Laser Synchronization with MicroTCA

MicroTCA.4 for Femtosecond-stable Optical Synchronization Systems at FLASH, XFEL and more.

Matthias Felber
LbSync Team
DESY MSK group

6th MicroTCA Workshop for Industry and Research

DESY, Hamburg, Germany
December 6, 2017
Overview

▶ Introduction / Motivation
  ▪ Lasers at FELs
  ▪ Optical Synchronization Systems

▶ Laser Synchronization
  ▪ How to Synchronize a Laser
  ▪ MicroTCA Components for Laser Synchronization
Motivation - Lasers at FELs (here: FLASH)

- 3rd harmonic sc module 3.9 GHz
- TESLA type superconducting accelerating modules 1.3 GHz
- FLASH1 fixed gap undulators
- FLASH1 Experimental Hall

RF Stations → Accelerating Structures → Bunch Compressors
- RF Gun Lasers
- 5 MeV
- 150 MeV
- 450 MeV
- 1250 MeV

sFLASH → FLASH1 → FLASH2 → FLASHForward

2 lasers

≥ 30 µs gap

Extraction to FLASH2
FLASH2 variable gap undulators
FLASH2 Experimental Hall

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Motivation - Lasers at FELs (here: FLASH)

Master Laser Oscillator  sFLASH  EO Diagnostics  Pump-Probe FL1

RF Stations  Accelerating Structures  sFLASH  Photon Diagnostics

RF Gun Lasers  Bunch Compressors  FLASH1  FlashForward

5 MeV  150 MeV  450 MeV  1250 MeV

Injector Lasers  Seeding  Plasma Acceleration  Pump-Probe FL2

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Optical Synchronization System with Endstations

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

- Master Oscillator RF-MO
- Master Laser Oscillator MLO
- Humidity and temperature stabilized synchronization room
- Free-space distribution FSD
- Link Stabilization Unit LSU
- Laser-to-laser L2L synchronization
  - Injector laser
  - Seed laser
  - Pump-probe laser
  - Further laser systems
- Laser-to-RF L2RF synchronization
  - LLRF
- Bunch arrival time monitoring BAM
  - Beam based feedback
- Required point-to-point stability: 10 fs

Remote locations

Courtesy C. Sydlo
Optical Synchronization System with Endstations

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

<table>
<thead>
<tr>
<th>Digital Feedback Loops</th>
<th>E-XFEL</th>
<th>FLASH</th>
<th>others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Synchronization</td>
<td>10x (15x)</td>
<td>7x (10x)</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>Link Stabilization</td>
<td>33x (52x)</td>
<td>16x (24x)</td>
<td>-</td>
</tr>
<tr>
<td>RF Stabilization</td>
<td>10x</td>
<td>3x</td>
<td>-</td>
</tr>
</tbody>
</table>

Laser-to-laser L2L synchronization
- Injector laser
- Seed laser
- Pump-probe laser
- Further laser systems

Laser-to-RF L2RF synchronization
- LLRF

Bunch arrival time monitoring BAM
- Beam based feedback

Remote locations

Required point-to-point stability: 10 fs

Courtesy C. Sydlo
Motivation: Time-resolved Pump-Probe experiments

Desired time resolution of user experiments is often in the fs range

> Laser synchronization

- Frequency and RF phase of the emitted pulse train are synchronized to the optical reference.

- Injector
- Pump-Probe
- FEL Seeding
- Plasma acceleration
**Injector Laser Sync at E-XFEL**

- Charge stability

  ![Charge stability graph](image)

  - Injector Laser1 (bad Synchronization)
  - Injector Laser2 (good Synchronization)

- Compression stability

  ![Compression stability graph](image)

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How to Synchronize a Laser

- Laser resonator needs **actuator** to change optical length → move a mirror
  - Piezo stacks for fast control: usually a few kHz bandwidth, μm range
  - Stepper motor or piezo driven delay stage for slow, coarse tuning
  - Temperature variation for coarse tuning (mostly driven by GPIO signal to laser controller)
How to Synchronize a Laser

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> Need reference signal and phase detector to measure the deviation
How to Synchronize a Laser

> Build a **Feedback Loop** to lock the laser (RF-)phase to the reference → PLL
How to Synchronize a Laser

Build a Feedback Loop to lock the laser (RF-)phase to the reference → PLL

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Method</th>
<th>Processing</th>
<th>Algorithm (FPGA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental Frequency</td>
<td>Direct Conversion</td>
<td>Direct Sampling</td>
<td>IQ -&gt; Phase</td>
</tr>
<tr>
<td>(1. harmonic)</td>
<td>PFA*</td>
<td>(non-IQ)</td>
<td></td>
</tr>
<tr>
<td>Laser RF Lock</td>
<td>Direct Conversion</td>
<td>Non-IQ sampling of</td>
<td>IQ -&gt; Phase</td>
</tr>
<tr>
<td>(1.3 GHz harmonic)</td>
<td>Downconversion</td>
<td>Intermediate Freq.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PFA* + Mixer</td>
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<td></td>
</tr>
<tr>
<td>Laser Optical Lock</td>
<td>Balanced Optical Cross-</td>
<td>Baseband Sampling</td>
<td>-</td>
</tr>
<tr>
<td>(for opt. Reference)</td>
<td>Correlator</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Balanced Detector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laser RF Lock</td>
<td>Laser2RF Phase Detector</td>
<td>Direct Sampling</td>
<td>IQ -&gt; Amplitude</td>
</tr>
<tr>
<td>(Electro-optical amplitude</td>
<td>Photodiode</td>
<td>(non-IQ)</td>
<td></td>
</tr>
<tr>
<td>modulation)</td>
<td></td>
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</tr>
</tbody>
</table>

*) PFA = Photodiode Filter Amplifier
MicroTCA Components for Laser Synchronization
MTCA Setups for Laser Synchronization

Simplified block diagram

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

Reference or Clock & LO

RTM for Laser Sync
- LASY

Zone 3
- Baseband
- IF
- Rep. Rate

AMC
- Digitizer / Processing
  - SIS8300L2

Backplane
- "Low-Latency Link"

AMC Carrier
- FMC20
- FMC-UNIO
- FMC-MD22

PiezoDriver
- PZT4

2x Piezo voltage
- <80kHz, ±80 V
- Piezo Motor

Stepper Motor
- or TTL coarse tuning
Motor Driver-FMC

DFMC-MD22

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

Available at CAEN ELS S.R.L.
**GPIO-FMC**

**DFMC-UNIO (or UNI-IO)**

- On-board microcontroller and CPLD
- Up to 48 general-purpose digital IO pins.
- In or Out configurable
- 5 V or 3.3 V configurable
- Optional Special Functions:
  - 2x Laser Shutter Control
  - 2x DAC (12 bit, 0-5 V, 50 mA)
  - 2x ADC (12 bit)
  - 2 x 2 pins useable as two independent power channels
  - 4 pins useable as standard UART (12V levels)
MTCA Setups for Laser Synchronization

**DRTM-PZT4 (PRTM-PZDR4)**
- 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

*Soon available at Piezotechnik Dr. Jänker GmbH*
MTCA Setups for Laser Synchronization

See also talk by K. Przygoda, tomorrow morning: "Single Cavity and Piezo Controls and Applications"

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See also talk by K. Przygoda, tomorrow morning: "Single Cavity and Piezo Controls and Applications"

See also talk by M. Fenner, tomorrow afternoon: "Safety Improvements of the MicroTCA Piezo Driver DRTM-PZT4"

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"Cavity and Piezo Controls and Applications"
See also talk by P. Jänker, tomorrow morning:
"Big things sometimes come in small pieces"
See also talk by M. Fenner, tomorrow:
"Safety Improvements of the MicroTCA Piezo Driver DRTM-PZT4"

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MTCA Setups for Laser Synchronization

DAMC-FMC20
- Dual FMC Carrier
- Processing: Spartan 6 (LX150)
- Communication: Spartan 6 (LX45)
- 2 x FMC (HPC/LPC)
- Zone 3: D1.0

Available at CAEN ELS S.R.L.
MTCA Setups for Laser Synchronization

AMC SIS8300L2
- 10 x ADC
  - 16 bit
  - 125 MSPS
  - DC or AC coupled
  - Assembly variants for BW (up to 340 MHz)
- 2 x DAC
  - 16 bit
- FPGA: Virtex 6
- Zone 3: A1.0, A1.0C or A1.1CO

Available at Struck Innovative Systeme GmbH
MTCA Setups for Laser Synchronization

DRTM-LASY (new development)
- Downconverter
- Reference tracking for eliminating LO and Clk drifts
- 2-tone calibration for removing channel-to-channel variations
- Low noise baseband channels for cross-correlator
- Low noise direct sampling channels
- Low noise L2RF channel
- Photodiode power supply
- Carrier for signal generation mezzanine (LO, Clk, 2nd tone calibration signal)
MTCA Setups for Laser Synchronization

Mode Locked Laser

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- RF, Repetition Rate

Reference or Clock & LO

Step Rate

2x Piezo voltage
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- ±80 V

Piezo Motor

Stepper Motor
- or TTL coarse tuning

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MTCA Setups for Laser Synchronization

Full laser sync setup – example: XFEL SASE1 Pump-Probe

→ LASY will simplify the setup and most likely improve the performance
MTCA Setups for Laser Synchronization

Full laser sync setup – example: XFEL SASE1 Pump-Probe
→ LASY will simplify the setup and most likely improve the performance

For more on Laser controls and electronics see also talk by C. Mohr, tomorrow at 12:00:
"Control Hardware and Software for Laser Systems at DESY and the European XFEL"
Thank you for your attention!

> Synchronization Team

- C. Sydlo
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- M. Titberidze
- M. Felber
- T. Kozak
- M. Hoffmann
- P. Prędki
- S. Jabłonski
- S. Ruzin

> With support from MSK

- Digital Electronics Team
- Analog Electronics Team
- Technicians
- Mechanics Workshop
- Firmware & Software Team
- Special Diagnostics