Transactions of the Korean Nuclear Society Autumn Meeting
Goyang, Korea, October 24-25, 2019

Modeling and Simulation Methodology on a Single Transistor for Radiation Hardened Design by Using Geant4

Jinsuk Oh, Inyong Kwon*
Korea Atomic Energy Research Institute
**Corresponding author: ikwon@kaeri.re.kr*

1. Introduction

In harsh environments like space and nuclear applications, the single-event-effects (SEE) can occur due to the radiation interaction between high energy particles and a circuit of a device [1]. Particularly, for digital circuit, latch-up and bit flip can lead reverse data state. To analyze this phenomenon, the devices should be needed to construct the electrical model and be evaluated for SEE from the transistor that is the basic elements of circuits. Therefore, it is necessary to improve the reliability of radiation-hardened-by-design (RHBD) techniques by simulating the interaction between particles and materials by numerical simulation tools such as Geant4, ROOT, and MCNP.

For this research, *Tool suIte for rAdiation Reliability Assessment* (TIARA-G4) that consists of two parts in modeling a device and simulating interaction between radiation source and circuit is a suitable tool that can comprehensively analysis the nuclear dynamic and properties on electronic devices. One part of TIARA-G4 is a function of Geant4 to model circuits and sources. The other part is called ROOT that is addressed for data processing. These two parts are easily linked via C++ , resulting in an integrated simulation property. In Section 2, we will describe each sub-class in details. In Section 3, the simulation methodology will be shown in a flow chart to evaluate SEE and soft-error rate (SER) induced by high energy particles.

In this paper, a research propose will be suggested for a methodology to analyze the SER in RHBD circuits by using Geant4 and ROOT. This method will be useful for designing and evaluating not general circuits, but RHBD circuits. Finally, further development plans for substantial data and work will be discussed in Section 4.

2. Tool Description

The simulation tool, TIARA-G4 is performed two simulation processing: Geant4 and ROOT.

The TIARA-G4 Monte-Carlo simulation complies with classes, libraries, and applications of Geant4. It is rewritten with C++ from the old version (TIARA) to compatible with other toolkits and designed to consider a physical interaction between more realistic circuits and diverse types of particles, such as protons, muons, and heavy ions. The ultimate objective of TIARA–G4 is exploited for more accurate evaluation for SER in any digital devices.

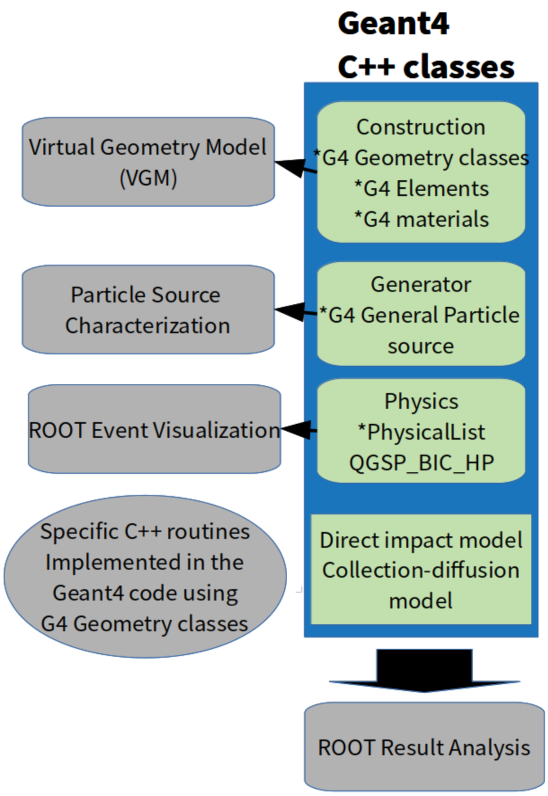

Fig. 1. Each class state of Geant4. The classes written with C++ language and compatible with ROOT [2].

2.1 Geant4

Geant4 is a unique toolkit only implemented in TIARA_G4 for the simulation of the passage of particles such as heavy ions, protons, muons and alpha particles through matters. It has been customized for various experimental conditions based on open source platform operated in LINUX. Its applications and capabilities are also developed continuously to be extended.

Geant4 is written with C++ for creating the classes at various of conditions, for instance, physics, construction, generator, etc. These classes compatible with other simulation tools can be customized by users. Basically, Geant4 kenel was made to study of diverse experiments, that can track atomic movements, including high-energy particles, radiation protection, space science and medical science [3]. Accordingly, its kenel involves geometry representation and navigation, tracking atomic movements, matter statements, notional interface to physics processes and various functionality for realistic experiments. To study a wide range of physics experiments, simulation processes of Geant4 are dealt with various interactions over an offered energy range from heavy particles to the high-energy particles at the different environments, such as large hadron collider (LHC), and radiation experiments.

In this work, Geant4 will be used partially to design the simulation flow as shown in Fig. 1, indicating the classes of Geant4 at the entire simulation steps of the TIARA-G4.

2.2 ROOT

ROOT is one of the scientific software toolkits to deal with large data processing. The toolkits will be used to analyze, visualize and store a big data provided by Geant4.

3. Methodology

The simulation flow of TIARA-G4 is generally described in Fig. 2 that indicates the simulation steps as diagram. Monte Carlo simulation code is started with constructing architecture of circuits. The development of computing technology allows for construction to the back-end-of-line (BEOL) from the front-end-of-line (FEOL). These chained processes could provide for more confident information for SER evaluation. These properties with various classes of Geant4 could allow to build controllable experimental conditions for a number of radiation sources and circuit architectures as user's needs. A wide range data made by each step of Geant4 is processed to the ROOT [4].

4. Expectation & Future work

By using the simulation tools, we will obtain the radiation effects on circuits completely applied to the proposed methodology before the radiation experiments. For the first step, we will analyze a single transistor and will extend to the target device, a SRAM array that would be constructed and visualized in ROOT, expecting a sample image like Fig. 3. The final goal of this research is to provide a design roadmap for circuit designers by anticipating the radiation effects on complicated circuits.

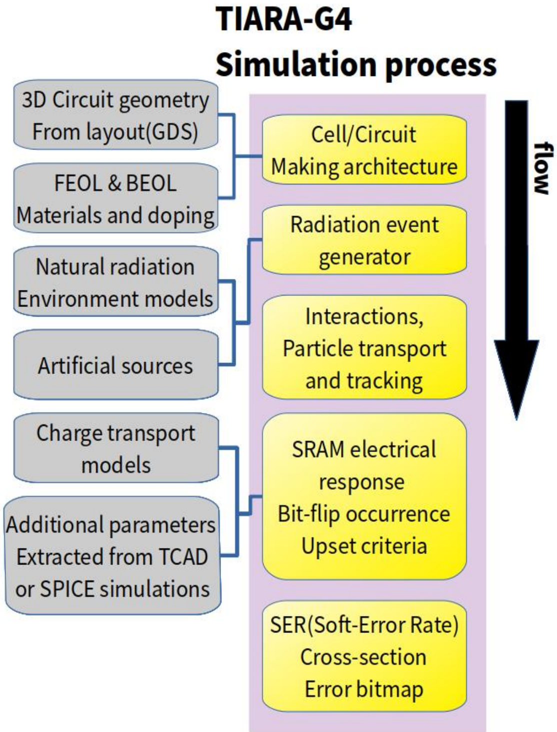

Fig. 2. This is overall simulation flow in TIARA-G4. Each step is linked with Geant4 and ROOT [2][4].

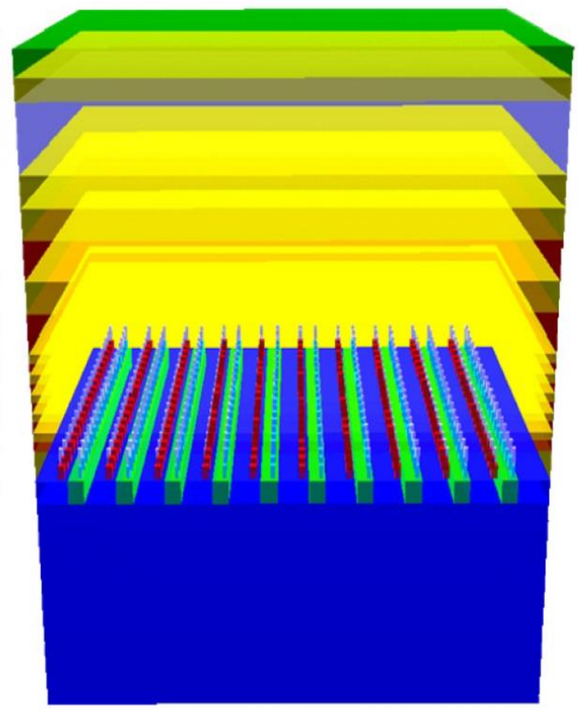

Fig. 3. This is a sample image of 3D visualization from the ROOT; the array of 10x20 SRAM constructed to the BEOL from a substrate [2].

REFERENCES

[1] M. Zhang and N. R. Shanbhag, "Soft-Error-Rate-Analysis (SERA) Methodology," in IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, vol. 25, no. 10, pp. 2140-2155, Oct. 2006. doi: 10.1109/TCAD.2005.862738

[2] J.L Autran, S. Semikh, D. Munteanu, S. Serre, G .Gasiot and P. Roche, "Soft-Error Rate of Advanced SRAM Memories: Modeling and monte Carlo Simulation, Numerical Simulation − From Theory to Industry", edited by Mykhaylo Andriychuk, ISBN : 978-953-51-0749-1, InTech, pp. 309-336, sept. 2012. Available online at http://dx.doi.org/10.5772/50111

[3] J. Allison et al., "Geant4 developments and applications," in IEEE Transactions on Nuclear Science,

vol. 53, no. 1, pp. 270-278, Feb. 2006.doi: 10.1109/TNS.2006.869826
[4] P. Roche, G. Gasiot, J. L. Autran, D. Munteanu, R. A. Reed and R. A. Weller, "Application of the TIARA Radiation Transport Tool to Single Event Effects Simulation," in IEEE Transactions on Nuclear Science, vol. 61, no. 3, pp. 1498-1500, June 2014.doi: 10.1109/TNS.2014.2318778