull curve fit and parameters

IV. Test Setup Modifications

After the first round of heavy-ion testing, the part was deemed application-critical, and an automatic failure-detection and recovery system was implemented on-board to mitigate the risk posed by frequent SEL. The on-board system detects either a high current (indicative of SEL) or a series of consecutive bad data frames (indicative of a SEFI), automatically cycles power to the ADV212, and reboots the device in as little as 200 ms. For the intended video application, this brief interruption is acceptable.

Although the initial testing produced no functionally-damaged parts, the time for each test run (conducted until a single SEL was detected) precluded demonstrating a large number of latchups. Since latchups cause a localized high-current event, accumulated physical damage is possible [4]. A second round of testing was necessary to validate the added detection-and-recovery circuitry, demonstrate that 1000 SEL cycles were possible without catastrophic failure, and to better characterize the SEL cross-section with a far larger sample size.

With the recovery circuitry added, a method was still needed to automatically test for thousands of latchup events. Latchup tests are commonly performed until a single failure is observed by the test engineer, and then the beam run is ended and the part manually reset. The fluence data and other run parameters from the facility are recorded and testing moves on to the next run. An automated test system was implemented to accelerate the process.

The test facility's shutter system does have a capability to be externally controlled with a TTL-level pulse, but the shutter movement is far slower than the recovery system, meaning that the freshly reset part would be exposed to beam throughout the recovery process and well into the next operating cycle before the shutter was closed. As a solution, an external Thorlabs SH1 optical beam shutter [5] was acquired and attached to the board directly over the exposed ADV212 device. This shutter, intended for optical benches, features a 60 mil aluminum shutter sufficient to block all ions of interest at the energy levels used, and has a 1" aperture. It closes in less than 30 ms after application of a 5-V pulse triggered by the tester FPGA after the latchup detection circuitry detects a SEL or SEFI.

When the ADV212 is successfully rebooted and a clean data frame processed, the FPGA commands the shutter to re-open allowing particles to strike the device again. The shutter, mounted to the test board and placed in front of the Texas A&M beamline, is shown in Fig. 3 on the lower right-hand side of the PCB, held firmly in place over the DUT with a clamp.

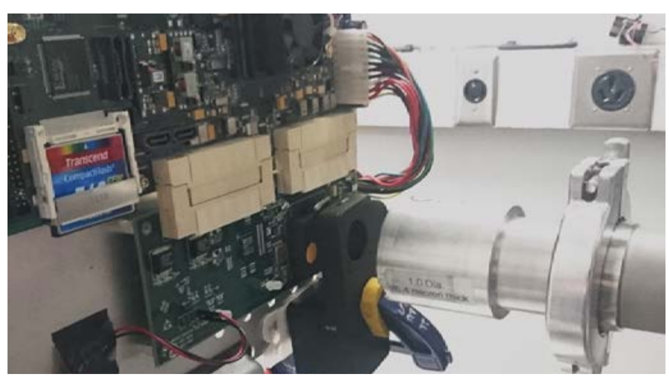

Figure 3. Optical shutter inserted between beam line and device under test

V. Secondary Heavy-Ion Test

The ADV212 was retested at the Texas A&M Cyclotron Facility in 2016, with the heavy ions listed in Table II. Most test runs were conducted with particle flux set as low as reasonably obtainable while maintaining uniformity and stability. Typically, this was between 100-200 particles/cm^2/s. At lower LET, where SEL events were somewhat less common, fluxes up to 500 or 1000 particles/cm^2/s were achievable. Flux levels were maintained to where large numbers of SEL could be recorded in a reasonable time, but yet the events would be well-spaced, and the additional shutter would spend the vast majority of its time in the normal, open position.

For this test, much larger raw fluence levels were possible for each beam run because multiple SEL events could now be recorded and automatically recovered from while the beam was temporarily blocked by the optical shutter. For improved statistics, runs were conducted until several hundred SELs were observed, which typically resulted in an effective fluence between 2x10^4 and 5x10^5 particles/cm^2. Longer runs were also conducted until 1000 latchup events were observed. Because the external shutter was closed for each SEL recovery, an adjustment was necessary to the facility's fluence data to account for that time spent closed. By taking the raw facility data and subtracting the time spent with the external shutter closed, an estimate of the fluence incident on the actual die could be calculated. Care was taken to minimize the percentage of time spent with the shutter closed to minimize the effects of this adjustment, and the flux was carefully monitored for uniformity.

TABLE II
IONS USED

Ion	Nominal LET (MeV*cm^2/mg)
N	1.3
Ne	2.7
Ar	13.0
Ag	42.8
Xe	52.3
Ho	70.0
Au	86.3

VI. RESULTS

With the latchup recovery circuitry and external shutter added for the second round of heavy-ion testing, data revealed a higher SEL sensitivity than observed in the first test. Single-event latchups were detected with an LET as low as 1.3 MeV-cm^2/mg and no threshold was found where the device could operate without latchup. The SEL cross-section from this testing is shown below in Fig. 4. A comparison of this data with that of Fig. 2 shows more than an order of magnitude difference in SEL cross-section at low LET (<10 MeV-cm^2/mg).

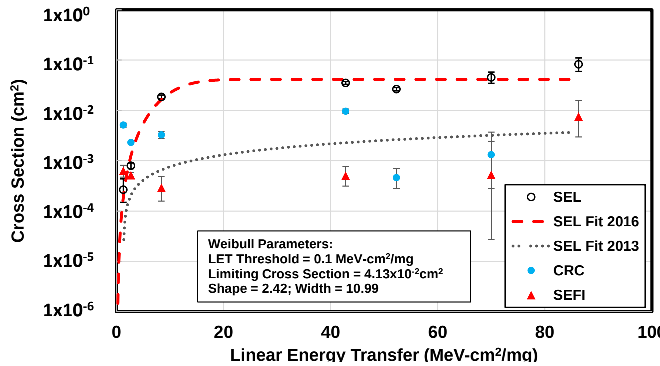

Figure 4. Chart of SEL, CRC, and SEFI events vs. LET

A continuous run with over 1000 detected and recovered SEL was performed at an LET of 42.8 MeV-cm^2/mg to demonstrate the ability of the ADV212 to recover successfully from a large number of latchup events without apparent damage. An additional lot-date code was tested and also passed this test.

The external shutter itself was validated with several beam runs to a fluence of 1x10^7/cm2 while the shutter was kept closed. No errors of any type were noted during these runs, showing that the shutter successfully blocks the beam as predicted.

Newly observed on this test were irreversibly-destructive events. These destructive SEL were found at high LET (above 42.8 MeV-cm^2/mg). The first was discovered when testing with gold ions (LET of 86.3 MeV-cm^2/mg). A relatively short run of 105 latchup and recovery cycles was completed, but the part could not be recovered afterwards. The DUT was replaced with a new part and the same destructive event recurred, this time at an LET of 70 MeV-cm^2/mg. Again the part was replaced, and with the LET further reduced to 52.3 MeV-cm^2/mg, the device survived the 1000 SEL test, but failed after an additional test of 896 cycles. All of these failure modes resulted in a device that could still be functionally commanded and operated, but with a constant stream of frame errors. To eliminate questions about the ADV212 internally warming from the rapid sequence of latch/recovery cycles, the test was repeated with a built-in 10 second cool-down period added before the shutter was re-opened. A new device was inserted into the tester, and it failed after just 7 SEL when exposed to gold ions at an LET of 86.3 MeV-cm^2/mg. All damaged parts were retested two weeks after irradiation and still failed to operate without error.

Other error signatures observed during testing included cyclic-redundancy check errors (CRC) during data processing of the image frame and SEFIs that did not cause the high current levels indicative of a latchup. Except at very low LET, these events occurred less often than the SEL events and are presented in Fig. 4.

The rate calculations listed in Table III were prepared for a polar, low-Earth orbit representative of the intended application using CRÈME96 [6]. A spherical aluminum shell 100 mil thick around the device was assumed. The new SEL rate was estimated at .294 SEL/device/day under quiet, solar minimum conditions, more than twenty times higher than the figure generated with the first data set. A “worst-day” rate was estimated at 621 SEL/device/day. Identical calculations for the image frame errors (CRC errors) estimated 16.3 error frames/device/day for a quiet, solar minimum environment and 40,200 (nearly one every two seconds) on a worst day simulation. Again, these figures were substantially higher than those generated with the initial data set acquired with manual test operation.

TABLE III
RATE ESTIMATE COMPARISONS WITH CREME96

Effect	New Data (Automated Shutter)	Older Data (Manual Operation)
Recoverable SEL	2.94×10^{-1}	1.28×10^{-2}
Destructive SEL	4.97×10^{-5}	0
CRC Frame Error	16.3	N/A

Units in failure/device/day.
Conditions: Quiet, Solar Minimum
Orbit: 705-km Polar
Shielding: 100-mil Al Sphere

VII. CONCLUSIONS

Both heavy-ion data sets show that the ADV212 has a significant cross-section to SEL, SEFI, and SEU even at very low LET. It was also demonstrated that, with proper over-current detection and recovery, the device can withstand well over 1000 SEL events without catastrophic failure. A risk of failure exists, but only for particles with an LET > 42.8 MeV-cm^2/mg.

The testing method described provides a means to rapidly test on-board recovery circuitry while helping to improve data fidelity with a larger sample size and faster detection of SEL. Finally, the vastly increased SEE cross-section data from the second test demonstrate the challenges of testing sensitive devices, particularly where human reaction time may be significant relative to the length of a beam run.

VIII. ACKNOWLEDGMENT

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