MicroTCA.4 Usage in the Femtosecond-Synchronization System at European XFEL

Enabling the XFEL for femtosecond precision user experiments!

Matthias Felber
for the LbSync Team
5th MicroTCA Workshop for Industry and Research
DESY, 8th December, 2016
Overview

> Introduction: Optical Synchronization System
> MicroTCA Setups
> Firmware & Software
Provide a global, femtosecond stable reference for the synchronization of timing-critical systems of the accelerator
Synchronization ≠ Timing

- Machine trigger (10 Hz)
- Digital clock
- ps stability
- Bunch pattern
- ...

Provide a global, femtosecond stable reference for the synchronization of timing-critical systems of the accelerator
Introduction – Optical Synchronization System

Provide a global, femtosecond stable reference for the synchronization of timing-critical systems of the accelerator

- Global accelerator “clock”:
  - RF Master Oscillator (MO)
Provide a global, femtosecond stable reference for the synchronization of timing-critical systems of the accelerator

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  - RF Master Oscillator (MO)

> Optical Synchronization System:
  - Distribute the clock without degrading its performance (jitter/uncertainty)
  - Either provide the distributed signal to other subsystems or make use of the distributed signal directly
Introduction – Optical Synchronization System

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Building blocks

> Source: Pulsed laser (‘Master Laser Oscillator’, MLO)
  - Locked to the MO

> Distribution Medium: Optical Fiber
  - Actively phase stabilized fiber links
    (LSU = Link Stabilization Unit)
Introduction – Sync Endstations

Provide a global, femtosecond stable reference for the synchronization of timing-critical systems of the accelerator

> Laser synchronization (L2RF & L2L)

- **Pump-Probe**, Injector-, Seed-, and Diagnostic-lasers: Frequency and phase of the emitted pulse train are synchronized to the optical reference.
Provide a global, femtosecond stable reference for the synchronization of timing-critical systems of the accelerator

> Laser synchronization (L2RF & L2L)
  - Pump-Probe-, Injector-, Seed-, and Diagnostic-lasers: Frequency and phase of the emitted pulse train are synchronized to the optical reference.

> RF synchronization (REFM-OPT)
  - Providing a synchronized reference for the precise control of the accelerating field in the cavities (LLRF) depends on a stable RF reference which is provided by the sync
Introduction – Sync Endstations

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- Laser synchronization (L2RF & L2L)
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- Bunch arrival time measurements (BAM)
  - Beam-Based Feedback to synchronize (= stabilize) the arrival time of individual bunches to the optical reference

Next Talk, 9:45 by Hannes Dinter
Introduction - Optical Links at the European XFEL

Sync Room
Injector Building
Up to 32 LSUs

Sub-Sync Room
Experimental Hall
Up to 20 LSUs

Link Stabilization Units

RF Master Oscillator

MLO1  MLO2

FSD

INJL  GUN  REFM  BAM

0m  20m  30m  40m  50m
XTIN  L1-XTL  L2-XTL

LLRF & BPM

L3 (Main LINAC)
21 RFS (+3)

UNDULATORS

INJL  REFM  GUN  BAM

5x

SEED  BAM  SEED  BAM

LSUs

Sub Distribution

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Introduction - Optical Links at the European XFEL

Digital Feedback Loops
- Laser Synchronization

Sync Room
- Injector Building
- Up to 32 LSUs

Link Stabilization Units

Sub-Sync Room
- Experimental Hall
- Up to 20 LSUs

Sub Distribution

LSUs

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Introduction - Optical Links at the European XFEL

Digital Feedback Loops
- Laser Synchronization
- Link Stabilization

Sync Room
Injector Building
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Link Stabilization

MLO1
MLO2
FSD

REFM
BAM

LSUs

Sub Distribution

2x

5x

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Introduction - Optical Links at the European XFEL

Digital Feedback Loops
- Laser Synchronization
- Link Stabilization
- RF Stabilization

Sync Room
- MLO1
- MLO2
- FSD
- Injector Building
- Up to 32 LSUs

Link Stabilization

Sub-Sync Room
- Experimental Hall
- Up to 20 LSUs

Sub Distribution
- LSUs

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Introduction - Optical Links at the European XFEL

Digital Feedback Loops
- Laser Synchronization
- Link Stabilization
- RF Stabilization
- Laser Diode Stabilization

Sync Room
Injector Building
Up to 32 LSUs

Sub-Sync Room
Experimental Hall
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Sub Distribution

Link Stabilization

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Introduction - Optical Links at the European XFEL

Digital Feedback Loops
- Laser Synchronization
- Link Stabilization
- RF Stabilization
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Sync Room
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Link Stabilization

Sub Distribution
- LSUs

LSUs
MTCA integrates many components in a compact form factor

Electronic Infrastructure for Opt. Sync at FLASH (2 MLOs, 16 LSUs)
- 4 x 42 HE Racks
- 5 x VME Crates
- 6 x PLCs
- 18 x Piezo-Driver
- 6 x Vector Modulators

MicroTCA for Opt. Sync at XFEL (2 MLOs, up to 32 LSUs)
- 2 x 42 HE Racks
- 3 x MicroTCA Crates
- 1 x PLCs
- Up to 32x LDD
MTCA Setups – LSU Control

One Channel requires $\frac{1}{4}$ of a set of 2 boards / 2 slots → 4 Link stabilizations with 2 slots

Laser Diode Driver

Link Stabilization Unit

OXC signal 1MHz, ±5V

Phase detector <1kHz, ±1V

Piezo voltage <40kHz, ±80V

Stepper Motor

RTM ADC uAD84 16 bit, 10 MSPS 1/4

RTM PiezoDriver uPZT4 >16 bit, >100kSPS 1/4

Power Monitor Forward

Power Monitor Reflected

Balanced Detector Monitor 1

Balanced Detector Monitor 2

AMC FMC25 1/4

AMC FMC20 1/4

DFMC-AD16 4 x 4 Ch

DFMC-MD22 4 x 1 Ch

Backplane 10 MBit/s

I2C, IPMI

1.3 GBit/s

Zone 3

Zone 3

Zone 3

Zone 3

Zone 3

ATT. ±1V
One Channel requires \( \frac{1}{4} \) of a set of 2 boards / 2 slots → 4 Link stabilizations with 2 slots
Digitizer-RTM

DRTM-AD84

- 8 x ADC:
  - 16 bit
  - 2 MSPS
  - 50 Ω or 1 kΩ
  - 90 MHz (2 MHz)
  - ±1 V

- 4 x DAC
  - 16 bit
  - 1 (16) MSPS
  - ±1 V / ±3 V @ 50 Ω

- Zone 3: D1.0 / D1.1
One Channel requires \( \frac{1}{4} \) of a set of 2 boards / 2 slots → 4 Link stabilizations with 2 slots
Controller-AMC

DAMC-FMC25

- Processing: Virtex 5
  - XC5VFX70T
  - XC5VFX100T
- Communication:
  - Spartan 6
- 2 x FMC (HPC)
- Zone 3: D1.1 / D1.2 / D1.3

Available at CAENels
MTCA Setups – LSU Control: Building Blocks

One Channel requires ¼ of a set of 2 boards / 2 slots
→ 4 Link stabilizations with 2 slots

- Laser Diode Driver
- Link Stabilization Unit
  - OXC signal 1MHz, ±5V
  - Phase detector <1kHz, ±1V
  - Piezo voltage <40kHz, ±80V
  - Stepper Motor

- RTM ADC uAD84
  - 16 bit, 10 MSPS 1/4

- RTM PiezoDriver uPZT4
  - >16 bit, >100kSPS 1/4

- Power Monitor Forward
- Power Monitor Reflected
- Balanced Detector Monitor 1
- Balanced Detector Monitor 2

- Zone 3
  - 1.3 GBit/s
  - I2C, IPMI

- AMC FMC25
  - 4 x 4 Ch 1/4

- AMC FMC20
  - DFMC-AD16
    - 4 x 1 Ch
    - 10 MBit/s
  - DFMC-MD22

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MTCA Setups – LSU Control: Building Blocks

Carrier-AMC

DAMC-FMC20

- Processing:
  - Spartan 6 (LX150)
- Communication:
  - Spartan 6 (LX45)
- 2 x FMC (HPC/LPC)
- Zone 3: D1.0

Available at CAENels
One Channel requires ¼ of a set of 2 boards / 2 slots → 4 Link stabilizations with 2 slots
Piezo Driver-RTM

DRTM-PZT4

- 4 x Channel
- HV-Supply
  - On-board ±100 V
  - Ext. input
- On-board DACs
- Monitoring ADCs
- Interlock support
- Metal-cover
- Zone 3: D1.0 / D1.1
  D1.2
MTCA Setups – LSU Control: Building Blocks

One Channel requires \( \frac{1}{4} \) of a set of 2 boards / 2 slots
\( \rightarrow \) 4 Link stabilizations with 2 slots

Laser Diode Driver

Link Stabilization Unit

- RTM ADC uAD84
  - 16 bit, 10 MSPS
  - 1/4

- RTM PiezoDriver uPZT4
  - >16 bit, >100kSPS
  - 1/4

- Power Monitor Forward
- Power Monitor Reflected
- Balanced Detector Monitor 1
- Balanced Detector Monitor 2

- AMC FMC25
  - 1/4

- AMC FMC20
  - 1/4

- DFMC-AD16
  - 4 x 4 Ch

- DFMC-MD22
  - 4 x 1 Ch

OXC signal
1 MHz, ±5 V

ATT. ±1 V

Phase detector
<1 kHz, ±1 V

Piezo voltage
<40 kHz, ±80 V

Stepper Motor

Backplane
10 MBit/s

I2C, IPMI

1.3 GBit/s

Zone 3

Zone 3

Zone 3

10 MBit/s
Motor Driver-FMC

DFMC-MD22

- Stepper Motor Driver
- 2 x Channel
- End switch readout
- Encoder readout

Available at CAENels
MTCA Setups – LSU Control: Building Blocks

One Channel requires $\frac{1}{4}$ of a set of 2 boards / 2 slots → 4 Link stabilizations with 2 slots
Monitor ADC-FMC

DFMC-AD16

- 16 x Channels
  - 18 bit
  - >100 kSPS
  - 1 MΩ
  - 23 kHz / 15 kHz
  - ±10 V / ±5 V
MTCA Setups – LSU Control: Building Blocks

SFP Communication-FMC

DFMC-SFP4

- Channels:
  - 4x no front panel
  - 2x with front panel
- Vita 57.1 compatible
- $V_{\text{adj}}$ can vary from 3.3 V down to 1.5 V
- I2C-controlled oscillator (10-280 MHz)

Available at CAENels
MTCA Setups - Laser Synchronization

Mode Locked Laser

- Balanced Detector
- OXC or MZI
- Baseband
- Photo Diode
- RF, Higher Harmonic
- RF, Repetition Rate

Reference or Clock & LO

RTM
DWC10 (modified)
future: LASY
1/2

RTM PiezoDriver
uPZT4
2/4

AMC
SIS8300L2

Backplane
10 MBit/s

AMC
FMC20

DFMC-UNIO

DFMC-MD22

2x Piezo voltage
<80kHz, ±80 V

Stepper Motor
or TTL coarse tuning

Zone 3
Baseband
Rep.Rate

Zone 3
10 MBit/s

Special RTM for Laser Synchronization LASY:
Poster by Ewa Janas
Applications

- General-Purpose IO Interfaces
- Laser and Shutter controls
- Industrial process control
- Manufacturing automation

Features

- Low-Pin-Count FMC Module
- Up to 48 general-purpose digital IO pins.
- 2 pins useable as 12-Bit DAC 0-5V, 50 mA drive)
- 2 pins useable as 12-Bit ADC
- 2 x 2 pins useable as two independent power channels
- Hardware current limit: 2 x 1A with soft-start
- 4 pins useable as standard UART (12V levels)
The firmware is always composed of two parts
Laser and Link Synchronization Firmware

The firmware is always composed of two parts

- **Board Support Package (BSP):** board dependent
  - Responsible for general PCB (AMC, FMC, RTM) functions support like clock distribution, communication (PCIe, LLL), support for on-board ADCs/DACs, memories (DDR2)
  - Prepared in pure VHLD (optimized and tested)
The firmware is always composed of two parts

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  - Prepared in pure VHLD (optimized and tested)

- **Application code:** board independent
  - FMC20 Laser & Link lock actuator application prepared in VHDL
  - SIS8300L2/FMC25 controller application prepared with Simulink-RapidX toolkit
  - RapidX binds code generated by Simulink with BSPs prepared by experts

**Advantages:**
- Reusable VHDL code - application can be easily reused on different hardware
- Much faster prototyping and development process
All core synchronization system software (Laser and link locking servers) is based on two main libraries:

- Control System Attacher library - CsaLib
- Device Module library - DevModLib
Laser and Link Synchronization Software

All core synchronization system software (Laser and link locking servers) is based on two main libraries:

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- Device Module library - DevModLib

Control System Attacher library - CsaLib
- Decouples Application Core Logic from Control System allowing to create independent reusable logic
- Some basic features need to be provided by Control System dependent side (history, config files)

- ‘Younger brother’ of Control System Apdater from ChimeraTK
  - Not such powerful – e.g. no real-time support
  - Only single front-end implementation existing – DOOCS
  - Follows similar principles – planned integration

Talk Martin Killenberg
Session 8, 15:45
Poster by Reinhard Steinbrück
Laser and Link Synchronization Software

Device Modules library - DevModLib
• Based on CsaLib and deviceaccess library from ChimeraTK
  • CsaLib provides data exchange with ‘external world’ – Control System
  • Deviceaccess (ChimeraTK) provides access to physical hardware
• Support for:
  • AMCs’ BSPs - FMC20, FMC25, SIS8300, SIS8300L
  • FMCs’ and RTMs’ BSPs – FMC-MD22, FMC-AD16, RTM-PZT4, RMT-AD84
  • Application logic - DAQ, Simulink-RapidX modules, higher level algorithm (ex. coarse tuning)
• Modular structure (C++ Object Oriented code) allowing core reuse for fast application development
• Each module has a jddd panel

Software components for
Struck SIS8300L2 BSP

Software components for
FMC25 BSP
Laser and Link Synchronization Software

DRTM – PZT4

DFMC – MD22

Laser Synchronization Controller

DRTM – PZT4 jddd panel

DFMC – MD22 jddd panel

Laser synchronization jddd panel
Thank you for your attention!