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CERN Radiation Hardness Assurance: Challenges and Solutions for Large-Scale Distributed System Exposed to High-Energy Particle Accelerator Environments

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The electronic systems at CERN, exposed to the harsh radiation environments of particle accelerators and experiments, require specific qualification procedures to ensure reliability under radiation. A large number of distributed systems, thermal neutron fluences in shielded areas, and spectra composed mainly of neutrons are some of the unique challenges that the LHC presents. CERN has developed its own radiation hardness assurance procedure that addresses them through specific test methodologies. Based on lessons learned from component and system qualification, this paper presents CERN's system qualification procedure, these test methods, and lessons learned.

Summary (500 words)

CERN's electronics systems, both in the accelerator and in experiments, are exposed to the peculiar harsh radiation environments induced by the different particle accelerators. As such, the ability of these systems to withstand the effects of radiation on electronics is crucial to maintaining the smooth operation of the accelerators and achieving the organization's ambitious objectives.

To ensure the reliability of systems exposed to these environments, they must pass a battery of qualification tests in specific conditions described in the CERN Radiation Hardness Assurance procedure. This procedure, much like those used in other fields such as space, provides detailed instructions on how to qualify components and systems. However, due to the unique radiation environments present in accelerator areas, the qualification procedure presents several distinct challenges that have been overcome through the development of dedicated test methodologies that are now integral to the qualification process.

One of the primary challenges in LHC systems is their distributed nature. Unlike many other environments, these systems can be composed of thousands of individual units, which creates two major constraints: Firstly, Commercial Off The Shelf (COTS) components should be used whenever possible to keep costs down. Secondly, systems are exposed to diverse range of radiation environments, imposing different challenges both in terms of source and type of radiation effects, and multiplicity of the conditions to be tested.

Therefore, systems are exposed to all radiation effects possible, including Total Ionizing Dose (TID), Displacement Damage (DD), and Single Event Effect (SEE) together. Unlike space, the accelerator environments are mainly neutron dominated, leading to specific challenges to be assessed. One of the most significant threats to system reliability is the estimation of Displacement Damage on optoelectronics, caused by Non-Ionizing Energy Loss (NIEL) scaling violation between neutrons and other particles typically used for qualification. Optoelectronics are often the most vulnerable components in a system exposed to a neutron environment and a specific qualification methodology was developed to ensure the degradation estimation reliability.

Another challenge is the large predominance of thermal neutrons in shielded areas, as certain technologies can be susceptible to thermal neutron-induced (SEE). A systematic approach must be followed to evaluate this risk as it was shown with FPGAs for instance that in these areas thermal neutrons can be by far the main contributor to the failures and their underestimation can have dramatic consequences. Another unique chal-

lenge of the LHC is the fact that components and systems are exposed to a wide variety of TID and DD levels that induces combined TID-DD effects at circuit-level or system-level that can lead to various degradation rate and profiles depending on the TID/DD ratios there are exposed to, and a very careful test process must be followed to assess this issue.
In this work the complete procedure, from component to system level testing with the different challenges, the associated test methodologies, and the lesson learned will be presented in detail with a compilation of actual degradations and failures observed during qualifications, providing a detailed full picture of the CERN System qualification procedure.

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