Overview of iRoC Technologies' Report "Radiation Results of the SER Test of Actel, Xilinx and Altera FPGA Instances"

Introduction

Particles contained in cosmic galactic rays enter the earth's atmosphere and collide with atoms of atmospheric gases. These collisions produce a wide variety of sub-atomic particles, many of which recombine quickly. However, a significant quantity of high-energy neutrons are also produced by these collisions. Neutrons possess no electrical charge, and do not recombine; instead, they are slowly attenuated by the atmosphere. While the greatest quantities of neutrons (called the neutron flux density) occur at an altitude of 60,000 feet, a significant number of neutrons penetrate the atmosphere and reach the earth's surface. These high-energy neutrons can cause flip-flops and memory cells in modern semiconductor electronics to change state. Given this discovery, the effects of neutrons on programmable logic devices, which use memory cells to determine their functionality, is a major concern.

Additionally, plastic package molding compounds contain tiny quantities of radioactive isotopes which emit alpha particles. Many of these alpha particles are sufficiently energetic to cause upsets in data flip-flops and memory cells, including the configuration SRAM memory in programmable logic.

In response to this concern, iRoC Technologies has conducted a series of tests to determine the failure rates of five different architectures of field programmable gate arrays (FPGAs), using three different programming technologies from three different vendors.

Testing FPGAs for Susceptibility to Neutrons – Experiments and Results

Testing in the natural environment on the earth's surface is a slow process due to the low neutron flux relative to higher altitudes. To perform testing in an expeditious and repeatable manner requires accelerated testing. Fortunately the neutron test facility at the Los Alamos Neutron Sciences Center (LANSCE) at Los Alamos National Laboratory in New Mexico, has a neutron source with an energy spectrum that closely matches the energy spectrum observed in atmospheric neutrons but at a much higher flux level. This allows for accelerated testing while maintaining close correlation with real-world conditions.

A significant investigation into neutron effects on the configuration of FPGAs was conducted in February 2004 by iRoC Technologies. The test methodology and results are documented in the iRoC report titled, "Radiation Results of SER Test of Actel, Xilinx, and Altera FPGA Instances." Testing was performed on a selection of three SRAM-based FPGA architectures from Xilinx and Altera, as well as antifuse- and flash-based FPGAs from Actel. Tests were performed in compliance with JEDEC specification JESD-89, which is recognized as the industry standard specification for the measurement of neutron effects. Each device was exposed to a cumulative neutron fluence of at least 9.3x108 n/cm2, which is equivalent to exposure to natural background neutron radiation at sea level for 7,600 years. The test team developed a design that was used to detect anomalous behavior indicative of changes in FPGA functionality. These changes are called logic errors or single event functional interrupts (SEFIs). Because these changes remain until detected and cleared, they are referred to as firm errors. Throughout the test, configuration files were read back from the FPGAs periodically to detect configuration upsets, although it was not possible to read back the configuration files from the Cyclone SRAM FPGAs from Altera. Configuration upsets are also referred to as single-event upsets (SEUs). Because of redundancy in FPGA routing architectures, not every configuration upset (SEU) causes a logic error (SEFI).

The testing demonstrated that antifuse- and Flash-based FPGAs are not subject to loss of configuration due to neutron effects. The tests also demonstrated that the three SRAM-based FPGA architectures are vulnerable to configuration loss due to neutrons and provided an indication of how frequently a configuration upset results in a logic error in each SRAM FPGA. The results are documented in Table 1. The failure rates are shown in FITs (Failures In Time). One FIT is defined as one failure in 10^9 hours. Therefore a FIT rate of 320 equates to 320 failures in 10^9 hours. Typically, integrated circuits have FIT rates below 100. In high-reliability applications, component engineers will look for FIT rates in the region of 10 to 20.

JESD-89 describes how neutron flux increases as altitude increases, up to a maximum at 60,000 feet. This was used to calculate the failure rates for a variety of altitudes.

Table 1: **Neutron Test Results (iRoC Testing at LANSCE)**

Vendor	Device	Configuration Upsets (SEUs)	Logic Errors (SEFIs)	Logic Error FIT Rates			
				Sea Level	5,000 ft.	30,000 ft.	60,000 ft.
Actel	AX1000	Not Measured	0	<0.08 FITs	<0.28 FITs	<12 FITs	<39 FITs
Actel	APA1000	Not Measured	0	<0.04 FITs	<0.13 FITs	<5.6 FITs	<18 FITs
Xilinx	XC2V3000	3,459	349	1,150 FITs	3,900 FITs	170,000 FITs	540,000 FITs
Xilinx	XC3S1000	1,936	405	320 FITs	1,100 FITs	47,000 FITs	150,000 FITs
Altera	EP1C20	Not Measured	453	460 FITs	1,600 FITs	67,000 FITs	220,000 FITs

Testing FPGAs for Susceptibility to Alpha Particles – Experiments and Results

Testing performed by iRoC Technologies quantifies the risk of functional failures in SRAM FPGAs due to alpha particles emitted from plastic package molding compounds. This testing also demonstrates that Actel's antifuse-based and Flash-based FPGAs do not suffer configuration loss or functional failure due to alpha particles emitted by packaging impurities. The results are documented in Table 2. Note that the quantity of alpha particles a device will be exposed to is determined by the molding compound and not by the elevation. The results show that alpha particles arising from packaging impurities can be a significant contributor to the device FIT rate at sea level. At high altitudes, the effects of atmospheric neutrons outweigh the effects of alpha particles.

Table 2: **Alpha Particle Test Results (iRoC Testing)**

Vendor	Device	Logic Error FIT Rates with Low-Alpha Mold Compound	Logic Error FIT Rates with Standard Mold Compound
Actel	AX1000	< 0.001 FITs	< 0.04 FITs
Actel	APA1000	< 0.001 FITs	< 0.04 FITs
Xilinx	XC2V3000	140 FITs	5,600 FITs
Xilinx	XC3S1000	260 FITs	10,400 FITs
Altera	EP1C20	100 FITs	4,000 FITs

Conclusion

SRAM-based FPGAs use SRAM cells to store the configuration data that gives the devices their functionality. An upset to one of these SRAM cells could result in the FPGA losing its configuration. When this occurs, the host system could malfunction. Neutrons arising from atmospheric collisions of galactic cosmic particles can cause upsets in the configuration memory of SRAM FPGAs, and therefore pose a significant reliability risk for many different types of electronic equipment, both airborne and ground-based. Alpha particles arising from radioactive impurities in package molding compounds pose a similar problem.

Radiation testing data has shown that Actel's antifuse-based and Flash-based FPGAs are not subject to loss of configuration due to upsets caused by atmospheric neutrons or alpha particles emitted from packaging materials. This makes them eminently suitable for applications—both ground-based and airborne—where high reliability is imperative.

For more information, visit our website at **www.actel.com**

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