Single-Event Effects in FPGAs

GROUND LEVEL AND ATMOSPHERIC BACKGROUND RADIATION EFFECTS IN FPGAs

Integrated Circuit (IC) malfunctions due to radiation effects have become common in ground-level and airborne applications. The effects of subatomic radiation particles on ICs are frequently referred to as "single-event effects." Particle radiation—such as neutrons arising in the atmosphere, or alphas arising in packaging materials—can cause flip-flops and memory cells to change state. A data error, which occurs as a result of the radiation-induced change in state of a flip-flop or memory cell, is called a "soft error." However, if a memory cell contains configuration data in an SRAM-based FPGA, the change in state is much more serious, as it can cause an unintended change in functionality of the FPGA. This is called a "firm error."

Programmable logic devices based on SRAM technology are susceptible to single-event errors where alpha and neutron radiation causes loss of configuration data. The loss of the underlying FPGA configuration is called a "firm error," and it will remain until detected and corrected. In contrast, a "soft error" is the transient corruption of a single bit of data. Firm errors can cause system-level functional failure, and are very difficult to prevent and correct.

Key Benefits

- **Actel Antifuse and Flash-Based FPGAs are Not Susceptible to Configuration Loss Due to Single-Event Errors (SEE) Caused by Alpha or Neutron Radiation**
- **No SEE Mitigation Techniques for Configuration Upsets are Required in Actel FPGAs, Reducing Overall System Cost**
- **Actel FPGAs Maintain System Integrity at High Altitudes and Sea Level**

Alpha and neutron-induced errors can destroy the integrity of data being stored in SRAM cells. This could lead to incorrect data being stored in the SRAM-based FPGA configuration memory that will result in malfunction. Systems using SRAM FPGA solutions at high altitudes need to incorporate error mitigation techniques to ensure that critical components maintain integrity. High reliability is a requirement for many applications, including military, aerospace, industrial control, medical, automotive, networking, and communications.

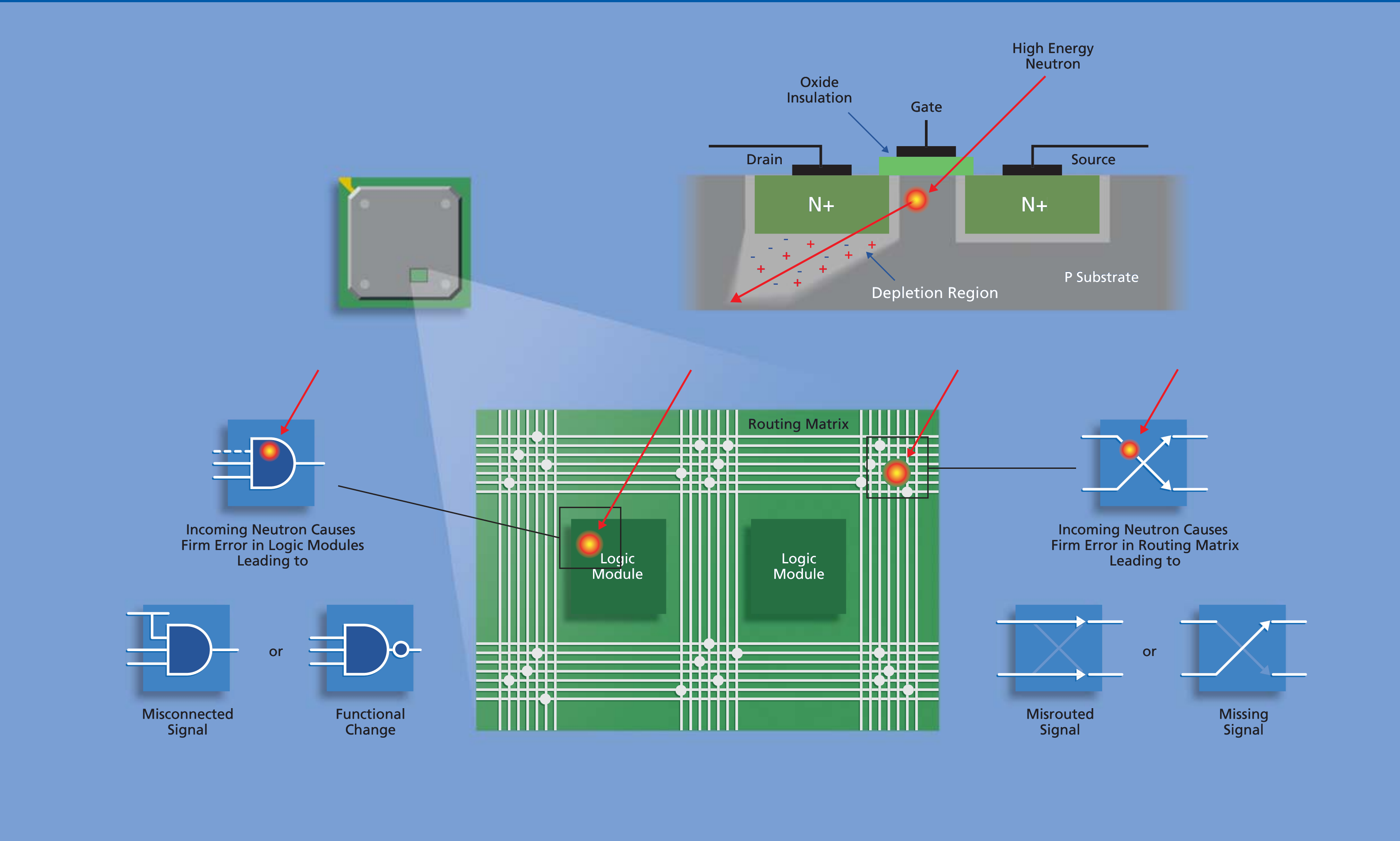
System malfunctions can cause severe losses to corporations, including financial and property losses. Actel is a recognized leader in FPGAs and continues to work with industry partners in providing FPGA solutions that are not susceptible to single-event effects.

SRAM Failure Mechanisms

Neutron Radiation High-energy neutrons, which are present in the atmosphere and at ground level, arise from the interaction of atmospheric gases and high-energy subatomic particles from the sun and deep space. A neutron striking a silicon atom in a semiconductor IC causes the ejection of heavy ions. These heavy ions can cause momentary current pulses, causing the data to change in memory cells or flip-flops. SRAM FPGAs, when exposed to neutron radiation, are susceptible to single-event effects, possibly leading to firm errors in the logic module or the routing matrix. Firm errors in the logic module can cause a functional change (for example, AND to NAND), resulting in system failure. Firm errors in the routing matrix can lead to misrouting or misconnection of signals which, in turn, could also lead to system failures. Figure 1 shows the effects of a firm error on an SRAM FPGA.

Alpha Radiation Alpha particles are emitted by naturally occurring radioactive isotopes. Alpha particles are generated by impurities (primarily Uranium and Thorium) in integrated circuit (IC) package molding compounds. Even with today's low-alpha compounds in package materials, sufficient alpha particles are generated to cause a significant rate of upsets in state-of-the-art SRAM FPGAs. Uranium (U238) and Thorium (Th232) present in molding compounds are part of today's SRAM packaging strategy. They can be a source of significant data upsets that can cause the contents of the flip-flops and memory cells to

Figure 1: Effects of Neutrons on SRAM FPGAs



change state, leading to data corruption in the FPGAs. These upsets are termed "soft errors," since the flip-flops and memory are not permanently damaged. However, data upsets in the configuration memory that is used to load the configuration into the SRAM FPGA can cause incorrect data to be loaded into the FPGA, which can cause a failure in the FPGA functionality. Even though low-alpha mold compounds are being introduced in FPGA packaging technology, they may not totally eliminate the radiation effects of alpha particles. The table below summarizes Failures-in-Time (FIT) rates for several devices that use SRAM FPGAs.

Testing and Results

Real world testing is slow, cumbersome, and provides inadequate results. A repeatable accelerated testing methodology is required to obtain a significant number of failures quickly. An independent organization, iRoC Technologies, conducted both alpha and neutron testing on FPGAs using three different programming technologies, with five different architectures from three major FPGA vendors. The FPGAs were tested until a significant number of failures were observed. Based on these results, the FIT rates were calculated.

The neutron testing was conducted by exposing the FPGAs to neutron radiation and calculating the FIT rates. The FIT rate number for SRAM FPGAs is much worse than acceptable standards for high-reliability applications at ground level. The results also indicated that the FIT rate increased rapidly with decreasing process geometry. Additionally, the FIT rate increases dramatically with altitude and greatly exceeds the acceptable FIT rate for commercial applications (< 100) and high-reliability applications (< 20). A summary of the test results is shown in the table below.

The alpha testing was conducted by exposing the FPGAs to alpha radiation and calculating the failure rates using industry-accepted figures for alpha emissions from low-alpha molding compounds. The FIT rates obtained were in the range of 100 to 200 FITs per 1 million gates. A typical high-reliability application will require a FIT rate per device of less than 20. SRAM FPGAs were observed to have FIT rates very much above the recommended FIT rates as opposed to Actel FPGA FIT rates, which were insignificant.

Neutron Radiation Test Results Summary

FPGA	Technology	Equivalent Functional FIT Rates per Device			
		Ground-Level Applications		Commercial Aviation	Military Aviation
		Sea Level	5,000 Feet	30,000 Feet	60,000 Feet
Actel AX1000 1 M Gate	0.15 µm Antifuse	No failures detected	No failures detected	No failures detected	No failures detected
Actel APA1000 1 M Gate	0.22 µm Flash	No failures detected	No failures detected	No failures detected	No failures detected
Actel A3PE600 600 k Gate	0.13 µm Flash	No failures detected	No failures detected	No failures detected	No failures detected
Vendor1 SRAM FPGA 3 M Gate	0.15 µm SRAM	1,150 FITs	3,900 FITs	170,000 FITs	540,000 FITs
Vendor1 SRAM FPGA 1 M Gate	90 nm SRAM	320 FITs	1,100 FITs	47,000 FITs	150,000 FITs
Vendor2 SRAM FPGA 1 M Gate	0.13 µm SRAM	460 FITs	1,600 FITs	67,000 FITs	220,000 FITs
Vendor2 SRAM FPGA 1 M Gate	90 nm SRAM	730 FITs	2,500 FITs	108,000 FITs	346,000 FITs
Vendor2 SRAM FPGA 2 M Gate	90 nm SRAM	1,600 FITs	5,500 FITs	236,000 FITs	751,000 FITs

* Design security features in Actel FPGA solutions prevent configuration read-back.

Alpha Radiation Test Results Summary

FPGA	Technology	Equivalent Failure-In-Time (FIT) Rate	
		Low-Alpha Mold Compound (0.001 α/cm²-hr)	Standard Mold Compound (0.04 α/cm²-hr)
Actel AX1000 1 M Gate	0.15 µm Antifuse	No failures detected	No failures detected
Actel APA1000 1 M Gate	0.22 µm Flash	No failures detected	No failures detected
Actel A3PE600 600 k Gate	0.13 µm Flash	No failures detected	No failures detected
Vendor1 SRAM FPGA 3 M Gate	0.15 µm SRAM	140 FITs	5,600 FITs
Vendor1 SRAM FPGA 1 M Gate	90 nm SRAM	260 FITs	10,400 FITs
Vendor2 SRAM FPGA 1 M Gate	0.13 µm SRAM	100 FITs	4,000 FITs

* Design security features in Actel FPGA solutions prevent configuration read-back.

Summary

FPGA technology plays a major role in long term system reliability. Applications using SRAM FPGAs are prone to malfunction due to exposure to background radiation, resulting from neutrons in the atmosphere and alpha particles contained in the molding compounds used in FPGA packages. Alphas and neutrons do not have this effect on Actel antifuse and flash-based FPGAs. Whether your designs will be used at ground level or at high altitude, Actel offers extremely reliable FPGAs under ALL conditions with long-term reliability. For more information on single-event effects and the testing conducted by iRoC Technologies along with the full test results, visit **http://www.actel.com/products/solutions/ser/default.aspx**.

To learn more about **Actel FPGA** solutions, visit **http://www.actel.com**. For specific information regarding **Single-Event Effects**, please contact your local **Actel** sales representative.

www.actel.com

Actel Corporation
2061 Stierlin Court
Mountain View, CA
94043-4655 USA
Phone 650.318.4200
Fax 650.318.4600

Actel Europe Ltd.
River Court, Meadows Business Park
Station Approach, Blackwater
Camberley Surrey GU17 9AB
United Kingdom
Phone +44 (0) 1276 609 300
Fax +44 (0) 1276 607 540

Actel Japan
EXOS Ebisu Building 4F
1-24-14 Ebisu Shibuya-ku
Tokyo 150, Japan
Phone +81.03.3445.7671
Fax +81.03.3445.7668
www.jp.actel.com

Actel Hong Kong
Suite 2114, Two Pacific Place
88 Queensway, Admiralty
Hong Kong
Phone +852 2185 6460
Fax +852 2185 6488
www.actel.com.cn

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