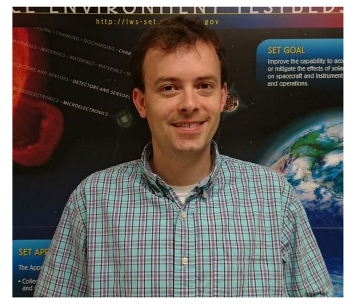

Edward P. Wilcox

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.

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 phenomenon will occur. Single-event latchup (SEL) testing is typically performed with the goal of verifying that the device does not latchup under heavy-ion irradiation, often with increased voltage and temperature (a worst-case condition). 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 a variety of reasons it may not be desirable to substitute an alternative part. For this test, we first identified a susceptibility to SEL, and then implemented a test setup to fully characterize the SEL rate and verify functionality after a large number of SEL.

Device Under Test

Table 1: Summary of Device Characteristics

P/N:	**ADV212BBCZ**
MFG:	**Analog Devices**
Type:	**Video Codec**
LDC:	**1216 & 1220**
Process:	**180nm CMOS**
Package:	**144 BGA**

The ADV212 is a single-chip CMOS JPEG2000 codec for video and image compression applications. 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.

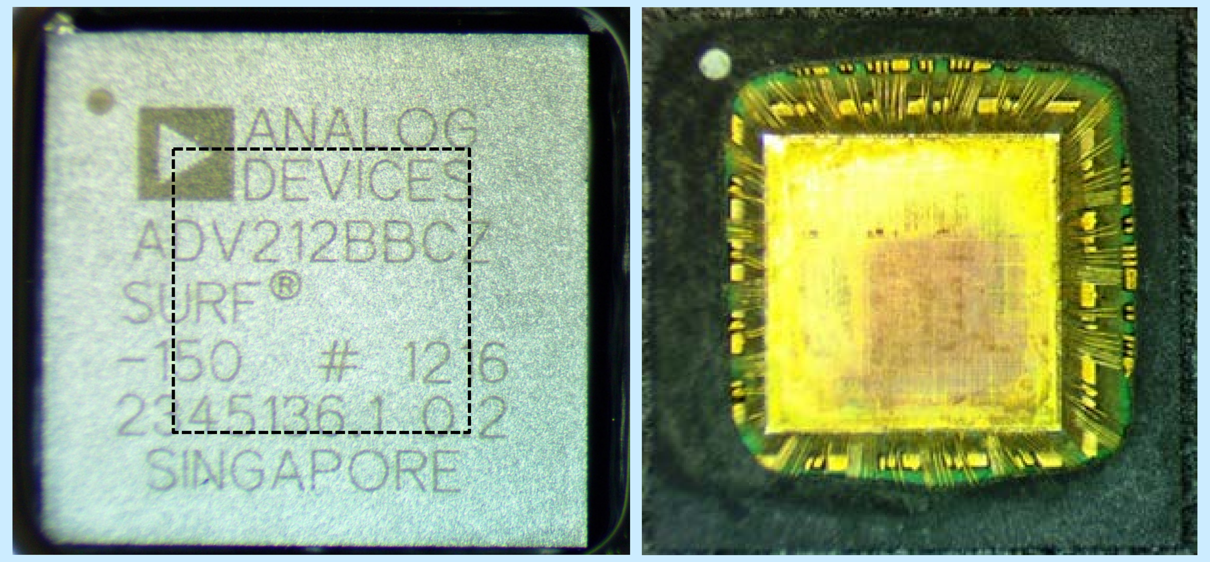

Figure 1: Packaged ADV212 with superimposed die outline obtained via x-ray (left), and test-ready ADV212 after nitric acid decapsulation (right).

A test apparatus featuring a Xilinx ML510 board was used to control and communicate with a pair of ADV212s – one under irradiation, and one protected (a so-called "golden" part). A pseudo-random bit sequence (PRBS) was fed into both devices to represent a raw image frame, and a cyclic redundancy check (CRC) used to compare the output of the compressed images to each other. The image size was 1000x1000 pixels, the frame rate was approximately 30 frames per second, and the compression level was set to 20. Any CRC discrepancy, failure to communicate, or high-current condition was detected and logged. The device was operated at nominal voltage levels (1.5 V_{core}, 2.5 V_{IO}) and at room temperature. Manual decapsulation with red fuming nitric acid was used to remove the plastic encapsulant and expose the silicon die (Fig. 1) before irradiation.

First Heavy-Ion Test Results

The ADV212 was first tested 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 single-event functional interrupts (SEFI), many of which were identified 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-cm²/mg, far below the typical requirements for approval. No parts were ever irreversibly damaged during testing at LET up to 85.4 MeV-cm²/mg. The data showing SEL cross-section and a Weibull curve fit are graphed in Fig. 2.

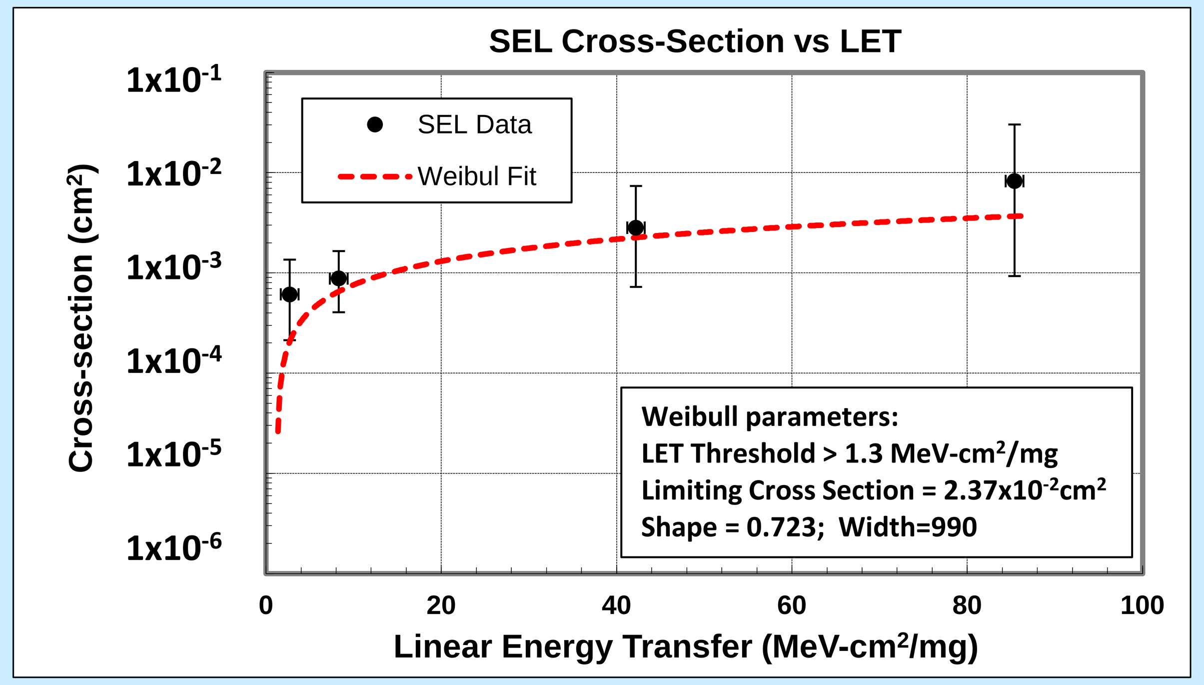

Figure 2. SEL cross-section with Weibull curve fit and parameters

Test Setup Improvements

Because the part was deemed design-critical, an automatic failure-detection and recovery system was implemented on-board to mitigate the risk posed by SEL. The system detects either a high current or a series of consecutive bad data frames and automatically cycles power to the ADV212. Because latchups cause a localized high-current event, physical damage is possible [4]. Initial testing had produced no irreversibly damaged parts, however the reset time for each test run precluded demonstrating a large number of latchups. A second round of testing was necessary to validate the detection-and-recovery circuitry, demonstrate that one thousand SEL cycles were possible without failure, and to better characterize the SEL cross-section.

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 test facility's shutter system can be externally operated, but is much slower than the on-board recovery system. As a solution, an external Thorlabs SH1 optical beam shutter [5] was attached to the board over the exposed 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 when triggered by the latchup detection circuitry. After the ADV212 successfully reboots, the shutter is re-opened 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, held firmly in place with a clamp. A Xilinx ML510 FPGA board is again used to control the DUT, provide sample data, and provide data to the test engineer's computer.

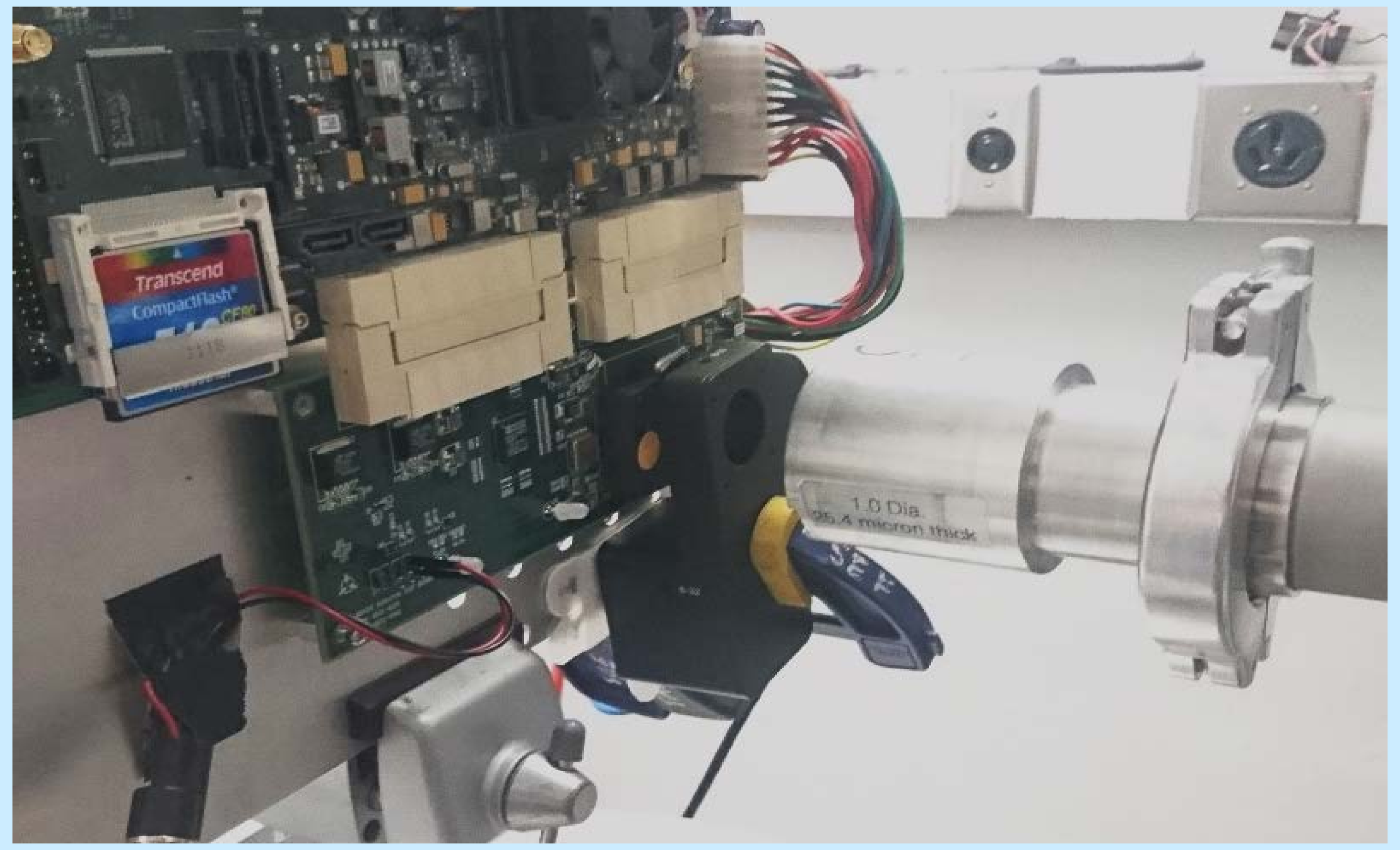

Figure 3. Optical shutter inserted between beam line and device under test

Second Heavy-Ion Test

The ADV212 was retested at the Texas A&M Cyclotron Facility in 2016, with the heavy ions listed in Table 2. 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/cm²/s.

Table 2: Heavy Ions Used at Texas A&M

Ion	Nominal LET (MeV*cm²/mg)	Range in Silicon
N	1.3	428 µm
Ne	2.7	316 µm
Ar	13	229 µm
Ag	42.8	156 µm
Xe	52.3	156 µm
Ho	70	156 µm
Au	86.3	155 µm

For this test, larger 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 2x10⁴ to 5x10⁵ particles/cm². Because the external shutter was closed for each SEL recovery, an adjustment was necessary to the facility's fluence data. By accounting for 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 any error from this adjustment.

Acronyms

BGA = Ball Grid Array
BJT = Bipolar Junction Transistor
CMOS = Complementary Metal Oxide Semiconductor
CODEC = Coder/Decoder
CRC = Cyclic Redundancy Check
DUT = Device Under Test
GSFC = Goddard Space Flight Center
LDC = Lot Date Code
LET = Linear Energy Transfer
MeV = Mega Electron Volt
PRBS = Pseudo-Random Bit Sequence
RAM = Random Access Memory
REAG = Radiation Effects & Analysis Group
SEE = Single-Event Effects
SEFI = Single-Event Functional Interrupt
SEL = Single-Event Latchup
SEU = Single-Event Upset
TAMU = Texas A&M University Cyclotron

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Acknowledgments

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Final Results and Data Comparison

With the latchup recovery circuitry and external shutter added, 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-cm²/mg and no threshold was found where the device could operate without latchup. A comparison of the new data (Fig. 4) with the old (Fig. 2) shows more than an order of magnitude difference in SEL cross-section at low LET (<10 MeV-cm²/mg).

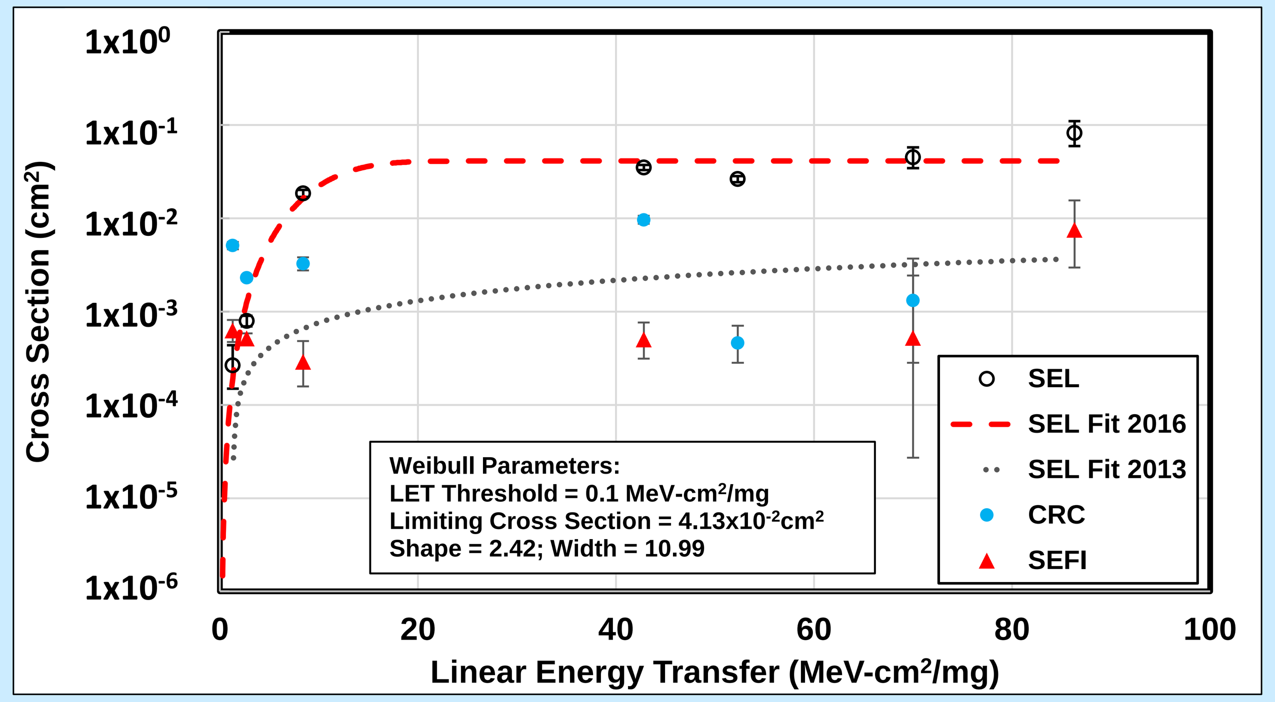

Figure 4. Chart of SEL, CRC, and SEFI events vs. LET

A continuous run with over 1000 detected and recovered SEL was performed at an LET of 42.8 MeV-cm²/mg to demonstrate the ability of the ADV212 to recover successfully from a large number of latchup events without apparent damage.

The external shutter's functionality was validated with several beam runs to a fluence of 1x10⁷/cm² with the shutter kept closed. As expected, no errors of any type were noted during these runs.

Newly observed on this test were irreversibly-destructive events. These were found at high LET (above 42.8 MeV-cm²/mg). With an LET of 52.3 MeV-cm²/mg, a device survived the 1000 SEL test, but failed after an additional test of 896 cycles. To alleviate concerns about dose or heat-related effects, a fresh device was irradiated with gold (LET of 86.3 MeV-cm²/mg) and it failed completely after just 7 SEL cycles. Additional devices failed at LET in between.

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 (Fig. 4).

Rate calculations were prepared for a polar, low-Earth orbit representative of the intended application using CRÈME96 [6] and compared with those generated using the initial data set. The estimated SEL rate was shown to be more than twenty times higher with the improved data.

Table 3: On-Orbit Rate Estimate Comparison

Rate Estimate Comparisons with CREME96	New Data	Old Data
Recoverable SEL	2.94×10^{-1}	1.28×10^{-2}
Destructive Events	4.97×10^{-5}	0
Conditions: Quiet, Solar Minimum Orbit: 705-km Polar Shielding: 100 mil Aluminum		

Summary

The data show that the ADV212 has a significant cross-section to SEL, SEFI, and SEU even at very low LET. However, 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-cm2/mg. The testing method shown provides a means to test on-board recovery circuitry while helping to improve data fidelity with a larger sample size and faster detection of SEL. Finally, the increased SEE cross-section with this test demonstrates the challenges of testing sensitive devices, particularly where human reaction time may be significant relative to the length of a beam run.

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