Using Classical Reliability Models and Single Event Upset (SEU) Data to Determine Optimum Implementation Schemes for Triple Modular Redundancy (TMR) in SRAM-based Field Programmable Gate Array (FPGA) Devices

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Abstract: Space applications are complex systems that require intricate trade analyses for optimum implementations. We focus on a subset of the trade process, using classical reliability theory and SEU data, to illustrate appropriate TMR scheme selection.

Introduction

This study investigates mitigation performance and offers analysis for a variety of TMR design strategies. The motivation is to provide a means for developers and decision-makers for critical applications. Risk is assessed by analyzing reliability across time using classical reliability models and measured single event upset (SEU) data.

In this study, reliability is also analyzed across particle fluence by transforming ionization rates curves [1] from the time domain to the fluence domain. As a benefit, analyzing mitigation in the fluence domain enhances the analysis accuracy by providing the ability to make direct comparisons to accelerated radiation test (ARDT) data [2].

Distributed TMR (DTMR) is targeted for complex blocks in digital logic (i.e., shift registers, RAMs, and memories) where the voters are placed.

Equation (1) describes the four categories of SEUs in FPGAs [3]. Mitigation strategies for complex blocks include utilizing partitioning, and this design can be modified into mitigation windows (MW). The effects of the SEU can be reduced by classical mitigation:

- The SEU is associated with an unused resource or disabled logic and consequently does not affect system operation.
- The SEU has a direct effect on the voter, outside the basic SEU mitigation strategy, where the voter feedback to DFFs are used to correct errors. This includes a block TMR (BTMR), only DFFs are affected by the SEU, then the MI2 will instructions, and the fault will not be tested from the system. This is a common signature of a complex block SEU in a TMR configuration that was obtained by performing heavy-ion testing at Texas A&M Cyclotron Institute.

Table 1 lists the classical reliability and Mean time to failure (MTTF) for TMR (BTMR) versus System with No Mitigation. The SEU fault only affects one of the TMR triplet copies within the same mitigation window (MW). If only one triple copy is affected, it will fail after a short period of time, however, the MI2 will write instructions, and the fault will not be tested from the system. This is a common signature of a complex block SEU in a TMR configuration that was obtained by performing heavy-ion testing at Texas A&M Cyclotron Institute.

MFTF = 1 / λ

Where

- λ: Failure rate

The primary design under investigation (DUI) was the Counter Array [2] as illustrated in Figure 7. Variations of the DUI were created that were manually developed: (1) no-mitigation (pure counters), (2) BTMR with partitioning, (3) DTMR with partitioning, and (4) DTMR without partitioning (feedback DTMR and LTMR in some areas). The primary design under investigation (DUI) was the Counter Array [2] as illustrated in Figure 7. Variations of the DUI were created that were manually developed: (1) no-mitigation (pure counters), (2) BTMR with partitioning, (3) DTMR with partitioning, and (4) DTMR without partitioning (feedback DTMR and LTMR in some areas). The primary design under investigation (DUI) was the Counter Array [2] as illustrated in Figure 7. Variations of the DUI were created that were manually developed: (1) no-mitigation (pure counters), (2) BTMR with partitioning, (3) DTMR with partitioning, and (4) DTMR without partitioning (feedback DTMR and LTMR in some areas).

Figure 9: Integral LET spectra for GCR during solar minimum. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. The LET spectrum for GCR during solar minimum is shown in Figure 9. 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