QDS R2E developments for the HL-LHC era

R. Denz

Acknowledgements:

G. Martin Garcia, T. Pridii, J. Spasic, J. Steckert and the QDS team

S. Danzeca, M. Barros Marin and the CERN radiation test service

R. Garcia Alia and the R2E project

12th HL-LHC Collaboration Meeting – 21 September 2022

Outline

T. Podzorny:

“DAQ systems for WP7”
https://indico.cern.ch/event/1161569/contributions/4921607/

J. Steckert:

“Deliverables for SC Link protection & current lead heater controls”
https://indico.cern.ch/event/1161569/contributions/4921614/

“PDSU prototype and test results”
https://indico.cern.ch/event/1161569/contributions/4921606/

“Symmetrical quench detection and QDS threshold management for HL-LHC”
https://indico.cern.ch/event/1161569/contributions/4921579/

HL-LHC Quench Detection Systems (QDS)

- HL-LHC QDS will be installed in the radiation free UR underground areas
  - For those areas radiation tolerance is not taken into account as a specific design constraint
- The only exception are the quench detection systems required for the protection of the 11 T dipoles
  - Once confirmed, those systems will be installed in the RR73 and RR77 underground areas, The expected radiation levels are rather moderate reaching up to TID ~ 0.5 Gy/year
    - R2E design nevertheless required
  - Development completed and systems qualified for use in RR73/77

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LHC Quench Detection Systems

- The radiation environment will change significantly for a substantial fraction of the LHC QDS & DAQ
- Dispersion suppressor (DS) areas around IP1 and IP5 are of major concern
  - Expected radiation levels[1] will reach the design limits for COTS based developments (typically TID = 200-300 Gy for units with programmable logic)
  - To a lesser extent IP2 and IP8 are as well of concern
    - Ion runs
    - LHCb request to increase its luminosity
- The elevated radiation levels in the LHC RR areas around IP1 and IP5 also require some mitigation measures

[1]https://edms.cern.ch/document/2302154/1.0

LHC QDS & DAQ – R2E performance

- HL-LHC R2E performance target (including all accelerator systems)
  - ~ 0.1 beam dumps / fb^{-1}
- QDS R2E performance requirements for HL-LHC
  - SEU mitigation must be bullet proof
  - TID should not affect device performance for at least one year
    - Ideally all exposed devices should remain operational during the period of one LHC run (~3 years) → TID ~ 300 Gy
    - TID related problems can also be mitigated by pre-emptive maintenance, e.g. by rotating highly exposed systems with those installed in low radiation zones

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LHC QDS – R2E performance LHC run 2

- QDS R2E performance LHC run 2 in 2018
  - 0.16 beam dumps / fb^{-1}
  - 9 trips of DQQBS type QDS installed in half cells 8, 9 and 11 around IP1 and IP5
  - Specific settings of the tertiary collimators in 2018 increased the losses in the dispersion suppressor areas significantly thus anticipating to a certain extent HL-LHC conditions
  - A part the DQQBS also the DAQ systems suffered from radiation induced effects (known vulnerability of the MicroFIP™ field-bus chip)
- The good news: none of the explicitly radiation tolerant QDS designs failed!
  - Re-testing nevertheless strongly recommended

DQQBS: busbar splice protection system

LHC QDS & DAQ inventory half-cells 8 - 13

- R2E conditions / requirements for QDS operation:
  - TID_{MAX} ≈ 100 Gy/ year, SEU immune, TID ≥ 200 Gy
- Only a fraction of the currently installed QDS equipment does not comply with those requirements and needs to be updated:

Equipment	IP1,2,5,8	Comment
Quench detection board type DQQBS	176	Same technology platform
Earth voltage feeler type DQQDE	96	
Communication board type DQAMC MB/MQ	136	Same technology platform
Communication board type DQAMG S	48	
	456	

- In addition to the device upgrade, the position of the QDS racks needs to be optimized with respect to the expected radiation distribution
- In case of IP2, the upgrade would be only required for the ion runs

LHC QDS & DAQ inventory in RR areas

- R2E conditions / requirements for QDS operations:
  - TID_{MAX} ≈ 25 Gy/ year, SEU immune, TID ≥ 100 Gy

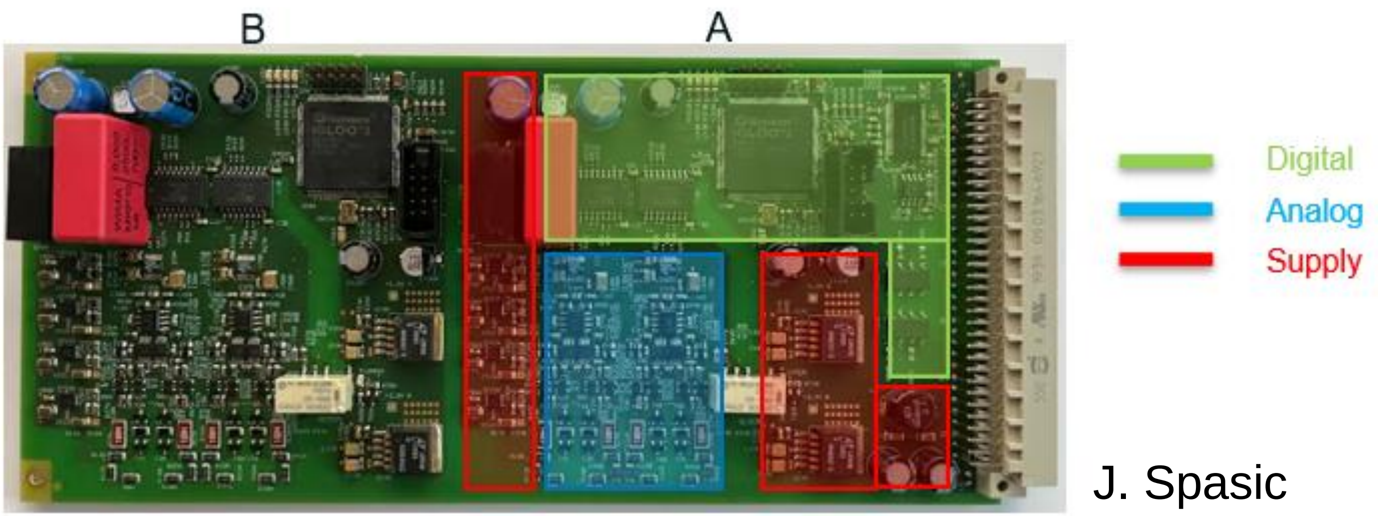
Equipment	RR13, 17, 53, 57	Comment
Current quench detection system DQQDC	224	Same technology platform as DQQBS and DQQDE
Communication board type DQAMG A/B	36	Same technology platform as DQAMC MB/MQ, DQAMG S
AC-DC power supplies	312	Different technology (linear instead of switch mode) and topology
Quench detection board type DQQBS	24	New device within QDS-CONS upgrade – same technology platform as DQQDC and DQQDE
Quench heater supervision system type DQHSU	32	New device within QDS-CONS upgrade – based on existing R2E qualified device
	628	

Upgrades in the RR areas are part of the QDS consolidation project (QDS-CONS)

DQQDC: HTS current lead quench detection system

LHC QDS & DAQ – R2E developments

- Quench detection system type DQQBS/DQQDC
  - Two independent detector boards integrated on one PCB
    - Fully backward compatible to existing device
  - Based on proven designs and components
  - FPGA used for filtering and quench detection algorithms
  - Uses proven UQDS analog input channel technology with 20-bit SAR ADC



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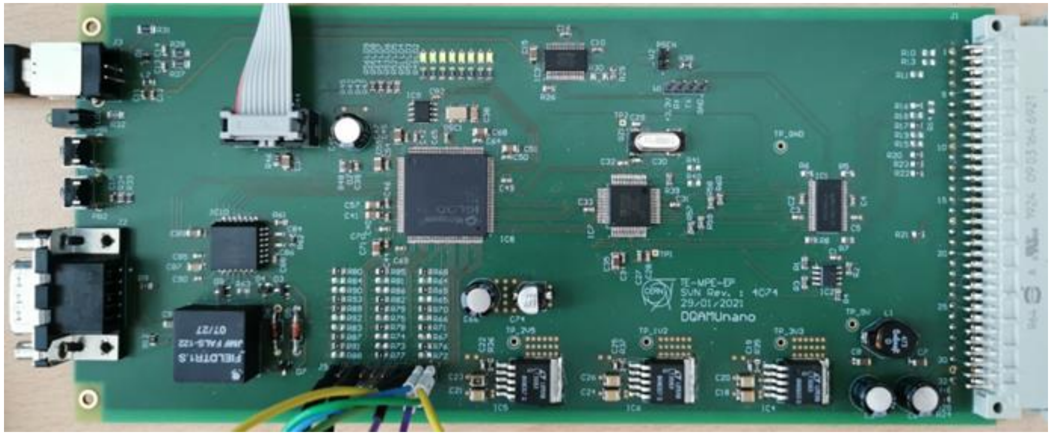
For further info see R2E Developments Status Review: https://indico.cern.ch/event/1127987/timetable/

LHC QDS & DAQ – R2E developments

- NanoFIP-based communication board type DQAMC/DQAMG
  - World-FIP™ based communications board as plug-in replacement for obsolete μFIP™ based systems type DQAMC, DQAMG A/B/S
  - NanoFIP IP-core + peripherals are implemented in M2GL010 FPGA
  - ADuC831™ micro-controller (radiation tolerant and robust, 20 years old but still in production) is used for local monitoring and communication
  - Includes substantial feature upgrade for improved time stamping and enhanced crate monitoring



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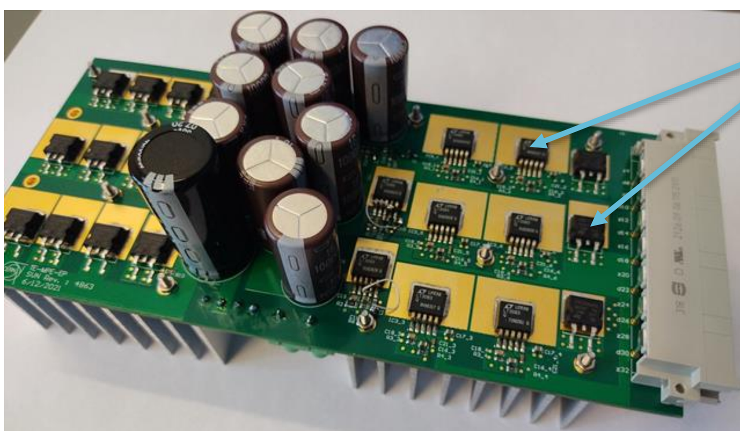
LHC QDS & DAQ – R2E developments

- Radiation tolerant linear power supply for QDS crates type DQGPU A and B
  - Total output power per crate: 120W (+5 V: 15 A, +15 V: 2A, -15 V: 0.5 A)
  - Energy efficient design ($V_{dropLDO}$ ~0.4 V, VF_{diode}~0.38 V)
  - Classical, very lean design based on tested COTS
  - Very lean design based on tested COTS
    ⚠ LT3083 linear regulator, STPS30M60S Schottky diode
  - Cooling provided by external fan tray (230V AC fans)

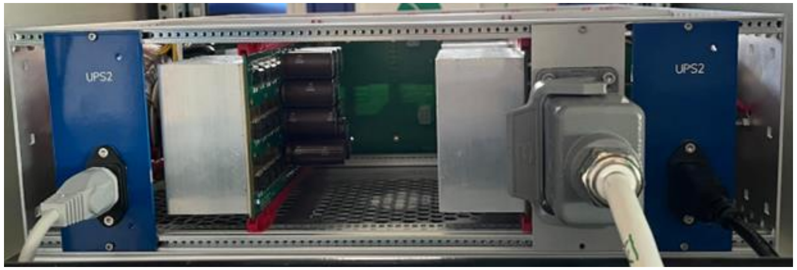


Innovative through-PCB cooling of semiconductors!

T. Pridii, J. Steckert

LHC QDS & DAQ – R2E qualification

- Component level
  - Whenever possible QDS R2E designs try to use already tested components or already used in one of our active radiation tolerant equipment; there is a very close collaboration with R2E/RADWG
  - Components will be typically tested for SEU immunity using a proton irradiation facility (Paul Scherrer Institut PSI) and TID using a ^{60}Co source (CC-60 facility @ CERN)
- Device and system level
  - All developments will be submitted to a fully functional test in the CERN CHARM mixed field radiation facility prior to installation in the LHC
    - Tests just resumed in June 2022 …



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LHC QDS & DAQ – R2E qualification

- Recent results

Equipment	SEU	TID limit [Gy]	Comment
DQQBS	OK	240	
DQQDS (symmetric quench detection	OK	280	Re-qualification device
AC-DC p			

Linear regulator LT3083 – a kind of surprise …

- Recent tests show reduced TID limit in mixed field radiation tests compared to proton radiation tests
- Problem observed by several teams
- TID ~ 150 Gy compared to 1 kGy with proton irradiation → still ok for applications in the RR underground areas
- Use of alternative part under consideration

- First res technol
- The suc more than a c
- Tests to be continued with the communication boards

Summary

- The successful HL-LHC operation not only requires the installation of new protection equipment for the HL-LHC circuits but a substantial upgrade of the existing quench detection system
- The significantly increased radiation levels in parts of the LHC tunnel and some underground areas are of major concern
- The development of new devices adapted to the HL-LHC conditions is advancing well and the results of the first radiation test campaign are promising