Operational experience with the MicroTCA.4-based LLRF system at FLASH.

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for the DESY LLRF team
LLRF15
2015/11/4
Overview

> Evolution of the LLRF System at DESY
> Overview of Hardware Components installed at FLASH
  ▪ Platform related
  ▪ Application related
> Performance
> Operation statistics
  ▪ Examples of failures (hardware, software/firmware)
> Summary

Slide contributions from:
• S. Pfeiffer
• M.K. Czwalinna
• F. Ludwig
Evolution of digital LLRF@DESY

- **DSP LLRF (VME-based) → monitoring system**
  - Basic controller functionality
  - Feedback and feed forward drive
  - Main digital VS feedback concept

- **Simcon (VME-based) → temp. backup system**
  - Integration complex controller structure
  - Beam based feedback system
  - Restructuring server + firmware layout

- **Switching to MicroTCA.4**
  - Layout change (ADC + main controller)
  - September 2011 → test setup ACC1
  - Permanent FLASH operation since Aug. 2013
  - Implementation of all commissioned software components from previous version

→ Known procedures, new features
MicroTCA.4 Hardware at FLASH

- **Platform** related modules provided by industry.
- **Application** related components developed in-house and in collaboration with universities and industry.
- Specification, debugging and system integration mainly on our side.

Typical MicroTCA.4 platform modules used at FLASH

**Wiener, 1kW**

**2U Schroff chassis**

**9U 12 slot ELMA**
- LLRF AMC backplane
- PCIe gen. 3 (8 Gbps)
- PtP: <6 Gbps (newer units can go up to 10 Gbps)

**9U 12 slot Schroff**
- LLRF AMC backplane
- PCIe gen. 3 (8 Gbps)
- PtP: 10 Gbps

**NAT MCH-PHYS**
- Host of the MCMC.
- Host of the PCIe switch: PCIe x 4 Gen 3 for each slot.
- Centralized CLK distribution to all AMCs.
- Transition to rear over Z3 (COM Express, management module for the RF backplane).

**Concurrent AM 900/412**
- 2-core 2.5 GHz Intel Core i7-3555LE processor
- 16 Gbytes of DDR3-1600
- X 8 PCIe Gen 3
- 2 x SATA interfaces for onboard storage
- 4 x Gigabit Ethernet interfaces
- 2 x USB 3.0 ports via front panel
- 3 serial port interfaces
- Display Port graphics interface via front panel
- Serial-over-LAN (SOL)
- Possibility to switch to a quad-core
**MicroTCA.4 Hardware Infrastructure at FLASH (cont’d)**

**Vector Modulator**
- Spartan 6
- Dual vector modulator output
- 2 x RF monitor outputs

**Down-Converter**
- 10 channels
- LO distribution
- Var. attenuators
- Temp. and LO pow. monitoring

**RF In**

**RF Out**

**Controller/Concentrator**
- Kintex 7
- 8 SFP channels
- 4 PtP on Z3
- 8 PtP on AMC backpl.
- 4 for PCIe
- 2 GbE and 2 on ports 2,3

**LLRF AMC BKCPL.**

**PtP links**

**Piezo, BAMs**

**To drift comp. module**

**From Master Timing**

**Digitizer**
- Virtex 6
- 5 dual channel 125 MSPS ADCs

**Timing**
- FP 4 x SFP conn. In/Outs
- FP 4 x 4 RJ45 Trigger/CLK/GPIO
- Z3 9 x Triggers/CLKs

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## Currently installed hardware at FLASH

<table>
<thead>
<tr>
<th>Hardware</th>
<th>RF GUN</th>
<th>ACC1</th>
<th>ACC39</th>
<th>ACC23</th>
<th>ACC45</th>
<th>ACC67</th>
<th>Test-stand</th>
</tr>
</thead>
<tbody>
<tr>
<td>MicroTCA .4 Crate</td>
<td>Schroff 2U</td>
<td>Schroff with LLRF AMC backplane and RTM backplane</td>
<td>Schroff with LLRF AMC backplane and RTM backplane</td>
<td>Schroff with LLRF AMC backplane and RTM backplane</td>
<td>ELMA with old AMC backplane, LLRF RTM backplane</td>
<td>ELMA with old AMC backplane, LLRF RTM backplane</td>
<td>ELMA with new AMC backplane, RTM backplane compatible</td>
</tr>
<tr>
<td>Power supply</td>
<td>1x Wiener PS</td>
<td>1x Wiener PS</td>
<td>1x Wiener PS</td>
<td>1x Wiener PS</td>
<td>PEM</td>
<td>PEM</td>
<td>PEM</td>
</tr>
<tr>
<td>Controller</td>
<td>SIS8300LS</td>
<td>uTC</td>
<td>uTC</td>
<td>TCK7</td>
<td>uTC</td>
<td>uTC</td>
<td>TCK7 + uTC</td>
</tr>
<tr>
<td>VM</td>
<td>DWCVM rev 1.1</td>
<td>VM 1.2</td>
<td>VM 1.2HF</td>
<td>VM 2.2LF</td>
<td>VM.1.2</td>
<td>VM 1.2</td>
<td>VM 2.2 + 1.2</td>
</tr>
<tr>
<td>Digitizer</td>
<td>SIS8300LS+KLM</td>
<td>SIS8300LS</td>
<td>SIS8300LS</td>
<td>SIS8300LS</td>
<td>SIS8300LS</td>
<td>SIS8300LS</td>
<td>SIS8300LS</td>
</tr>
<tr>
<td>DWC</td>
<td>DWCVM rev 1.1</td>
<td>Vers 2.2</td>
<td>Partly broken</td>
<td>Vers 2.2</td>
<td>Vers 2.2</td>
<td>Vers 2.2</td>
<td>Vers 2.2</td>
</tr>
<tr>
<td>Piezo ctrl.</td>
<td>x</td>
<td>Installed No HW protection</td>
<td>x</td>
<td>De-installed</td>
<td>Installed No HW protection</td>
<td>Installed No HW protection</td>
<td>XFEL box for tests</td>
</tr>
<tr>
<td>DCM</td>
<td>x</td>
<td>dummy</td>
<td>dummy</td>
<td>yes</td>
<td>dummy</td>
<td>dummy</td>
<td>yes</td>
</tr>
<tr>
<td>REFM opt</td>
<td>x</td>
<td>dummy</td>
<td>dummy</td>
<td>dummy</td>
<td>dummy</td>
<td>dummy</td>
<td>dummy</td>
</tr>
<tr>
<td>LOGM</td>
<td>x</td>
<td>V2 1U</td>
<td>V2 1U PLL</td>
<td>V2 1U</td>
<td>V1 2U</td>
<td>V1 2U</td>
<td>2U first module</td>
</tr>
</tbody>
</table>
MicroTCA.4 LLRF System – signal flow
RF stability measurement results (in-loop regulation)

**Stability (rms) @ 9MHz**

<table>
<thead>
<tr>
<th></th>
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<th>ACC45</th>
<th>ACC67</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ampl. Intra pulse [%]</td>
<td>0.0067</td>
<td>0.0266</td>
<td>0.0055</td>
<td>0.0079</td>
<td>0.0069</td>
</tr>
<tr>
<td>Ampl. pulse to pulse [%]</td>
<td>0.0017</td>
<td>0.0053</td>
<td>0.0012</td>
<td>0.0009</td>
<td>0.0019</td>
</tr>
<tr>
<td>Phase Intra pulse [deg]</td>
<td>0.0100</td>
<td>0.0233</td>
<td>0.0074</td>
<td>0.0099</td>
<td>0.0089</td>
</tr>
<tr>
<td>Phase pulse to pulse [deg]</td>
<td>0.0028</td>
<td>0.0108</td>
<td>0.0017</td>
<td>0.0023</td>
<td>0.0031</td>
</tr>
</tbody>
</table>

**Requirement:** < 0.01% in amplitude and < 0.01deg in phase
Without fast intra-train beam based feedback $\rightarrow$ averaged arrival time jitter $\approx 40$ fs for all bunches

- BAM resolution for 3BC2 higher then for 4DBC3
- Resolution is limited by the lock between RF to the optical synchronization system (RF stab. can be better)
Regular FLASH operation

- System for all SC modules in operation since >2 years
  - Startup issues mainly due to software migration
  - Hardware mostly prototype versions (no major issues found)
  - Partly installed inside the accelerator tunnel

- RF-Gun in regular operation since Jan 2015

- Currently concentrating on upgrades in smaller steps
  - Software/Firmware + specific HW components

- Regular operation for FLASH1 and FLASH2.

See talk by V. Ayvazyan: “Low Level RF Control Implementation and Simultaneous Operation of Two FEL Undulator Beamlines at FLASH“ - Wed

✓ System fulfills expectations regarding quality and reliability.
✓ Gained valuable experience for the XFEL commissioning and operation!

See talk by J. Branlard: “LLRF installation and commissioning at the European XFEL“ - Wed
Downtime per RF station in 2015

- Tunnel installation requires access (machine recovery counted)
  - Exchanging parts, hardware failures
- RF-Gun system was installed in this year
- ACC45 tuning time for variable gradients
LLRF counted downtime in categories (2015)

- Infrastructure (Timing, power, cooling water, crate, boards) 57%
- Server (crashes, malfunction, restarts) 20%
- Automation (diverging routines, not working functions,...) 5%
- Firmware (malfunctions, required reboots, crashing) 3%
- Operation (misusage, exceeding thresholds,...) 4%
- Performance (no machine operation, because of not working regulation) 11%
Examples of most recent hardware failures

- **Broken Zone3 connection**
  - VM ACC39 exchange for upgrade
  - FLASH installation space very limited

- **Failures of SSD’s / Raid array**
  - Mainly visible on the RF GUN
  - Often not the SSD’s are broken but the RAID (sw) was loosing a disk
  - Installed new special single-level-cell type SSDs
  - Installation of radiation monitors to study what is the correlation

- **In the past we have seen:**
  - Broken cables (optical and copper)
  - Power cuts of the whole rack system

- **We have not seen:**
  - Individual modules dying or degrading in performance or availability
Typical problems requiring LLRF-expert intervention

> The ability to control the system is lost, but the machine continues operation with running firmware
  - No access to the system due to in-tunnel installation
  - Used to be a MCH FW issue

> Frequent gradient changes require manual cavity tuning
  - Piezo tuners are not in use because of an incident
  - Cavity tuning performed by step motors
  - Controller design is optimized to tuned cavities => performance degradation

> Software malfunction and bugs
  - Frequent updates of the server to add new features and bug fixes

> Interaction with the timing system
  - LLRF-expert is often called first

Usually most of these problems are fixed by the on-call LLRF Expert.
What do we eventually expect from the system upgrade?

> Better short term and long term stability of the detected RF fields compared to the past.

> A system where there is enough room and processing power for additional FPGA and SW functionality (virtual probes, cavity simulator for exception handling, etc.).

> Using all the convenient features provided by MicroTCA.4:
  - redundancy
  - hot-swapping
  - remotely accessible details about modules
  - e-keying
  - remote programming of FPGAs over HPM.1
  - handling of critical and non-critical events, etc.)

The system deployed at FLASH is capable of providing all this but there is still work to be done.

See talk by F. Ludwig: “Field detection and drift calibration for the European XFEL“ - Fr

See talk by M. Hoffmann: “Sub-10 fs RF regulation at REGAE “ - Fr

See talk by S. Pfeiffer: “Frequency control through pulse width modulation for NC cavities“ - Thu
Summary

> 2 years of operation of FLASH with MicroTCA.4 LLRF system
  ▪ Short term performance achieved → Improvement in regulation performance
  ▪ System is operating stably (main issues found and fixed)

> Continuing with the upgrade of the system
  ▪ Software development, further automation routines
  ▪ Upgrade of hardware components
  ▪ Integration of module for improving long term stability

> Next major milestones → Integration with optical synchronization system
  ▪ Recommissioning of the fast intra-train feedback
  ▪ Link stabilized reference

Thank you for your attention