System-level qualification guidelines as a part of RHA procedure for accelerator applications

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RADSAGA Final Conference and Industrial event

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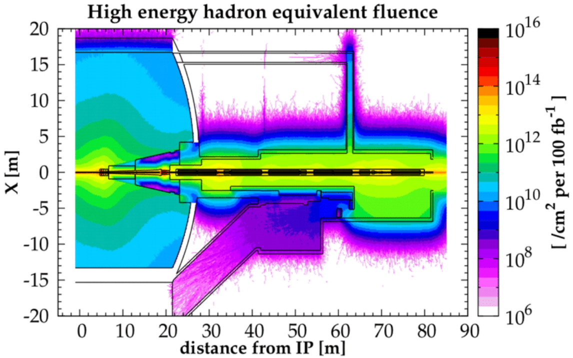
RADiation and Reliability Challenges for Electronics used in Space, Aviation, Ground and Accelerators (RADSAGA) is a project funded by the European Commission under the Horizon2020 Framework Program under the Grant Agreement 721624.
RADSAGA began in Mars 2017 and will run for 5 years.

Presentation outline

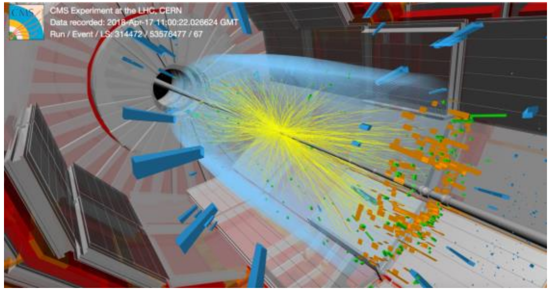
1. Radiation environment at particle accelerators
2. Radiation Hardness Assurance Procedures – current status at CERN
3. RHAPV document
4. System-level testing as a part of the existing RHA guidelines
5. System-level testing: new to R2E
6. System-level test guidelines for accelerator electronics: development strategy
7. Devices to be subjected to system-level tests
8. SEE Tester v2 – functional description
9. Further plans and timeline

Radiation environment at particle accelerators

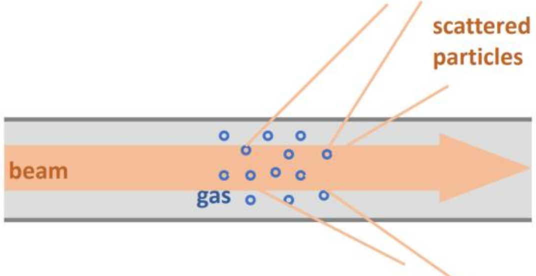
- LHC interaction points – scattering from the organized particle collisions
- Interactions with beam-intercepting devices (collimators, magnets, absorbers)
- Beam-gas interactions



The radiation environment near LHC IP1 region (FLUKA simulation) [2]



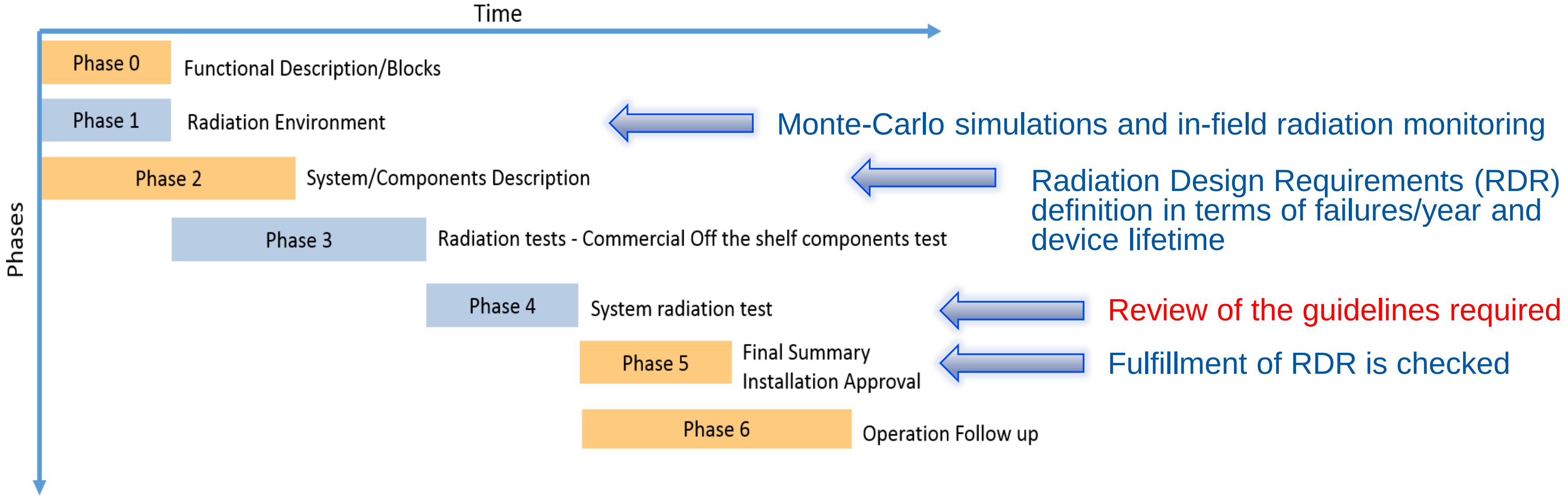
Particle collision at CMS experiment [1]



Beam-gas interaction [1]

The accelerator environment poses a serious challenge for the functionality assurance at CERN, especially in the case of the demanding requirements of the High-Luminosity LHC (0.1 dumps/fb^{-1}, 5x lower than during 2017)

Radiation Hardness Assurance Procedures – current status at CERN



Initial version of RHA procedure was developed by S. Danzeca, R. Ferraro and G. Tsiligiannis (CERN BE-CEM-EPR), including the preliminary system-level testing guidelines

Responsible sides fill in the RHAPV document [4]

RHAPV document

Central to the RHA procedure is the RHAPV document (Radiation Hardness Assurance Protocol), which is being completed on the course of the development process by:

a. Group/section responsible for the project development
b. R2E project
c. RADWG (Radiation Working Group)
d. MCWG (Monitoring and Calculation Working Group)

Main chapters:

Project description

Scope of the project, criticality and lifetime, installation location, etc.

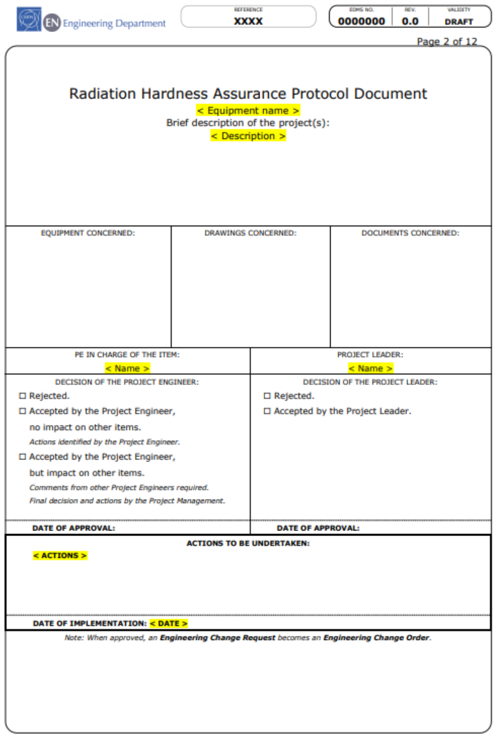
Radiation environment definition

To be assessed by RADWG and MCWG

Radiation testing

- ❑ Component level test summary
- ❑ System-level test summary

Final summary



Engineering Department

REFERENCE	EDMS NO.	REV.	VALIDITY
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Radiation Hardness Assurance Protocol Document

< Equipment name >

Brief description of the project(s):

< Description >

EQUIPMENT CONCERNED:	DRAWINGS CONCERNED:	DOCUMENTS CONCERNED:

PE IN CHARGE OF THE ITEM:	PROJECT LEADER:
< Name >	< Name >
DECISION OF THE PROJECT ENGINEER: ☐ Rejected. ☐ Accepted by the Project Engineer, no impact on other items. *Actions identified by the Project Engineer.* ☐ Accepted by the Project Engineer, but impact on other items. *Comments from other Project Engineers required.* *Final decision and actions by the Project Management.*	DECISION OF THE PROJECT LEADER: ☐ Rejected. ☐ Accepted by the Project Leader.
DATE OF APPROVAL:	DATE OF APPROVAL:

ACTIONS TO BE UNDERTAKEN:

< ACTIONS >

DATE OF IMPLEMENTATION: < DATE >

*Note: When approved, an **Engineering Change Request** becomes an **Engineering Change Order**.*

System-level testing as a part of the existing RHA guidelines: failure modes

Parameters to be monitored during tests are the system-level failure modes, which are determined by analyzing the device on the component, circuit and system level, and determining how SEEs can be propagated.

Failure Modes	Failure Causes	Metrics affected
Permanent loss of Functionality/Capability	TID/DD Failures Destructive SEE	System Reliability : Probability of meeting requirements at end of life
Temporary loss of Functionality/Capability	SEFI, spurious reset, etc.	System Availability
Information Integrity loss	SEU, MBU, stuck bits, SEFI	Example: Bit error rate, sample error rate, frame error rate…
Performance Degradation	TID/DD	Examples: System speed, decreased resolution…

System-level testing as a part of the existing RHA guidelines: proposed rules

- The expected TID and HEH fluence of the radiation environment considering the entire design lifetime shall be defined in the RAHPV document.
- Test conditions (System speed, voltage, temperature…) shall be worse or equivalent to the application.
- In-flux testing is mandatory, most of the failure modes cannot be detected with step-stress testing.
- The dose rate must be adjusted so that at the end of the irradiation the system has received at least up to the ionizing dose expected in the operation lifetime following the RDR specification.
- Operational parameters during the test shall comply with the maximum parameter degradation acceptable to ensure system operation in compliance with system performance requirements.
- The analysis of system failures resulting of non-destructive SEL should be performed with special care, by using an anti-latchup circuitry embedded in the system or control at the Power Supply software in order to estimate the failure rate.
- For system failures resulting of SET, SEU, MCU, SEFI and other soft errors, the maximum fault coverage should be targeted during testing, i.e., the system must pass through all the possible states that it would pass during normal operation.
- The availability of the system in its different operational modes and its main functionalities must be measured: If Mean Time Between Failure = MTBF, Mean Time To Recover = MTTR, Availability = MTBF/(MTBF+MTTR)
- All the numeric lines involving data transfer shall be monitored.
- If mitigation technics are implemented, the error rates shall be measured also before this mitigation processes in order to measure their performances.

System-level tests for CERN accelerator electronics should be carried out at the CHARM facility

System-level tests: new to R2E

A considerable amount of component-level radiation effects data are already gathered by R2E and available in the RADWG database (used at RHA phase 3). Tests are performed by following the established (device-specific) procedures.

System-level tests (RHA phase 4) remain the subject of interest considering that:

- substantial complexity of accelerator electronic systems makes component-level tests much less reliable if not supplemented by system-level ones;
- system-level tests are an important part of the RHA procedure, which cannot be complete without the relevant guidelines;
- The existing guidelines need revision and standardization (to be comparable with RADSAGA System-Level Testing Guideline for Space Systems)
- as electronics reliability is a part of the goals and mission of the R2E project at CERN, such an important aspect cannot be overlooked.

System-level test guidelines for accelerator electronics: development strategy

Starting point - RADSAGA System-Level Testing Guideline for Space Systems (A. Coronetti)

↓

Definition of a „system” as a part of accelerator electronics

Classification of accelerator devices in the context of the risk assessment

Analysis of accelerator radiation environment (simulations, in-field data collection)

Development of equivalent methodology for accelerator electronics

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Verification of designed methodology based on the current R2E developments

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System-Level Testing Guideline for Accelerators

Devices to be subjected to system-level tests

In the scope of the guidelines development, subjected to system-level tests are the electronic devices currently developed in R2E for the accelerator environment.

1. SEU tester v2 (target environment: CHARM facility)

Upgrade and modernization of the SEU tester v1 to include several useful features:

- on-board DUT supply voltage regulation
- logical level isolation for I/O lines
- DUT analog signal monitoring and others.

2. RadMon Detector Readout Module (target environment: LHC tunnel)

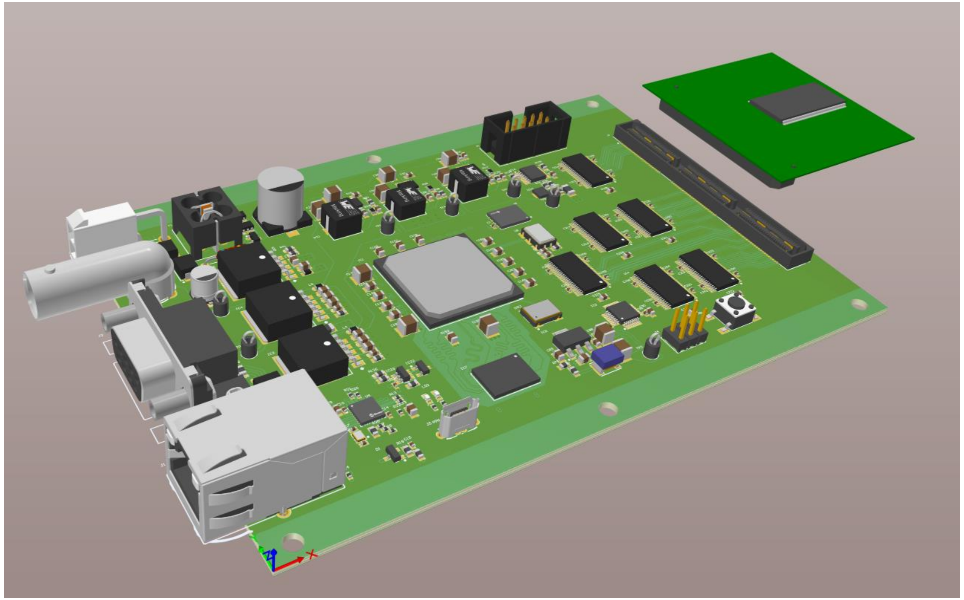
Integration of a new module in the existing RadMon device:

- readout system for the semiconductor detectors to perform spectrometry in LHC tunel
- adaptive readout frontend and power supply to accomodate different detector types

SEE Tester v2 (1)

A new version of SEE Tester was developed to increase the range of tested devices as well to implement features necessary for advanced testing (supply voltage regulation, ADC)

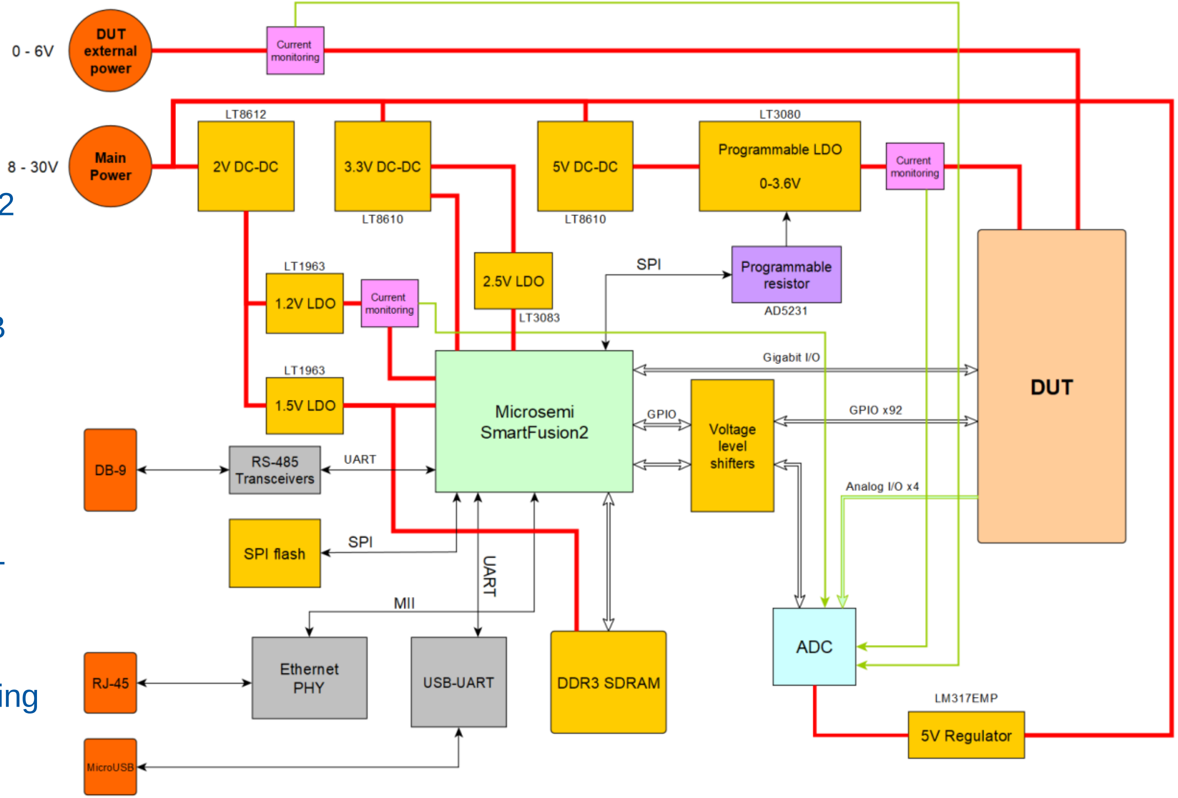
COTS components, predominantly tested by R2E, were used



SEE Tester v2 (2)

Main features:

- Based on Microsemi SmartFusion2 SoC
- Interfaces: Ethernet, RS-485, USB
- External 4Gb DDR3 SDRAM memory for data acquisition
- External and programmmable (0 - 3,6V) voltage supplies for the DUT with power cycle possiblity
- DUT current consumption monitoring



SEE Tester – plans and timeline

Dedicated firmware project – June 2021

Device verification and electrical tests – August-September 2021

Preliminary system-level tests with radiation sources (e.g. Co-60) – October-November 2021

System-level tests at CHARM – 2022

Although most of the used electronic components have radiation effects data, the missing data should be completed in accordance with existing RHA sequence.

RADSAGA

Thank you for your attention

References

[1] G. Lerner, “Accelerator radiation environment: modeling and monitoring tools and approaches”, presentation, ISAE-SUPAERO EEOS-207, 3 June 2020

[2] R. Garcia Alia et al., “Direct Ionization Impact on Accelerator Mixed-Field Soft Error Rate”, IEEE Transactions on Nuclear Science PP(99):1-1, November 2019, DOI:10.1109/TNS.2019.2951307

[3] R. Bartolini, “Electron beam dynamics in storage rings”, presentation, John Adams Institute for Accelerator Science – Graduate Accelerator Physics Course, 12 November 2014

[4] Radiation hardness assurance project validation document (template), CERN EDMS no. 2028777