SESEE: A Soft Error Simulation and Estimation Engine

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Abstract
Soft errors are radiation induced ionization events that upset the logic state of the circuit. The sources of these radiations are cosmic in origin; hence traditionally these upsets affected the space and aviation electronics. Due to technology scaling, these upsets are manifesting as errors in general off-the-shelf electronics circuits and hence a good simulation and error estimation tool is needed. In this work we present a new tool called Soft Error Simulation and Estimation Engine (SESEE). In this tool we simulate neutron induced soft error from basic principles, and use this information along with the information from circuit layout and spice-level simulation to calculate the circuit's soft error rate (SER). Also as a case study the soft error rate of a custom SRAM array is evaluated.

1. Introduction

Soft errors are the most benign form of radiation effects on the circuitry, where radiation directly or indirectly induces a localized ionization capable of upsetting internal data states. While these errors cause an upset event, the circuit itself is not damaged. Soft errors can cause errors at both logic and memory circuits. Recently, soft errors have been identified as a dominant source of failure in commercial designs [6, 11]. Therefore, analysis of traditional designs for soft error rates and protecting them against soft errors is of paramount importance.
There has been considerable effort spent on understanding the phenomenon. Soft errors by there very nature calls for an interdisciplinary approach. The phenomenon by itself has its origin in nuclear and device physics, but most solutions exist in either circuit or architecture level of abstraction. Earlier studies and tools from IBM and Fujitsu gave us an in-depth understanding of the problem but ignored the circuit topology and design [1, 2, 3]. Our tool calculates SER by not only accounting for the charge collection process but also considers the circuit design and layout topology.

2. Soft Error Simulation Tool

The tool is based on as two sub processes, first is modeling the exact neutron–silicon substrate interaction, and second is interpreting the effect of such an interaction on the electrical properties of the circuit. There are three processes that are accounted for an accurate analysis of neutron–silicon substrate interaction; they are atmospheric neutron spectrum, neutron–nucleus collisions within the silicon substrate and, the ion track generation by the products in the silicon medium and the subsequent charge collection. Based on the information thus obtained we created a data base of the charge collected for a spectrum of incident neutron flux. Next, we developed a flow to extract the required spatial and electrical information from the layout and spice-netlist of a given circuit. Using such an information, accurate and design dependant soft error rate is obtained. This in turn makes our tool unique from previous work [2, 3]. The overall tool flow is given in figure 1; the following subsections will describe the tool in detail.

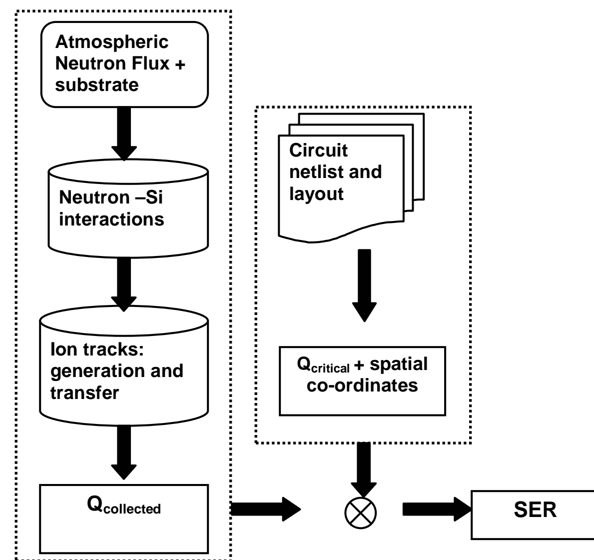

Figure 1: Tool Flow

2.1. Neutron Collision

The cosmic rays consist of muon, neutrons and protons (negligible). About 99% of soft-errors by secondary cosmic-rays are caused by cosmic-ray neutrons. The inputs for the neutron-Si collision analyzer are the cosmic-ray neutron spectrum from [5] along with the technology dependent process parameters such as the concentration of the P type acceptor and N type donor ions. MCNP codes are used to model the interactions themselves [8]. MCNP is a general-purpose Monte Carlo N-Particle code that can be used for neutron, electron, and photon. MCNP codes account for both elastic scattering and non-elastic scattering. It is known that elastic neutron-nucleus collisions involve small recoil

energies; hence they have very little effect in device operation [10]. Non-elastic collisions, on the other hand, mainly involve absorption and inelastic scattering. Absorption is a major contributor for low energies neutrons, where as inelastic scatterings play a key role in energy transfer of high neutron energies. The elimination of ^{10}B from the manufacturing process makes inelastic collisions of neutrons with silicon atoms, as a principle source of soft errors.

MCNP models both of these and the reaction products thus obtained, are parsed and transferred to another Monte Carlo code, TRIM, for charged particle transport analysis in the substrate medium [4, 9] . TRIM is used to calculate the full target recoil cascade and the associated ion tracks. Using MCNP and TRIM together provides us with an accurate analysis of the charge creation and collection by a typical neutron strike; this charge is referred as $Q_{collected}$. Since the atmospheric neutron flux distribution is a well studied phenomenon, we created a database of the $Q_{collected}$ for the different neutron energies. Next, we use this database in conjunction with the layout and circuit information to get the SER.

2.2. Circuit and layout detail

To obtain the spatial and electrical information of the circuit we use the layout and spice-netlists. In general, the critical charge (also called as $Q_{critical}$) is used by the circuit designers to quantify the circuit's susceptibility to the soft error. For a soft error to occur at a specific node in a circuit, the collected charge $Q_{collected}$ at that particular node should be more than $Q_{critical}$[7]. This value is obtained from the circuit simulation of the spice-netlists. The critical charge is estimated by the injecting a suitable current pulse which accounts for funneling and then noting the minimum time required for a change in the value stored at that node.

The probability of a given radiation event to generate an upset at a given node is dependent on the node's location and proximity of the strike; hence the spatial information of the circuit is important and shouldn't be neglected. For example, in the figure 2, an ionization event can potentially cause the errors in any of the adjacent cells (shown in the shaded region) depending on the ionization tracks, the magnitude of the $Q_{collected}$, and the size of the cells. To account for these, we created a custom extractor which extracts the layout information from the custom designs and creates a data structure that maps the spatial information with the electrical information ($Q_{critical}$). This data structure describes each node with its $Q_{critical}$ and its spatial co-ordinates with respect to a fixed location. For a particle strike at a random location, combination of this data structure with the database of the $Q_{collected}$ will provide us with the exact SER of the all the nodes of the circuit. Such information is also useful in examining the multi-bit errors induced by single radiation event.

3. Conclusion

In this work, we presented a new tool to evaluate the neutron induced soft error rate. This work accounts for both the physics and the electrical properties of the soft error phenomenon. Our work is an improvement over the previous work as we account for both the charge creation process and, the circuit's design and layout topology dependency. The combination of MCNP and TRIM enables to model the charge collection better than previous approaches in [2, 3]. The use of spatial information takes the SER analysis a step further and accounts for circuit topology. The proposed tool framework is suitable for ASIC design methodology, as the methodology is scalable to do library characterization.

4. References

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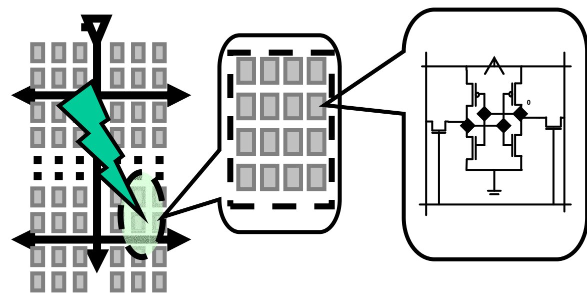

Figure 2: Typical SRAM memory