New developments and missing components of an optical synchronization system

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Present status & evaluation of optical synchronization system

- **Proof-of-principle experiments** performed for Master Laser Oscillator, Link stabilization, Laser to RF conversion and Laser to Laser locking (<1-10fs achievable)
- **Engineering** of individual components on the way
- Optical synchronization system is very complex (reliability), cost and labor intensive
- Unclear for an accelerator and a larger system (>10 links) how much diagnostics and redundancy is required (remote control, software development)
- Rigid system: time overlap with electron/photon beam, within cross-correlator required + dispersion compensation, phase shift of generated RF not simply possible
  - **Advantage:** unambiguousness of synchronization (bucket jump can be excluded)
  - **Disadvantage:** significant overhead required for implementation and commissioning as well as loss of flexibility
- Some solutions are not appropriate for requirements (cost versus benefit)

**Next steps:** simplification of system components and cost reduction
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**Optical synchronization system**

- Several operation points of accelerator
  - ⇒ e.g. BC0 is turned off it requires to shift timings of
    - Beam arrival monitor (schemes based on direct zero-crossing sampling)
    - Two-color optical cross-correlator for laser locking

**Missing:** alternative to optical delay lines for timing shifts (open)

- 2 end-stations in close vicinity (two links are too expensive!!!!)

**Missing:** inexpensive optical link stabilization for short distances

- RF generation at many locations (low cost version at reduced performance ~20fs)

**Missing:** either an appropriate RF sub-distribution or fiber link stabilization + L2RF converter
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RF generation by direct conversion

Pro:
- Small optical input power required ~ 5-10 mW sufficient
- Very cheap and easy to build (<1k€ for good components)
- Excess to entire frequency comb
- Gating or amplitude mod. allows to generate other freq.
- Drift stability <10fs over hours have been demonstrated (see talk Frank Ludwig)

Bandwidth of detector >10GHz commercially available

Cons.:
- Amplitude dependence (AM to PM conversion)
  1-2 ps/mW@10mW hence $\sigma_{dP/P} < 1e^{-3} \Rightarrow < 10$ fs
- Temperature dependence
  340fs/°C hence $\sigma T < 0.03$ °C $\Rightarrow < 10$ fs
- If high power amplifier is used: no control

Missing: compact direct conversion module including temperature stabilization suited for frequencies between 500 MHz – 3 GHz (PD selection, Ethernet interface, PD/BPF + Ampl. packaged, $P_{\text{out}}=10$dBm)
RF based synchronization without phase det.

Beat in frequency domain by adding second pulse train

\[ \Delta T = \frac{1}{f_{\text{rep}}} \]

\[ \Delta t \]

\[ \Delta t = \frac{1}{30} T_0 \]

\[ \Delta t = 0.1 T_0 \]

\[ \Delta t = 0.48 T_0 \]

\[ \Delta t = 0.5 T_0 \]

Balanced detection \( P(f_{n+1}) - P(f_n) \)

Detected amplitude (a.u.)

Time delay between pulse trains \( \Delta t / \Delta T \)

J. Zemella, Diploma thesis, F. Loehl
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Link stabilization

\[ \Delta T = 1/f_{\text{rep}} \]

- Short link <50m
- Pro: Problem of photo detector is eliminated since only amplitudes are detected
  - No dispersion compensation is required (as long as pulse is short enough)
  - Timing overlap is not difficult (many working points, does not need to be exact)
  - Selection of filter: higher accuracy but smaller dynamic range
  - Can be used to monitor the fiber length variation without correction (expensive)
- Cons: 1 fs is not realistic
  - Loss changes at link arm would be detected as timing changes

Detection scheme has been patent by DESY
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Short link experiment setup

Inloop and out-of-loop detector

Delay line (presently used for calibration)

Fiber (meanwhile exit room)

Sketch of experimental setup

09.03.2009, Trieste, II Timing & Synchronization Workshop
Holger Schlarb, WP18 European XFEL, DESY

Courtesy: J. Zemella
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Short link experiment setup
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Short link experiment setup

- Inloop detector: $t_{std} = 192.92$ fs
- Out-of-loop detector: $t_{std} = 84.63$ fs
- 2 x inloop - out-of-loop detector: $t_{std} = 14.48$ fs, $t_{std,6-12h} = 8.91$ fs
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Implementation of entire system 06/2008 - 2010

- Short link to server more end-stations
- Synchronization of both photo injector lasers &
- Providing RF for 3th cavity (monitoring/source)
- Monitoring for 1.3GHz at Kryo hall
- Engineered version ~ spring 2010
Other interesting developments

- PM fiber link to avoid polarization control (cost/reliability)
  - Problem: no PM DCF fiber exists
  - Option: PM link but SMF-DCF (stability)

- Optical down converter to avoid RF generation entirely
  - Problem: 1) for amplitude detection a dynamic range of laser pulse readout of better than 80dB is required (10MHz BW), 60dB is typically achieved
    2) cannot cope with large phase changes (< 1deg)
    3) too large costs
  - Option: for CW machines, split A and $\varphi$ detection

- XFEL 10MHz has been chosen
  - Problem: 216MHz incompatible, have to switch to MLO with $f_{\text{rep}}=200$MHz but now 1.3GHz $\neq n f_{\text{rep}}$
  - Option: Modification of Sagnac loop operation point
    Other interferometer style of L2RF converters

- Fiber with lower temperature coefficients
  - Problem: index of refraction $\sim 7\times10^{-6} /^\circ\text{C}$ but expansion coefficient $\sim 1\times10^{-7} /^\circ\text{C}$
Thanks for your attention