18th International School on the Effects of Radiation on Embedded Systems for Space Applications (SERESSA)

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CERN

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Organizers:

Book of Abstracts

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Accelerator Radiation Environment and Neutron Effects in Electronics

Corresponding Author: matteo.cecchetto@cern.ch

The talk introduces the radiation environment in the Large Hadron Collider (LHC) accelerator at CERN and the radiation-induced effects in electronics, presenting several comparisons with the atmospheric environment. The talk shows how the radiation levels are measured and simulated in critical areas, focusing on thermal and higher energy neutrons, which are the main contributors to SEEs. In addition, the SEEs induced by neutrons between 0.1 and 10 MeV are compared to the overall error rate due to the full neutron spectra, showing that in some cases they can induce more failures than more energetic neutrons. The related Radiation hardness Assurance (RHA) implications are presented.

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Analyzing data extracted from radiation tests in advanced SRAMs

Corresponding Author: ja.clemente@fdi.ucm.es

When researchers perform experiments on advanced SRAMs in order to assess their sensitivity against radiation, it is important to correctly classify the observed errors according to their multiplicity (Single Bit Upsets (SBUs), Multiple Cell Upsets (MCUs), etc). However, this might become a challenge in modern devices that implement mechanisms to detect and correct such errors (bit interleaving and Error Correcting Codes (ECC), amongst others). The reason is that this information is usually intellectual property (IP) of the manufacturers. In this talk we will discuss how this problem can be solved, even if said proprietary information is unknown to researchers. In addition, we will discuss the impact of error accumulation in experiments where too many bitflips are observed (due to a high particle flux, for example), and why the probability of observed so-called "false multiple events" is not negligible.

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COTS in (Deep) Space

Corresponding Author: hans-juergen.sedlmayr@dlr.de

The usage of commercial off-the-shelf (COTS) technologies in (deep) space missions might be a risk for the mission. But sometimes radiation tolerant parts are not feasible due to space or performance requirements. This paper gives a brief overview of the usage of COTS in (deep) space missions at the DLR Institute of Robotics and Mechatronics and the associated radiation assurance activities.

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System-Level Design and Radiation Test Methodologies based on a novel Software-Defined Radio Architecture for Space Applications

Corresponding Author: jan.budroweit@dlr.de

Designing hardware for space is always challenging since material and electronics will be forced by the harsh environment, in particular due to radiation. There is truly a large diversity in space hardware design as seen from the space industry and agencies or the CubeSat community, that is mainly driven by costs, time and reliability aspects.
In this talk the different approaches, their advantages and disadvantages are discussed and a new approach in space hardware design will be presented including the selection of critical system elements/electronics and the qualification methodology for a radiation-tolerant communication system that has been developed by the speaker.

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Radiation Mitigation Techniques for Mixed-Signal Circuits

Corresponding Author: daniel-loveless@utc.edu

This talk overviews of basic and state-of-the-art approaches for the mitigation of radiation effects in analog and mixed-signal (analog + digital) circuits. The hardening of such components is typically thought to require a "brute force"approach; that is, area and power are often sacrificed through the increase of capacitance, device size, and current drive. Moreover, there are no standard metrics for radiation effects in analog and mixed-signal circuits as the responses are dependent on the circuit topology, implementation, operating mode, and technology. This presentation addresses these challenges by classifying various techniques based on a few underlying principles and illustrates how these mitigation principles can be manifest in topology-specific examples.

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SEE effects on VLSI devices: challenges and solutions

Corresponding Author: luca.sterpone@polito.it

Radiation effects on VLSI technology are provoked when radiation particles such as neutrons, protons or heavy ions hit a sensitive region of the integrated circuits. Due to the progressive technology scaling, VLSI devices are becoming, more and more vulnerable to Single Event Effects (SEEs) and are subject to cumulative ionizing damage known as Total Ionization Dose (TID). This talk will firstly describe the state-of-the-art methodologies used for analyzing the impact of radiation effects on modern FPGAs and ASICs by means of Computer Aided Design (CAD) tools and secondly, it will describe the state-of-the-art CAD design techniques for their mitigation.

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System hardening and real space applications

Corresponding Author: michel.pignol@cnes.fr

This talk describes the suitable protection at architecture and system level against the effects of radiation on electronic components and digital systems. After the description of the general architecture of a space avionics system, the potential solutions for each type of units constituting an on-board computer are presented through the example of real space applications: avionics bus, links, memory units, and –the main part –processing units i.e. fault-tolerant architectures.

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Modeling Cumulative Radiation Effects in Semiconductor Devices and Integrated Circuits

Corresponding Author: hbarnaby@asu.edu

Designing integrated circuits requires accurate models to capture the physics of a circuit's fundamental device, the transistor. Successful modeling of transistor operation has been one of the great achievements in physics and engineering in the past 100 years. Models are particularly important when we consider the challenges posed by cumulative radiation damage. Accurate modeling at the device-level is critical to helping us simulate radiation effects in circuits, through compact models that are radiation-aware. In this course, Professor Barnaby will review models for Complimentary MOS (CMOS) field-effect transistors (FETs) and Bipolar Junction Transistors (BJT). Once the mechanisms of radiation damage in these transistors have been presented, he will describe, the various methods used to model these cumulative effects, from devices to integrated circuits.

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Introduction to OMERE: a tool for space environment and radiation effects on electronics devices I

Corresponding Author: leo.coic@trad.fr

This talk introduces the OMERE freeware and its capabilities. OMERE is a tool developed by TRAD with the support of the CNES according to the need of major actors of the European space industry. It is dedicated to accurately model the space environment for earth and interplanetary missions with industry approved and up to date environment models as well as estimate its effect on electronic devices. During this talk the main capabilities of the OMERE software will be showcased and we will go through the different steps necessary to perform calculations.

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The Phoenix GPS Receiver for Rocket and Satellite Applications: An Example for the Successful Utilization of COTS Technology in Space Projects

Corresponding Author: markus.markgraf@dlr.de

This talk aims to provide a practical example of the successful application of an entirely COTS-based GPS receiver in various space projects such as sounding rocket flights and LEO satellites missions. Almost any Earth-orbiting satellite mission planned and realized during the last two decades has, at any point, considered to employ a GNSS receiver as part of the satellite. However, for the majority of these projects, a fully space-qualified GNSS receiver is out of reach due to the extremely high costs typically associated with such hardware. For projects with a more limited budget the use of a COTS-based version of the desired device is typically the only viable alternative. Driven by this motivation, DLR's space flight technology group has commenced to explore, develop and test COTS-based GPS sensors about 20 years ago. As an outcome of this work, among others, the Phoenix GPS receiver for space applications has been developed, tested and finally made available to numerous small- and mid-scale space projects. In this talk, the Phoenix GPS receiver will be introduced in more detail. An overview about the conducted space qualification program and the so far gathered flight heritage of the sensor will be provided.

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The challenges of testing COTs devices at European Irradiation Facilities

Corresponding Author: alessandra.costantino@esa.int

In this presentation, ESA will report on recent testing done on COTs devices at various irradiation facilities. Lessons learned and best practices will also be presented highlighting the challenges we are facing when testing COTS devices in different packages.

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Radiation Hardening by Software: Advanced FDIR and Redundancy Concepts with COTS in Space

Corresponding Author: klaus.schilling@telematik-zentrum.de

Redundancy concepts in combination with advanced Fault Detection, Identification and Recovery (FDIR) software is a promising approach for improving reliability in spacecraft hardware. In the CubeSat mission UWE-3 this concept provided seamless operations for 6.5 years, despite only commercial of the shelf components were employed. UWE-3 on its polar LEO encountered significant SEU but due to internal redundancy switching from of the OBDH operations always continued without any interruption.

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Earth Observation Mission Scenarios and their Implications for Satellite Radiation Resilience

Corresponding Author: nicolaus.hanowski@esa.int

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Single Event Multiple Transient Analysis of Digital Circuits using Satisfiability Modulo Theories

Corresponding Author: otmane.aitmohamed@concordia.ca

In this talk, we will be discussing the practical use of formal based techniques, such as SAT, SMT and probabilistic model checker to analyze SEEs at logical and higher abstraction levels. Through examples, we will illustrate each approach and its benefits.

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Sensitivity characterization of SRAM-based FPGA against SEU and SET

Corresponding Author: fakhreddine.ghaffari@ensea.fr

One solution for emulating transient faults such as SEU, MBU or SET resulting from particle accelerators or even from real particle radiation in space, consists in irradiating the circuit with electromagnetic radiation. The objective of this work is to characterize an FPGA circuit based on SRAM memory (Cyclone V SoC of the DE10-Nano board) against transient faults resulting from electromagnetic radiation. The fault injection tool used is the ChipSHOUTER. A complete testbed has been realized allowing the reliable reproduction of the fault injection campaigns. The analysis and interpretation of the results of fault injection campaigns on different DUT (Design Under Test) are detailed in this presentation. This work allowed us to better understand the sensitivity of this circuit, built on TSMC's 28 nm low-power (28LP) process technology, against transient faults.

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Error rate prediction for programmable circuits: methodology, tools and studied cases

Corresponding Author: raoul.velazco@univ-grenoble-alpes.fr

Perturbations provoked by Single Event Upsets (SEUs) increase with the reduction of transistor's features. In this talk will be presented a strategy allowing to estimate SEU error-rates based on a limited radiation ground testing and fault injection results. A flexible and versatile test platform, well

suited to implement such a strategy will be described. Experimental results obtained for different processors illustrate the accuracy of error rate predictions.

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The Value of "Test-As-You-Fly": Modernizing FPGA Experimentation And Data Analysis for Critical Space Missions

Corresponding Author: melanie.d.berg@nasa.gov

New methods for characterizing FPGA performance in radiation environments are presented. Application of the new methods are illustrated via walking through FPGA manufacturer Single Event Data and how they are used to calculate system-level error rates for various space environments. This presentation shows that old test and evaluation methods are insufficient while new methods provide better characterization and assistance for determining suitable design/mitigation strategies for space missions.

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Mitigation of Soft Errors at Circuit Level

Corresponding Author: reis@inf.ufrgs.br

The mitigation of soft errors (SE) should be considered in all design abstraction levels. This talk will discuss the efficiency of mitigation techniques to decrease the soft error susceptibility on the circuit/physical design levels. Several techniques are considered: transistor reordering, sleep transistors, decoupling cells, and use of Schmitt Triggers. The use of logic multi-level design improves over 45% on average the SET results for the cells evaluated. The LETth considering the work-function fluctuation (WFF) impact is smaller than the LETth at ideal conditions. When using decoupling cells, the soft error susceptibility decreases, in our test cases. The results show that a design using a sleep transistor or Schmitt Trigger is very promising for soft error mitigation.

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Fundamentals of the Pulsed-Laser Technique for Single-Event Effects Testing

Corresponding Authors: iadrian@gatech.edu, joelmh1976@gmail.com, stephen.buchner@nrl.navy.mil, vincent.pouget@ies.univ-montp2.fr, dalem101@gmail.com;dale.mcmorrow@nrl.navy.mil;

Carrier generation induced by pulsed-laser excitation has become an essential tool for the investigation of single-event effects (SEEs) of micro- and nano-electronic structures. The qualitative capabilities of this approach include, among others, sensitive node identification, radiation hardened circuit verification, basic mechanisms investigations, model validation and calibration, screening devices for space missions, and fault injection to understand error propagation in complex circuits. Recent effort has built upon the success enabled by these qualitative benefits, and has focused on putting the laser SEE approaches on a more quantitative basis. This presentation will present the basic physics associated with the single-photon and two-photon excitation processes, as well as numerous case studies.

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Modelling and prediction of Single Event Transient and Single Event Upset

Corresponding Author: frederic.wrobel@ies.univ-montp2.fr

Neutrons, protons and ions are particles are able to trigger Single Event Upset in modern technologies. In this talk, we'll see how these particles can interact with the matter of the electronic device, create some electron-pairs in the semiconductor and how the resulting parasitic current can lead to an SEE. We will also present the key parameters that are required in order to evaluate the sensitivity of a given technology. The main quantities such as fluence, flux, cross section will be explained, and some case studies will be presented.

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School Opening

Corresponding Authors: raoul.velazco@univ-grenoble-alpes.fr, ruben.garcia.alia@cern.ch, ygor.aguiar@cern.ch

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Introduction to G4SEE: a toolkit for simulating radiation effects in electronics I

Corresponding Author: david.lucsanyi@cern.ch

G4SEE, a novel Geant4-based Monte Carlo simulation toolkit is being developed at CERN for the radiation effects community, and released as a free and open-source code. It has been already demonstrated and validated experimentally by measurements of inelastic energy deposition single events of monoenergetic neutrons below 20 MeV. These two hands-on lectures will give an introduction on how to use the G4SEE toolkit in simple, but real-life scenarios to simulate, analyse and better understand the nuclear physics of Single Event Effects induced by neutrons and protons in microelectronic structures.

G4SEE website: https://cern.ch/g4see

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Introduction to G4SEE: a toolkit for simulating radiation effects in electronics II

Corresponding Author: david.lucsanyi@cern.ch

G4SEE, a novel Geant4-based Monte Carlo simulation toolkit is being developed at CERN for the radiation effects community, and released as a free and open-source code. It has been already demonstrated and validated experimentally by measurements of inelastic energy deposition single events of monoenergetic neutrons below 20 MeV. These two hands-on lectures will give an introduction on how to use the G4SEE toolkit in simple, but real-life scenarios to simulate, analyse and better understand the nuclear physics of Single Event Effects induced by neutrons and protons in microelectronic structures.

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Introduction to OMERE: a tool for space environment and radiation effects on electronics devices II

Corresponding Author: leo.coic@trad.fr

This talk introduces the OMERE freeware and its capabilities. OMERE is a tool developed by TRAD with the support of the CNES according to the need of major actors of the European space industry. It is dedicated to accurately model the space environment for earth and interplanetary missions with industry approved and up to date environment models as well as estimate its effect on electronic devices. During this talk the main capabilities of the OMERE software will be showcased and we will go through the different steps necessary to perform calculations.

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School Closure

Corresponding Authors: raoul.velazco@univ-grenoble-alpes.fr, ygor.aguiar@cern.ch

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Social Dinner

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TID Mechanisms in Nanometer-Scale Microelectronic Technologies

Corresponding Author: stefano.bonaldo@dei.unipd.it

Ionizing radiation may affect the reliability of the electronic devices, inducing a variation of their nominal electrical characteristics and degrading their performance. The lecture focuses on the dissection of TID mechanisms based on the evaluation of measurable effects affecting the electrical response of transistors. Technologies dedicated to high-energy-physics experiments have been tested at ultra-high doses, never explored thus far. Different approaches, as charge pumping, low frequency noise and technology computer-aided design simulations allow to identify the location, density and energy levels of the defects, whose investigation is essential for proposing solutions to improve their TID tolerance. The evolution of fabrication processes in the semiconductor industry leads to an unpredictable trend in TID effects, requiring continuous efforts for testing and qualifications of electronics.

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Fundamental Mechanisms of Non-Destructive SEEs in Devices and Circuits

Corresponding Author: stephen.buchner@nrl.navy.mil

This talk will present the basic mechanisms responsible for SEEs, starting with the interaction of a particle with a solid to excite electrons into mobile states. The next step is the movement of charge to a sensitive node, where it is collected by a junction electric field and causes a voltage disturbance in the circuit that ultimately corrupts data to form an SEE. Emphasis will be on non-destructive SEEs (SEUs and SETs) that appear as corrupted data or signals. Topics to be covered include the effects of bias, temperature, and operating frequency. Mitigation approaches to eliminate SEEs will be addressed.

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Radiation Hardness Assurance (RHA)

Corresponding Author: stephen.buchner@nrl.navy.mil

This presentation will describe the RHA steps required to ensure that the parts selected for a space project will be able to perform their function when exposed to the ionizing radiation present in space. The talk will present two examples illustrating why RHA is necessary, The steps involved in RHA begin with mission objectives that determine orbit and duration. That information is used to establish the radiation environment that leads to various radiation phenomena, such as TID, DDD and SEEs. Parts must be assessed for their performance in a radiation environment and, if necessary, mitigated, or the part must be replaced.

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Introduction to 'Radiation to Materials': methodologies and examples

Corresponding Author: matteo.ferrari.2@cern.ch

Despite being sensitive to radiation, polymeric materials such as lubricants, elastomers, insulators, glues are used out of necessity in devices operating in extreme high-radiation conditions. Radiation tolerant materials are fundamental for the development of technological and industrial sectors such as space, particle accelerators, high-power targets, fission and fusion technologies, radioactive waste management. In the talk, concepts of radiation to matter interaction will be recalled and a general overview on radiation effects in materials will be presented, as well as methodologies to perform rigorous irradiation and post-irradiation characterizations. Multi-scales and multidisciplinary approaches to irradiation tests will be correlated to real-life applications.

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Single-Event Effect Criticality Analysis

Corresponding Authors: anthony.b.sanders@nasa.gov, jonathan.pellish@nasa.gov

In July 2021, the NASA Engineering and Safety Center released Avionics Radiation Hardness Assurance (RHA) Guidelines, which included an update for a methodology called Single-Event Effects Criticality Analysis (SEECA)1. SEECA was originally developed by NASA in the mid-1990s and offers a methodology to identify the impact of single-event effects (SEE) on mission, system, and subsystem reliability2. It provides guidelines for the assessment of SEE-induced failure modes or impacts throughout a mission's concept of operations. Techniques like SEECA are increasingly important for successful use of complex embedded devices in space systems.

This presentation will guide when and how to use SEECA for verification of availability, performance, schedule, and cost risk associated with SEE for a chosen environment throughout the design process. SEECA may be used in determining the severity of faults caused by SEEs, accounting for criticality of functions performed, and identifying when to design for SEE tolerance. A completed SEECA is a tool for radiation tolerant design, requirements generation for SEEs, design verification, and requirements validation. This presentation will describe SEE hazards and suggest how to use a SEECA to categorize these threats from a systems perspective for active design trades.

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The RADNEXT irradiation facility network

Corresponding Author: andrea.coronetti@cern.ch

RADNEXT is an EU financed 4-year project that gathers more than 30 partners involved in radiation effects on electronics research, including ˜20 irradiation infrastructure capable of delivering ion, proton, neutron and other more exotic beams. RADNEXT aims at building and maintaining a European network of irradiation facilities while easing access to facilities to users from research and industry. This holistic approach includes many joint research activities including the harmonization of dosimetry techniques across facilities, the development of simulations tools for beamlines and radiation effects in devices, the reliance of alternative beams, such as X-rays as opposed to γ-rays for TID testing, and testing techniques, such as system-level testing.

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CELESTA project

Corresponding Authors: alessandro.zimmaro@cern.ch, raffaello.secondo@cern.ch, ruben.garcia.alia@cern.ch

CELESTA is a student cubesat mission product of a collaboration between the “Centre Spatial Universitaire de Montpellier” (CSUM) and CERN. This cubesat activity will be first of all put in the framework of the more global “Radiation to Electronics” program at CERN. The cubesat payload, consisting of radiation monitors and effects experiments, will then be presented, including its ground based calibration and testing against radiation, as well as the preliminary in-orbit results. In addition, an outlook will be provided related to present and future developments of CERN’s space radiation monitor (RadMON), to be embarked in many more space missions to come.

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Registration