Lab Talk: LLRF Status and Activities at PSI

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

LLRF Workshop 2017, Barcelona

Version 3, 13.10.2017
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
- Planning
  - HIPA injector 2 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>
</tr>
</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>
</tr>
<tr>
<td>Controls integration</td>
<td>Analog interface</td>
<td>Analog interface</td>
<td>Analog interface</td>
<td>Full remote access</td>
</tr>
</tbody>
</table>

Table: LLRF systems in operation:

**SwissFEL:** 6 x 3 GHz; 2 x 12 GHz; 28 x 5.7 GHz (2 types) \[\Rightarrow 36 \text{ RF Stations}\]
*(today with test facility and Athos)*

**HIPA:** 8 x 50 MHz (3 types); 4 x 150 MHz (3 types); 1 x 500 MHz \[\Rightarrow 13 \text{ RF Stations}\]
*(today situation with test facility)*

**SLS:** 7 x 500 MHz (3 types); 2x 3 GHz; 1x1.5 GHz SC passive \[\Rightarrow 10 \text{ RF Stations}\]
*(today with test facility)*

**Proscan:** 1 x 72.8 MHz \[\Rightarrow 1 \text{ RF Station}\]

**total 60 RF Stations**
- Realization & Commissioning
- Operation & Maintenance
SwissFEL Project Summary & Outlook

### Status (as of Oct. 2017)

- **RF systems installed**
- **Beam operation**
- **RF conditioning**

Overall: 22/34

Beam op: Injector 7/7
Linac 1/26

### Schedule

<table>
<thead>
<tr>
<th></th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aramis</strong></td>
<td>Pilot experiments</td>
<td>Start user operation</td>
<td></td>
<td></td>
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<tr>
<td><strong>Athos</strong></td>
<td>Dual bunch operation</td>
<td>Individual control</td>
<td>Individual control</td>
<td>RF Operational</td>
</tr>
<tr>
<td>- dual bunch operation</td>
<td>Installation</td>
<td>Commissioning</td>
<td></td>
<td>Pilot experiments</td>
</tr>
<tr>
<td>- RF systems installation &amp; commissioning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- user operation</td>
<td></td>
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</tbody>
</table>
SwissFEL LLRF System Key Points
- S-, X-, C-band use similar IF 40 MHz and share digit. processing platform fw/sw
- Control system and processing platform based on Linux mainline kernel
- Full remote access: 100 Hz live synchronous data stream of all 24 ADC waveforms

RF Stability

<table>
<thead>
<tr>
<th>RF Station</th>
<th>Phase Tolerance (rms) Required / Reached</th>
<th>Voltage Tolerance (rms) Required / Reached</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-band ACC (2.9988 GHz)</td>
<td>0.018 / 0.016 degS</td>
<td>0.018 / 0.006 %</td>
</tr>
<tr>
<td>C-band (5.7120 GHz)</td>
<td>0.036 / 0.018 degC</td>
<td>0.018 / 0.003 %</td>
</tr>
<tr>
<td>X-band (11.9952 GHz)</td>
<td>0.072 / 0.38 degX</td>
<td>0.018 / 0.082 %</td>
</tr>
</tbody>
</table>

- RF receiver frontends S- and C-band in “pizza box”
- Jitter Measurement to 10ppm Level for Pulsed RF Power Amplifiers 3 - 12GHz

RF Station Automation for Operation
- Master sequence state controller: Simplify operation for ctrl. room
Low-Level RF High Level Application

- Collection of user triggered or permanently running jobs that use / optimize RF signal figures.
  - RF pulse shaping & optimization, group delay calibration, DAC offset correction, loop gain/phase calibration, structure detuning measurement

Beam Based Optimization Algorithms and Procedures

- Collection of user triggered jobs that use / optimize beam signal figures by tuning of the LLRF knobs.
  - Optimize the DAC / RF pulse vs. beam timing
  - Find the exact beam interaction time
  - Optimize RF performance & jitter study

→ To facilitate operators / experts life
- Operation & Maintenance
- Planning for Injector 2 RF upgrade
Project outline: Replacement of the following Inj. 2 RF related components...
1. 2x 150 MHz → 2x 50 MHz resonators
2. RF amplifier chain (tube lifetime)
3. Digital LLRF, RF ILK + tuning systems

Schedule Inj. 2 (simplified and only resonators 2+4)

<table>
<thead>
<tr>
<th></th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
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</thead>
<tbody>
<tr>
<td>Res. 2</td>
<td>- Res. Installation as vacuum chamber - LLRF installation</td>
<td>- Commissioning &amp; operation</td>
<td></td>
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<tr>
<td>Res. 4</td>
<td>- Res. Installation as vacuum chamber - LLRF installation</td>
<td></td>
<td>- Commissioning &amp; operation</td>
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</tbody>
</table>

LLRF Roadmap
1. IF 40 MHz → RF 50 MHz
2. Base on SwissFEL LLRF proc. platform (FPGA, CPU, FMC) for CW operation
- Operation & Maintenance
- Planning for SLS 2.0 Upgrade
Goal: Upgrade storage ring to provide factor >30 improved emittance + harder X-rays

For all subsystems such as RF/LLRF: Upgrade to ensure other 20+ years operation, to optimize operation + maintenance cost, optimize perf. ...

Schedule

<table>
<thead>
<tr>
<th></th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<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></td>
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<tr>
<td>financing period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>green</td>
<td>green</td>
<td>green</td>
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<tr>
<td>procurement/ testing/pre-assembly</td>
<td></td>
<td></td>
<td></td>
<td>red</td>
<td>red</td>
<td>red</td>
<td>red</td>
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<tr>
<td>maximum &quot;dark&quot; period</td>
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LLRF Roadmap in preparatory phase

1. Internally define with other groups next processing platform requirements and start development
   → 500 MHz systems: ready for test stand operation 2021/22.

2. Upgrade Linac stations (currently with feed-forward only) with the SwissFEL type digital LLRF (exact fit: pulsed 3 Hz @ S-band)
SwissFEL
- LLRF System is ready and has no show-stoppers
- Due to in-house development have the flexibility for upgrades or new feature requests with reasonable cost and manpower effort
- RF vs. beam jitter and drift stability to be studied and optimized
- Consolidation phase with user operation and dual bunch commissioning Athos is the main task for the next two years

HIPA Injector 2 Upgrade
- Concept to re-use digital back-end (ADC, DAC, processing board) from SwissFEL
- LLRF implementation in 2018, first RF operation new resonator 2019

SLS 2.0 Upgrade
- Next processing platform requirements driven by internal demands for various applications: Need to start now to be ready 2020 for test stand systems
  - E.g. stay with VME because of internal synergies and cost-optimal electronic housing until requirements demand for new bus standard.
My thanks go to

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