Protection system for the SC links definition

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International Review of the Conceptual Design of the Cold Powering System for the HL-LHC Superconducting Magnets

Outline

- Requirements for quench detection and boundary conditions
  - Link layout, voltage taps, detection settings
- Proposed solutions
  - Quench detection electronics, integration into LHC supervision etc.
- Open issues
  - Powering scheme for higher order correctors
  - Crosstalk in MgB_2 cables
- Summary

Requirements

- Requirements defined by equipment specialist → see presentation by Amalia
- Active protection for current leads and MgB_2 cables
  - Quench detection systems will trigger a fast power abort of the power converter(s) and a discharge of the circuit by active protection means (= quench heaters, CLIQ, energy extraction systems for 2 kA correctors tbc)
- Usage of a Nb_3Sn wire for the supervision of the complete MgB_2 cable link
  - Hardwired interlock or integration into LHC software interlocks (SIS)
- Monitoring of individual splices requested
  - MgB_2 → HTS and MgB_2 → NbTi
  - Interlocking capability can be added on request

Proposed quench detection settings

- Current leads
  - Resistive part: U_{TH} = ± 100 mV, t_{EVAL} ≤ 1 sec
  - HTS part: U_{TH} = ± 1 mV, t_{EVAL} ≤ 500 ms
- MgB_2 cables
  - U_{TH} = ± 50 mV ... ± 100 mV, t_{EVAL} ≤ ~1 sec
- Nb_3Sn wire
  - Trigger on transition to resistive state
- Detection filter settings for all quench detection systems can be modified remotely for each individual channel
  - Maximum permitted settings will be hardcoded

Instrumentation for quench detection systems

- All voltage taps required for protection must be redundant
  - Exact location for some taps still to be defined
  - Final implementation to be approved by equipment specialist and MP3
- Current leads
  - Very well done for LHC; no issues so far → just copy
  - Taps brought out from the warm terminal of each lead
  - Warm instrumentation cabling on the DFB level (between lead and proximity equipment) may need to be revised with respect to LHC
- MgB_2 cables
  - Voltage taps to be brought out on DFH and DFX level
  - The instrumentation cable from the DFX must be routed along the SC link DSH towards the DFH
    - No need to route instrumentation wires through the link itself

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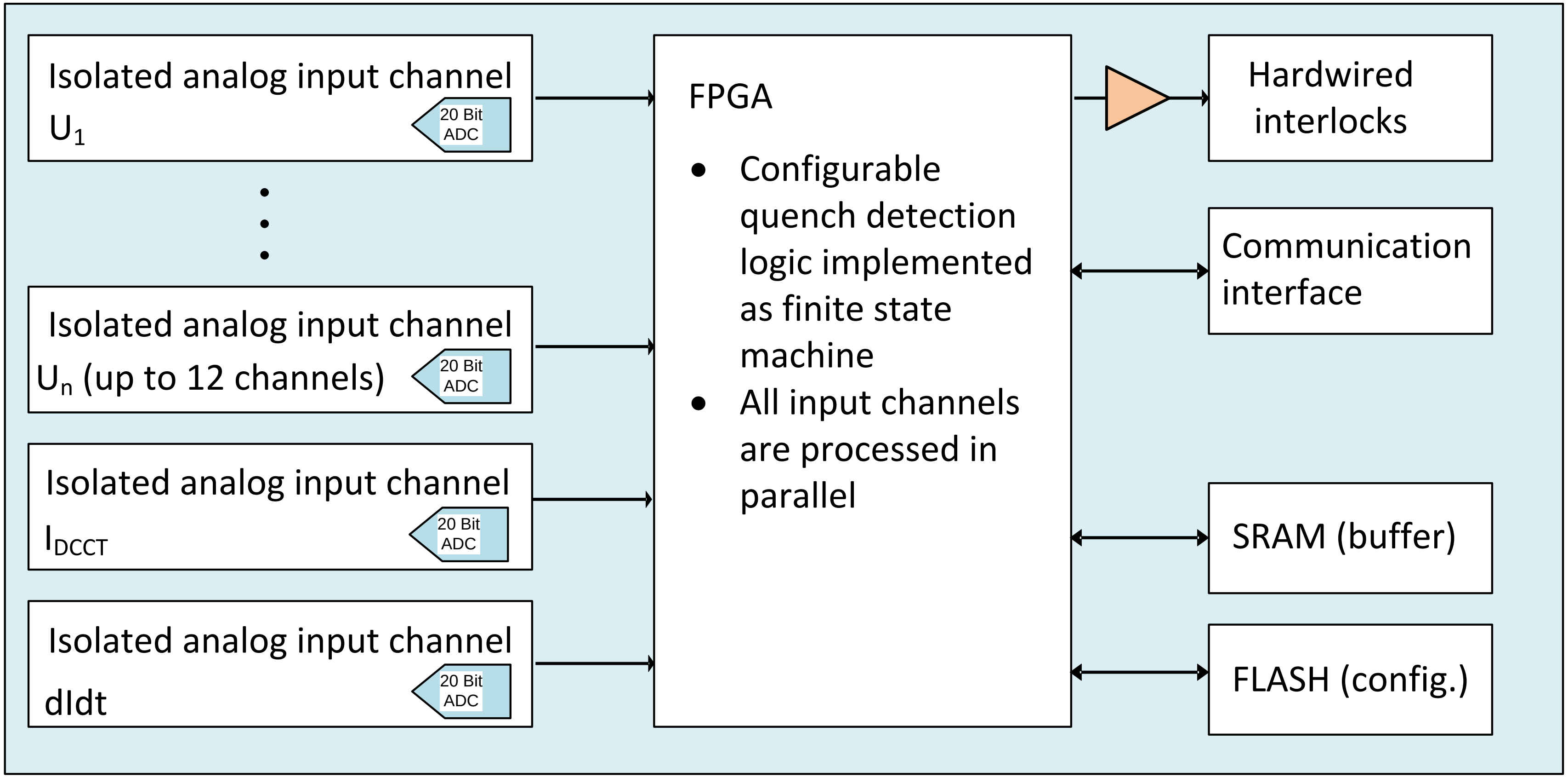
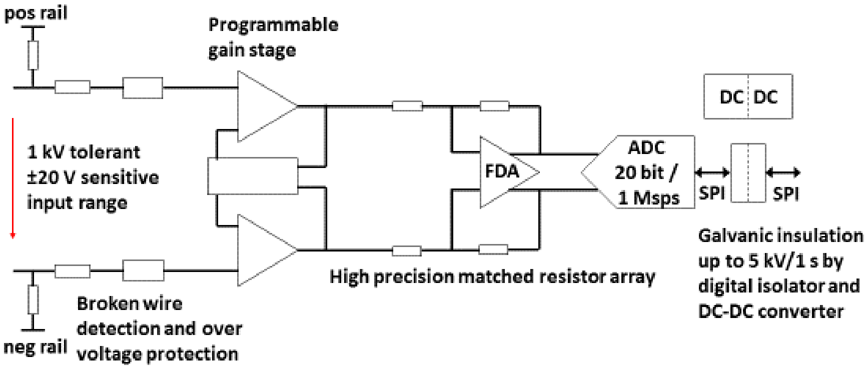
Quench Detection Systems

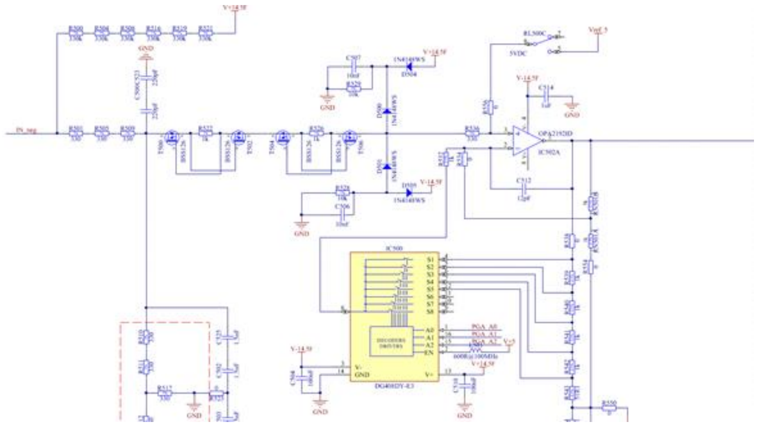
- Quench Detection Systems (QDS) for current leads and MgB_2 cables will be based on the next generation of QDS systems currently being developed for HL-LHC
  - Completely new development based on the experience gained with the LHC QDS so far
  - Each QDS system is independent and equipped with its own interfaces for interlocks and communication
  - Aim of the new designs is a versatile system capable of covering most of the quench detection requirements for the superconducting circuits of the LHC
- The new QDS is to a very large extent software-defined
  - Functional components like filters, voltage comparators or time discriminators are implemented in the device firmware and no longer in hardware
- HL-HC QDS in point 1 and 5 will be installed in radiation free areas
  - More flexibility in selection of electronic components
  - Avoids tedious radiation test campaigns

QDS for HL-LHC: Conceptual Design



QDS for HL-LHC: Polyvalent Analog Input Channel





Parameter	Value
Active input voltage range	±20 mV ... ±20 V
Max. differential input voltage	1 kV (1 sec)
Insulation withstand voltage level	5 kV (1 sec), 2.5 kV (10 min)
Resolution (20 Bit 1 Msps ADC)	40 nV/LSB ... 40μV/LSB
Cut-off frequency	100 kHz

QDS for HL-LHC: Signal Processing

- Effective input signal filtering is crucial for the suppression of erroneous QDS triggers
  - New analog input stages have a relatively large bandwidth with a cut-off frequency of 100 kHz
  - Digital signal processing with tailor made filter chains adapted to the properties of the protected element
    - Non-linear filters for voltage spike suppression
    - FIR filters adapted to the LHC noise environment for high precision measurements, e.g. HTS leads, MgB_2 links and superconducting bus-bars
- QDS device configuration can be remotely updated and checked
  - Essential feature during system test and commissioning
  - Eases system maintenance significantly

Open Issues

- Powering scheme for IT higher order correctors needs to be confirmed
  - MgB_2 cable links versus local powering → important input as not always active quench detections systems are required
  - With few exceptions the magnets are self protected
- Crosstalk and other electromagnetic compatibility issues affecting in the MgB_2 cable links may still require some attention (see presentation by Yifeng Yang)
  - Quench heater firing and CLIQ activation to be avoided in case of simple circuit trips e.g. power converter fault
  - System should be immune to external electrical perturbations
  - The relatively long permitted evaluation times should allow to implement efficient measures assuring sufficient immunity

Summary

- Requirements in terms of protection as specified by the equipment designer are fully compatible with the quench detection electronics too be used within HL-LHC
  - Proposed voltage tap layout is appropriate; there is no need to route instrumentation wires through the cold part of the link but external warm cabling should be aligned to the link cryostat
  - Additional functionality like the usage of a Nb_3Sn wire for the protection of the complete link can be accommodated as well
  - Monitoring of splices will be integrated as requested
- Development of the next generation of quench detection systems for HL-LHC is advancing well
  - Prototype systems will be available for validation within test program of the cable demonstrator and prototype