Femtosecond precision synchronization system of the European XFEL.

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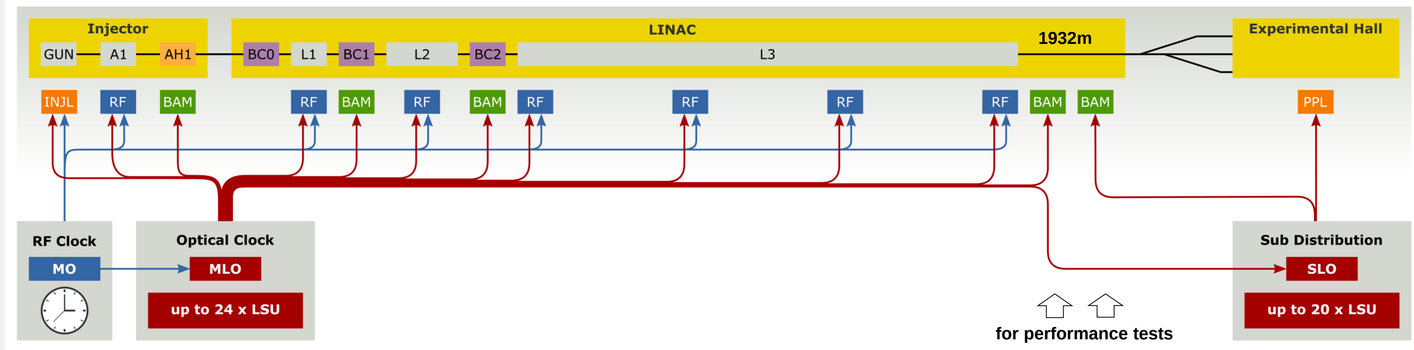
Abstract

At European XFEL a large scale optical synchronization system was installed to provide femtosecond stable reference signals for laser locking, for beam instrumentation and to allow for precision RF accelerating field control. The poster summarizes the system architecture and key components together with recently achieved results.

Synchronization system architecture

Original specs: Point-to-point < 10 fs rms short term and < 10 fs pkpk long term synchronization accuracy



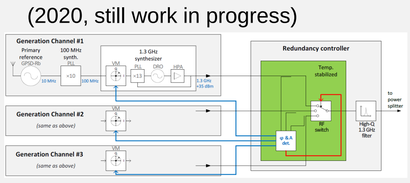
Architecture:

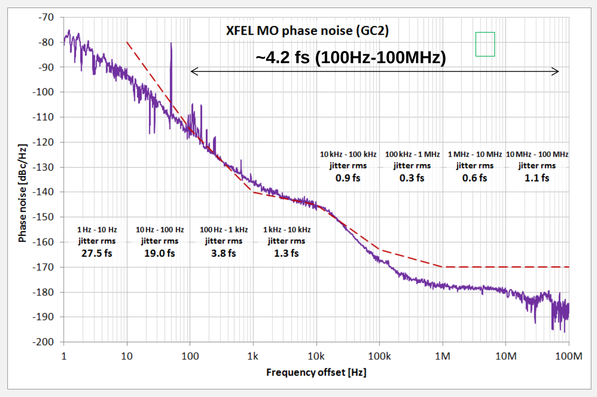
- **Optical clock** (Master Laser Oscillator, MLO) locked to **RF Master Oscillator** (MO), provides stable pulsed optical reference
- **RF Distribution** in main linac & SASE beamlines distributed conventionally (RF coax) for reliability reasons (270 clients)
- Optical reference distributed via **length-stabilized optical fiber links** and used for
  - **Laser locking** (injector, pump-probe, …)
  - **RF re-synchronization** (REFM-OPT)
  - **Bunch Arrival time Monitors** (BAM)

Master Oscillator (MO)

Design:

- phase stability of 10^{-11} by locking to GPS
- 100MHz OCXO
- 1.3GHz DRO
- 24/7 operation, 3 redundant setups (2020, still work in progress)

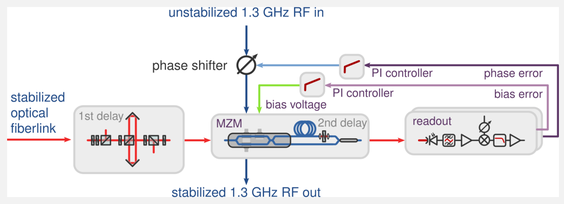


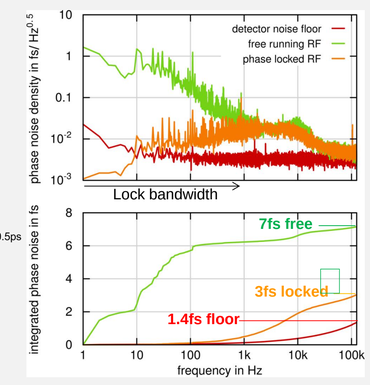


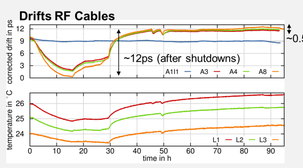
RF-resynchronization (REFM-OPT)

Method:

- Drift-free laser-to-RF phase detector to control phase shifter
- Mach-Zehnder amplitude modulator with bias feedback
- 1st delay used to sample 0° & 180° phase of RF



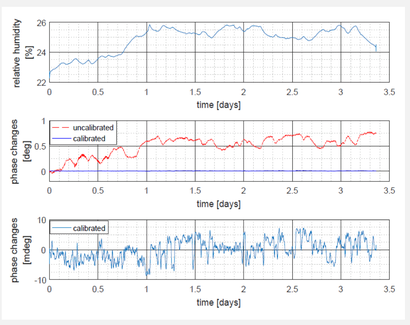


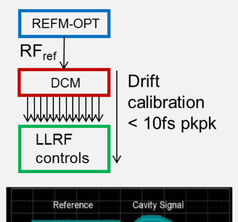


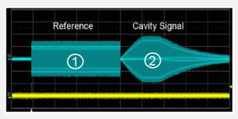
Drift calibration module

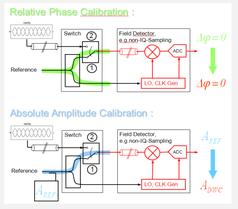
Method:

- Use ultra-stable RF reference to remove electronic drifts within the LLRF system
- Switch to RF reference between consecutive RF pulses









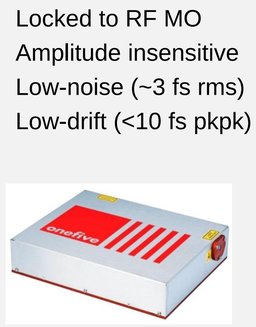
Master Laser Oscillator (MLO)

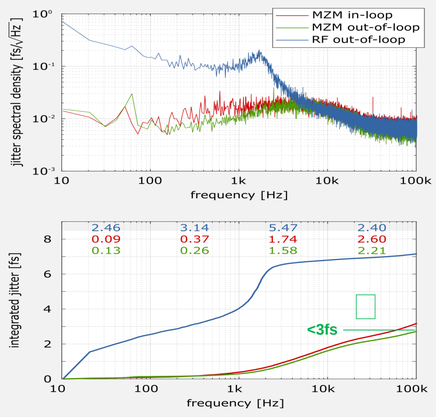
Mode locked oscillator:

- Commercial (NKT, former Onefive)
- Repetition rate 216 MHz → 1.3 GHz / 6
- Ultra-low phase noise, 1550 nm
- 24/7 operation
- 2 MLO installed for redundancy, fast switching

Laser-to-RF Synchronization:

- Locked to RF MO
- Amplitude insensitive
- Low-noise (~3 fs rms)
- Low-drift (<10 fs pkpk)

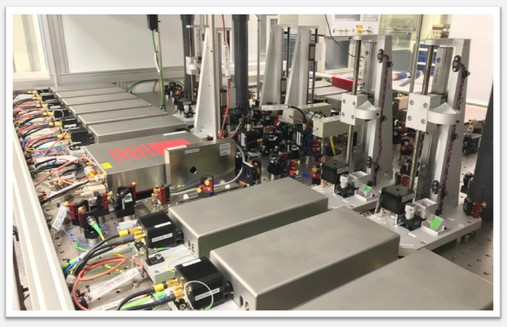




Laser distribution & optical links

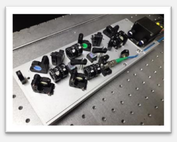
Distribution:

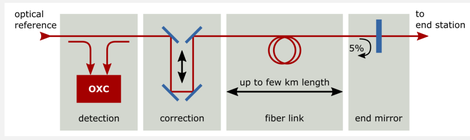
- Free space on SuperInvar optical table



Optical Link Stabilization Units (LSU):

- Polarization maintaining optical fibers (PM)
- Timing detection: optical cross-correlation (OXC)



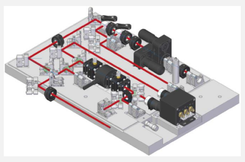


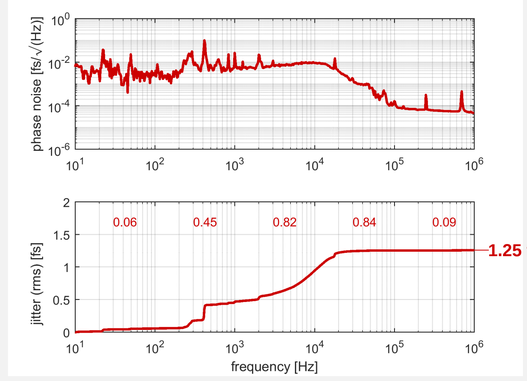
- Typically performance < 0.5 fs rms

SLO / Laser oscillator locking

Method:

- Balanced optical cross-correlation
- 1.25 fs rms jitter (MLO – SLO)
- Overall: MO - PP Laser osc.: ~ 6 fs rms (dominated by PPL osc. lock)

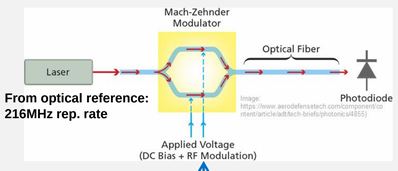


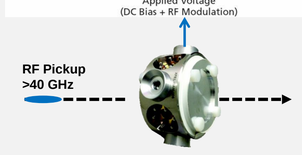


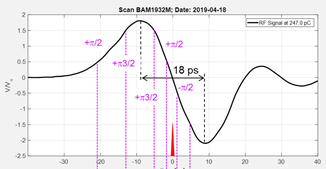
Bunch Arrival time Monitor (BAM)

Method:

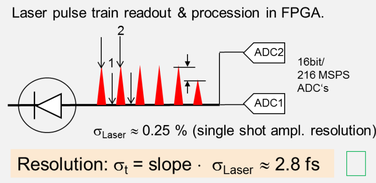
- Fast pickup signal applied to MZI (~ 40GHz) + over-modulation





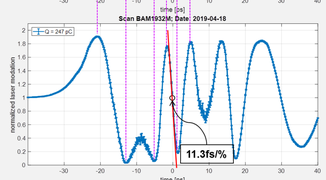


Laser pulse train readout & procession in FPGA.



$\sigma_{Laser} \approx 0.25$ % (single shot ampl. resolution)

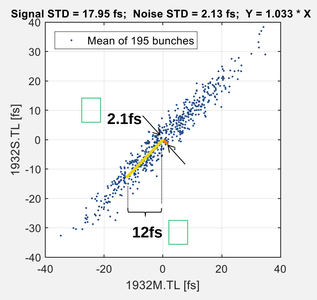
Resolution: σ_t = slope · $\sigma_{Laser} \approx 2.8$ fs



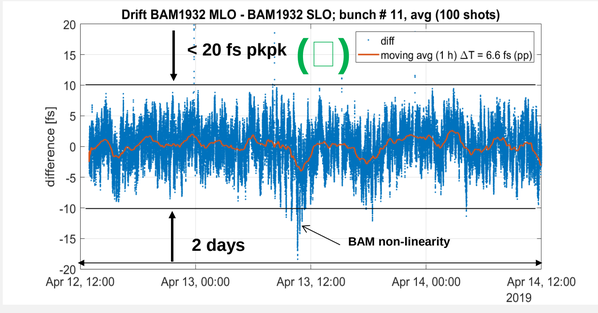
Evaluation in accelerator using beam

Reference system including MLO – SLO chain:

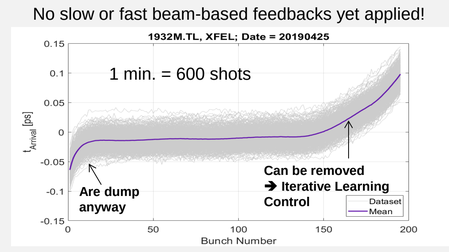
short term

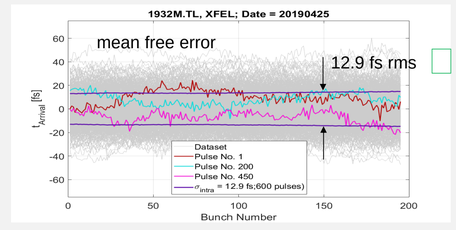


long term



No slow or fast beam-based feedbacks yet applied!





Conclusion

➔ **synchronization architecture of the EUXFEL allows to reach sub-5 fs capabilities in accelerators when fast intra-bunch train feedbacks are applied**

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