LLRF Commissioning and First Operation of the European XFEL. with some insight on operation issues.

Julien Branlard, for the LLRF team
XFEL MicroTCA.4 LLRF installation
MicroTCA workshop, DESY, 6.12.2017
INTRODUCTION: the European XFEL

European X-ray Free Electron Laser
- 17.5 GeV light source user facility
- TESLA superconducting 1.3GHz RF cavities
- 1.4 msec pulses at 10 Hz
- e- beam 1.35 mA nom. - 4.5 mA max
- 2009: construction starts
- 2017: commissioning + first user operation

https://www.youtube.com/watch?v=p3G90p4glQA

Electron beam is generated
Energy of electron beam is amplified
Powerful light with short wavelength is produced
X-ray free-electron laser is created

Electron gun Accelerator Undulator Beamline

INTRODUCTION: XFEL milestones

> **2006**: Publication *Technical Design Report* (TDR)
> **2009**: Civil engineering starts
> **2013**: End of underground construction
> **Oct. 2013**: First RF tests in the injector
> **2014**: Installation of the first experimental huts
> **Dec. 2015**: First accelerated beam in the injector
> **2015-2016**: Main Linac installation (L1, L2, L3)
> **Sep. 2017**: First user run
> …
INTRODUCTION: XFEL RF station

Technical commissioning represents >50% of the commissioning time

Intersystem commissioning is a key factor of the commissioning time

* not installed yet
LLRF for XFEL: system description

- AMC: Advanced Mezzanine Card
- RTM: Rear Transition Module
- 12 slots, hot swap
- Redundant power supply
LLRF for XFEL: crate occupation - FRONT

- Power module (1kW)
- CPU (quad core)
- Timing
- MCH (PHYS80)
- Main controller (TCK7)
- Machine protection (DAMC2)
- Digitizers (SIS8300)
- Redundant power module

**MASTER**

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<tr>
<th>UPM</th>
<th>MCH</th>
<th>CPU</th>
<th>X2 TIMER</th>
<th>DAMC02</th>
<th>TCK7</th>
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**SLAVE**

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LLRF for XFEL: crate occupation - REAR

- **uLOG** (Reference, CLK, LO)
- Down converters
- Vector modulator
- Machine protection
- Timing
- Power module
LLRF for XFEL: standard system for an RF station

- 2x 9U 12 slot crates (Pentair)
- 4x 1kW power supply (Wiener)
- 2x MCH 80-lane PHYS (NAT)
- 2x CPU quad core (Concurrent)
- 2x timer AMC module (NAT)
- 2x timer RTM module (NAT)
- 2x DAMC2 (DESY)
- 2x MPS-RTM (DESY)
- 2x TCK7 (Vadatech)
- 1x VM (DESY)
- 1x CLKFT (DESY)
- 13x SIS8300 digitizers (Struck)
- 13x DWC1300 down converter (Struck)
- 2x uLOG (DESY/Dynamique)

50 MicroTCA.4 components / RF station

x 26 RF stations
+ non-standard RF stations
+ test setup
+ spares

> 2000 components
**COMMISSIONING:** planning

> **Pre-commissioning**

- Board level.
- Crate level.
- Rack level.

> **Large machine → large team**

- E.g. for XFEL
  - 20 people.
  - 8 LLRF experts.
  - Support from other institutes.

> **Parallel work**

- RF station wise.
COMMISSIONING: tools

Beam operation to T4D 11 GeV, 1 bunches, 0.5 nC, 1 Hz

L3 / CL / TLD

Operation Mode: SASE1/3, TLD
Beam Mode: Short
Personal Interlock: XTL Beam Permission

- **IN operation ON beam**
- **IN operation but shifted OFF beam**
- **Not ready for beam operation hence shifted OFF beam**

Magnets

LINAC Mode: Grounded

RF-station shifted off beam

1 @99 %

1 @97 %

10381 MeV

COMMISSIONING: LLRF milestones

RF ONLY

> Initial checks.  
LLRF system ready for commissioning?

> RF signal checks: **Forward** and **Reflected**.  
Cabling issues? Signal saturation?

> Frequency tuning.  
From parking position to resonance.

> RF signal checks: **Probe**.  
Cabling issues? Signal saturation?

> Coupler tuning.  
Target $Q_L = 4.6e6$.

> Power-based gradient calibration.  
Coarse

> Closed-loop operation.  
Feedback, learning feedforward, …

READY FOR BEAM

> Establish beam transport.  
30 bunches, 0.5nC.

> Cavity phasing.  
Using waveguide phase shifters.

> Beam-based gradient calibration.  
Fine relative calibration.  
Absolute validation using energy server.
COMMISSIONING: tool example & automation

> Power-based calibration

1. Dynamic range optimization

“Adjust attenuation so that available signal uses the optimal range of the digitizers.”

2. Forward power calibration

“Scale forward power signals so they read actual kW, based on the power meter measurements.”

3. Probe and Reflected signal calibration

“Scale reflected and probe signals so that Probe = Forward + Reflected.”
COMMISSIONING: updates

> Migration to Ubuntu 16
- Installation stretched between 2014 to 2016
- All crates installed by default with Ubuntu 12
- Migration to Ubuntu 16 in Oct/Nov 2016
- Recompilation + deployment of all servers for new OS release
- Kernel update planned for end of this year

> Upgrade to PCIe gen 2
- New firmware implementation (board support package)
- Deployment this winter shutdown (first the SIS8300, later TCK7)
- Benefit: factor 2 DNA transfer speed
COMMISSIONING: software and firmware

Tests
- Most of the time, test on real HW → not ideal.
- Working on alternative (VirtualLab: virtual time + devices)

Deployment / update
- Set of scripts (hand config. station by station inevitably fails).
- Debian package calls configuration script. Everything specific to that station. Specific names, specific HW config, etc…

Generic approach
- Same for different servers.
- Same for different facilities.
**OPERATION:** reset after reboot

- **RESET dividers to a defined state after crate reboot**
- **Several MicroTCA modules involved**
- **Fixed relationship between TRIG, CLK and 1.3 GHz reference**
- **Use the absolute phase offset from the reference channel as template for the other channels**
OPERATION: isolated failures (1/2)

> CPU overheating
  - Reason unknown
  - CPU exchange (May 2017 A13S)

> CPU overload
  - A1/AH1
  - 2x LLRF system in 1 crate
  - Investigate a 2-CPU solution?
OPERATION: isolated failures (2/2)

> SSDs exchange
  - RAID redundancy lost, slow writing to disk
  - FLASH: 20 occurrences in 6 years

> Device needs to be reprogrammed
  - MCH (x1)
  - TCK7 (x1)
  - FLASH: 2-3 occurrences

> Lost Ethernet communication with device
  - 1 occurrence so far: (Nov. 2017 TMCB REFM-OPT)
  - FLASH: 5-6 times (PDU)
OPERATION: is radiation an issue?

- Regular TLD read outs
- On-line dark current beam loss monitors
- Weekly survey (MARWIN)
OPERATION: is radiation an issue?

Radiation

- Online monitor
- Regular survey
- XFEL : MARWIN

MARWIN: Mobiler und Autonomer Roboter für Wartung und INSpekion
> Machine-level overviews panels

- Summary panels
- Statistical analysis
- Overview system health

> Machine-level diagnostics & predictive maintenance

- Monitoring
  CPU load, fan speeds, temperatures, voltages, radiation doses, ...

- Alarm server
  Loss of reference, loss of lock, over temperature

- Data correlation
  Improve fault detection (more signals / model-based).

- Trip logger
  Down time statistics. Where to focus our effort?
OUTLOOK: what’s next?

> XFEL advanced operation

- Performance meas. & improvement (energy, stability, uptime)
  - study time, advanced commissioning
  - software / firmware upgrade

> XFEL hardware upgrade

- Improved diagnostics
  - Klystron protection, (KLM-RTM)
  - Beam diagnostics (HOM-RTM)
  - Direct sampling (DS800)

- Hardware upgrades
  - CPU ?, GPU?
  - ADCs ?
  - Main FPGA board ?
QUESTIONS?

Thank you for your attention!