Roger Kalt on behalf of the LLRF team :: Paul Scherrer Institut

Lab Talk: LLRF Status and Activities at PSI

LLRF Workshop 2019, Chicago
4 Accelerator Facilities
- SwissFEL (Swiss Free Electron Laser)
- SLS (Swiss Light Source)
- HIPA (High Intensity Proton Accelerator)
- Proscan (Proton Cancer Therapy)

4 Mandates of the LLRF team
- Operation & Maintenance
  - All
- Realization & Commissioning
  - SwissFEL-Athos Beamline
- Planning
  - HIPA injector Cyclotron RF upgrade
- Upgrade
  - SLS 2.0 storage ring upgrade
RF systems in operation

<table>
<thead>
<tr>
<th>Facility:</th>
<th>HIPA</th>
<th>SLS</th>
<th>Proscan</th>
<th>SwissFEL</th>
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</thead>
<tbody>
<tr>
<td>System Type</td>
<td>Analog</td>
<td>Analog</td>
<td>Analog</td>
<td>Digital</td>
</tr>
<tr>
<td>RF Op. Type</td>
<td>CW</td>
<td>Pulsed 3 Hz + CW</td>
<td>CW</td>
<td>Pulsed 100 Hz</td>
</tr>
<tr>
<td>Hardware</td>
<td>Own design</td>
<td>External institute</td>
<td>Internal HIPA + Ext. company</td>
<td>COTS (Controls HW) + own RF</td>
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<tr>
<td>Controls integration</td>
<td>Analog interface</td>
<td>Analog interface</td>
<td>Analog interface</td>
<td>Full remote access</td>
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</tbody>
</table>

Table: LLRF systems in operation:

**SwissFEL:** 6 x 3 GHz; 2 x 12 GHz; 28 x 5.7 GHz (2 types) ⇒ 36 RF Stations *(today with test facility and Athos)*

**HIPA:** 8 x 50 MHz (3 types); 4 x 150 MHz (3 types); 1 x 500 MHz ⇒ 13 RF Stations *(today situation with test facility)*

**SLS:** 7 x 500 MHz (3 types); 2x 3 GHz; 1x1.5 GHz SC passive ⇒ 10 RF Stations *(today with test facility)*

**Proscan:** 1 x 72.8 MHz ⇒ 1 RF Station

**total 60 RF Stations**
- Main Beamline Aramis: Operation & Maintenance
- 2nd Beamline Athos: Realization & Commissioning
- RF Teststand: Installation of C-band RF system
**Status** (as of Sept. 2019)

1x X-band LLRF FE development, modulator in-house development.

1x C-band LLRF installed, modulator commissioning...

All 34 RF systems are installed and in operation

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**Schedule**

<table>
<thead>
<tr>
<th></th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
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<tbody>
<tr>
<td>Aramis</td>
<td>User operation</td>
<td>replace X-band LLRF FE</td>
<td></td>
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<tr>
<td>Athos</td>
<td></td>
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<tr>
<td></td>
<td>- dual bunch operation</td>
<td>Establish permanent dual bunch</td>
<td></td>
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<tr>
<td></td>
<td>- RF systems installation &amp; commissioning</td>
<td>LLRF FE &amp; mod. development</td>
<td>Commissioning</td>
</tr>
<tr>
<td></td>
<td>- user operation</td>
<td></td>
<td>User operation</td>
</tr>
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</table>

FE: Analog front-end for LLRF (Receiver, Upconverter)
RF- and Beam-Stability Analysis
- LLRF system fulfills stability requirements
- Model-based prediction of RF vs. beam jitter
- Identify critical RF stations, then jitter contributing subsystems like:
  - HV modulator
    - Different issues, e.g. loose conn.
  - Pre-amplifier
    - Broken units – repair program
  - Klystron multipactor
    - Different for each klystron
  - BOC multipactor
    - A problem below 40 MW input power

LLRF Tuning for Dual Bunch Operation
- Keep basic low-level RF functionalities on lower-layer as is
- High-level setup and automation tools for independent tuning of both bunches created.

RF Systems Availability Analysis
- Implemented dedicated RF systems fault events database
Low-Level RF Hardware

- Fuse broken, PS broken, cable loose
  - Check & tighten all cables 1x / year
- Commercial LO amplifiers have production problems: Results in sudden phase jumps up to 1.5 deg.
  - In-house development of low-noise narrow-band LO amplifier

Low Level RF Software / Algorithms

- Sudden software crash or stall, ~10-20 events / year
  - Reboot, have a proper configuration parameters restore mechanism.
- Gun recovery from RF trip takes ~20min
  - Instead of pickups implement virtual probe based on FOR/REF dir. coupler sig.
- Race conditions of LLRF trigger vs. RF phase reference
  - FPGA based race detection and automatic correction
- BOC detuning over LLRF phase measurement stuck
  - Control room alarms on the ACC voltage: Expected vs. measurement
- Klystron output RF amplitude setting procedure is not robust enough for all use cases
  - Klystron LUT, forbidden multipactor areas, HV feedback, operation pt. det. algorithm
- Operation & Maintenance of old RF stations
- Implementation & Commissioning for Injector Cyclotron RF upgrade
HIPA Injector Cyclotron RF Upgrade Project

RF Upgrade Project General Scope
- Exchange of two 150 MHz resonators with 50 Mhz
- Complete renewal of RF systems of all resonators

Status LLRF Upgrade
- Low-power tests with cavity + tuner plungers done
- Fw/Sw implementation on-going
  - Generic re-usable code open-sourced on GitHub.com/psi_fpga_all
- RF frontend HW prototypes [filters, selectable attenuators] produced & characterized (pizza box style)
- HW installations & cabling partly completed

RF Upgrade Project Roadmap
- Solve cavity tuner plungers and hot-spot problems at the 50 MHz RF test stand
- Amplifier chain RF-commissioning stand-alone
- Amplifier chain connection to the already installed cavity

LLRF Upgrade Roadmap
- System integration & exception handling tests (e.g. startup)
- Handle >90dB dynamic range for cavity tuning
- Operation & Maintenance
- Planning for SLS 2.0 Upgrade
Goal: Upgrade storage ring to provide factor >30 improved brightness + harder X-rays
For all subsystems such as RF/LLRF: Upgrade to ensure other 20+ years operation, to optimize operation + maintenance cost, optimize perf. … ➔ Upgrade analog to digital 500 MHz LLRF / tuning system.

Schedule (simplified)

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<tr>
<th></th>
<th>2019</th>
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<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
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<tbody>
<tr>
<td>SLS-2 preparatory phase</td>
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<td>financing period</td>
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<tr>
<td>procurement/testing/pre-assembly</td>
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<tr>
<td>maximum &quot;dark&quot; period</td>
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Status
1. Decision for SSA’s in Aug-2019, but some klystrons may stay
2. Internally with other groups next processing platform options evaluated: CompactPCI-Serial or internal platform developed for BPM’s.
3. Upgrade of Linac RF stations (currently with feed-forward only) with the SwissFEL type digital LLRF (exact fit: pulsed 3 Hz @ S-band)
**SwissFEL**

- LLRF System weak points known – most of them are in software / algorithms.
  - Replacement of the commercial LO amplifiers with in-house development.
  - Consolidation of the RF amplitude setting procedure
- Studies like RF vs. beam jitter to be continued → Talk
  - Identified weak RF stations and subcomponents
  - LLRF is not the limiting subcomponent for the critical RF stations such as injector S- and X-band.

- **Operation:**
  - Establish dual bunch operation as default
  - Beam-rate: Go up to 100 Hz
  - Training of other colleagues for operation procedures and problem handling.

**HIPA Injector Cyclotron Upgrade**

- LLRF upgrade to new digital LLRF on-going, first RF station in operation 2020.

**SLS 2.0 Upgrade**

- Next processing platform selection process almost completed.
- Implementation of prototype 500 MHz prototype LLRF for RF test stand 2020
My thanks go to

- All team members
- All colleagues for their contributions to the workshop