Following a long RADECS tradition, a full-day short course is organized on the first day of the RADECS 2017 conference. Intended for both beginners in the field and experienced scientists, the course will cover a variety of radiation effects seen from the different perspective of experts involved in applications sharing the common constraint of radiation tolerance: Space, Avionics, Ground, and High Energy Physics. This unique opportunity to learn from renowned professionals is conceived to expose the attendees to both basic mechanisms and best practices as they have been explored and developed in the different communities over the last decades. The ambition is to enlarge the limited representation of radiation effects our daily activities in a specialized field generates, and extend it to embrace the much richer, complex and – alas – often surprising reality.

The course is organized in four main chapters, and will begin with a review of the different radiation environments encountered in our fictitious one-day travel from Space to Ground and Below. Other than describing the environments, the main constraints imposed on reliable operation of electronics components in each case will be covered. The second chapter will focus on Total Ionizing Dose effects. A first lecture will lead us through the complexity of the phenomenology of charge transport and trapping in silicon dioxide, with its consequences on the operation of CMOS and linear bipolar circuits. Difficulties and common practices in providing a reliable dosimetry during TID testing at different sources will then be discussed. During the third chapter, dedicated to displacement damage, focus will be first on basic mechanisms and their consequence in optoelectronics devices for Space missions. The same problematic will then be addressed from a High Energy Physics point of view, with particular attention to silicon detectors and their qualification for very large radiation levels. The last chapter will illustrate in sequence the industrial point of view for part qualification for Space flights, and the approach adopted instead in High Energy Physics applications. Both will present standards and best practices, and several case studies.

Electronic and paper copies of detailed course notes will be provided to all registered attendees.
Chapter 1: Radiation environments: Space, Avionics, Ground and Below

Dr. Giovanni Santin from ESA/ESTEC and RHEA System, in collaboration with Dr. Pete Truscott from Kallisto Consultancy, Dr. Remi Gaillard, Consultant, and Dr. Rubén Garcia Alia from CERN, will cover the similarities and distinctive traits of the diverse radiation environments to which electronics and humans are exposed in space, avionics, ground systems and at accelerators. For space, an introduction to new models for traditional Earth orbit scenarios shall be complemented with a discussion of challenges brought by extreme events, or by radiation exposure in ambitious deep space exploration programmes, including Jupiter missions or planetary habitats. The atmospheric environment will also be described with its implications on avionics reliability and radiation protection. The requirements posed by radiation at ground level to the development of high reliability systems will be addressed. The journey will end at underground modern accelerators with a review of the constraints imposed by the mixed radiation field on the design and operation of both detectors and accelerator systems.

Chapter 2: Total Ionizing Dose Effects and Dosimetry

2.1 Evolution of Total Ionizing Dose Effects in MOS Devices with Moore’s Law Scaling

Prof. Dan Fleetwood from Vanderbilt University will present an overview of the basic mechanisms of MOS TID radiation response. These include charge generation, transport, trapping, and annealing. The nature of oxide, interface, and border traps in SiO$_2$ will be discussed, from both the perspectives of defect microstructure and hardness assurance testing. Effects will be considered that occur at very high doses, e.g., in high- luminosity particle-accelerator applications, but are typically not observed below ~ 1 Mrad(SiO$_2$). Charge trapping in high-K dielectrics in Si-based and alternative-channel devices will be briefly reviewed, with an emphasis on effects in advanced gate stacks and emerging nanoscale technologies. Finally, progress will be highlighted in modeling and simulation of radiation effects enabled by the rapid advances in computing technology and computational methods that have occurred over the last 50+ years due in large part to Moore’s Law scaling.

2.2 Dosimetry Techniques and Radiation Test Facilities for Total Ionizing Dose Testing

Dr. Federico Ravotti from CERN will address dosimetry and monitoring techniques for Total Ionizing Dose (TID) testing of electronics devices. He will first discuss the basic principles of dosimetry as well as the most common dosimetric quantities and units used for the measure of the energy deposited in a given medium by ionizing radiation. In a second chapter, he will give an overview of the available dosimetry techniques for ionizing radiation, along with the basic mechanisms exploited for their use. In a third section, he will address issues and factors affecting the dosimetry measurements, as well as some practical ‘hints’ about the selection and use of the presented techniques. Finally, a synthesis of the existing radiation test facilities for TID testing will be given. Their interest, limitations and some practical aspects involving the organization of radiation test campaigns will be discussed.
Chapter 3: Displacement Damage Dose in Space and High Energy Physic

3.1 Displacement Damage in Optoelectronic Devices Dedicated to Space Applications

Dr. Cédric Virmontois from CNES will present a review, compiled with his colleague Dr. Olivier Gilard, of radiation-induced displacement damage effects in optoelectronic devices operating in space radiation environments. The physics of the displacement damage mechanism and the electrical effects of induced defects will be discussed. Displacement damage-induced electrical degradation on silicon devices as well as other semiconductor type, as HgCdTe, InSb or InGaAs, will be addressed through the analysis of the key parameters of these components. Recent results concerning random telegraph signal and dark current spectroscopy in image sensors will be displayed. Then a section will illustrate prediction of the electrical degradation, comparison with in-orbit data and mitigation techniques. Finally, displacement damage testing will be discussed based on standards, guidelines and test sources.

3.2 Displacement damage in silicon detectors for High Energy Physics

Dr. Michael Moll from CERN will focus on radiation damage issues caused by displacement damage in silicon sensors operating in the harsh radiation environments of High Energy Physics Experiments. The origin and parameterization of the changes in device parameters such as depletion voltage (effective doping concentration), leakage current and charge trapping, respectively charge collection efficiency, as function of particle type, particle fluence and annealing time and temperature will be reviewed. Impact of impurities in the silicon base material, material engineering approaches and NIEL hypothesis violations evidenced for example by exposing the sensors to radiation of different particle type will be presented. Differences on how segmented and non-segmented devices are affected and how device engineering can improve radiation hardness will be explained and characterization techniques used to study sensor performance and the electric field distribution inside the irradiated devices will be outlined. Finally, mitigation techniques, recent developments in radiation hardening and simulation techniques using TCAD modelling will be shown. Some material on silicon devices with intrinsic gain (SiPM, LGAD, APD) and non-silicon based detectors will be given. The course will conclude with radiation damage issues in presently operating experiments and give an outlook of radiation hardened technologies to be used in future upgrades of the present detection systems.
Chapter 4: Electronic systems qualification for radiation environments

4.1 Industrial point of view for space applications: Best practices from parts selection to flight.

Throughout a course mainly focused on Single Events Effects (SEE) aspects, Dr. Aminata Carvalho from Airbus Defense and Space, will address the Space applications from the industrial standpoint. From parts selection to flight, from project definition to equipment qualification and mission lifetime, the radiation qualification process will be discussed. As starting point, the Space Radiation Hardness Assurance (RHA) standards will be briefly reviewed. To provide a better overview of the equipment supplier management procedure the key RHA flow will be presented through a practical case. Parts procurement, traceability, package selection and opening issues, concurrent engineering for equipment design, SEE characterization including heavy ions testing and proton issues handling, as well as mitigation techniques implementation, events rates estimation and risk ranking, will be dealt with.

4.2 Qualification of Electronics Components for a Radiation Environment with focus on Single Event Effects: When standards do not exist – High Energy Physics

Dr. Slavosz Uznanski from CERN will address the problem of components and systems radiation qualification in HEP applications, focusing on the recent experience with the Large Hadron Collider (LHC). The radiation environment inside the LHC accelerator and experiments varies significantly depending on the location: in some places it is comparable to avionic or LEO orbit applications while in others it significantly differs. Thus, the testing standards used for space are not directly applicable in all cases. This course will describe how the problem of testing and qualification of components and systems has been dealt with in view of ensuring the required reliability to the complex electronics systems at the LHC. The radiation hardness assurance policies of both the accelerator and experiments will be illustrated through practical examples of two different design cases: 1) an LHC accelerator control system and 2) a highly redundant LHC detector system.

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