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on behalf of the LbSyn-Team

FEL Seminar
28. October 2014
What You Can Expect From This Talk...

1. Infrastructure & Synchronisation Lab.
2. Building Blocks of the Optical Synchronisation System.
3. Synchronisation System @ FLASH Facility.
4. Upgrades and Extensions Planned for the Near Future
5. Summary
6. Bibliography
Location & Infrastructure

- Synch. lab in hall3: constructed in 2006
- in the meantime: upgraded climatization with temp. & humidity stabilisation
- synchronised optical signal distributed via optical fibres:
  - started with 11 endstations at FLASH1
  - in 2012/2013 extended with additional 9 endstations (4 to be installed)
  - + 3 cables to injector hutch & 1 cable to injector laser lab
- in total: 672 optical (SMF) p-2-p connections installed at FLASH
- shared fibre distribution by MSK/MSC4: synchronisation, timing & MPS
Synchronisation Lab

- concept for shielding: is crucial due to acoustics, vibrations & EMI:
  - copper ground & optical table resting on its own concrete fundament
  - cover for optical table: not sufficient for acoustic isolation

- temperature stabilisation: upgraded in 2010:
  - cover of optical table: “low-pass filter” for ambient temperature
  - stability on optical table: 30mK pk-to-pk
  - additional, actively stabilised rel. humidity: 2 % pk-to-pk

- mandatory effort because of coefficients of RF & optical cables:
  - 35 - 50 fs/Km
  - 2 - 5 fs/%m
• master laser oscillator (MLO):
  • pulsed SESAM-based laser (Origami-15 from OneFive)
  • 200 fs pulses @ 216.667 MHz repetition rate
  • 1550 nm central wavelength (telecommunication standard)

• link stabilisation unit (Link Box)
  at end-station: out-of-loop jitter \( \leq 1 \) fs
16 + 2 ports foreseen for individual stabilised fibre-links

- 6 of which are occupied with active fibre-links and are in permanent operation
- 2 are connected to fibre-links and need to be re-commissioned
- 2 more reserved for FLASH1
- 1 to be installed in near future for FLASHForward
- 4 reserved for FLASH2
- 1 more for FLASHForward

- optics all mounted on Invar base plate to minimize temperature induced drifts of optical path length (not stabilised)
Link-Stabiliser Units (LSU)

- Optical Cross-Correlation (OXC) for detecting changes in transit time
- sensitivity typically $\leq 300 \text{ as/mV}$
- regulation with $\leq 3 \text{ kHz BW}$ & slow compensation of drifts
- careful tuning of intra-link optical power, spectral & temporal pulse profile
  Details: [Zummack et al.2013]
- reported out-of-loop timing jitter (for 300 m SMF link) $\leq 1 \text{ fs RMS}$
  Details: [Schulz et al.2013]

![Diagram of LSU setup](courtesy of C. Sydlo)
BAM: Bunch Arrival Time Monitor

- e-bunch induces transient voltage signal in RF pickup
- combination of RF signals to reduce orbit dependency
- detection of RF voltage slope in EOM (electro-optical modulator)
- sensitivity: typically 15 – 30 fs/% amplitude modulation
- today, resolution limited by electronic noise
REFMopt: RF Resynchronisation

- optical reference module (REFMopt)
- balanced scheme with dual-output Electro-Optical Modulator (EOM)
- laser pulse train (216.667 MHz) samples RF wave (1.3 GHz)
- amplitude modulation is down-mixed to baseband with IQ demodulator (LO generation of 433.33 MHz)
- interleaving of pulse train for distinguishing between RF phase drift and EOM bias drift
- correcting phase drifts of 1.3 GHz signal by use of a VM (vector modulator) or phase shifter

Details: [Lamb et al.2013]

![Diagram of RF2Laser phase detection](chart.png)

stabilised optical pulse train

unstabilised RF (1.3 GHz)

re-synchronised RF (1.3 GHz)

courtesy of T. Lamb
LRF Modules: RF Locking of External Lasers

- RF-Lock Box setup:
  - Optical power monitoring
  - RF signal generation & phase comparison

- generation of RF signal from stabilised, optical pulse train
- phase comparison between converted RF and reference RF
- error signal to controller electronics (VME)

- RF-Locking of external laser:
  - cascaded loops: 108 MHz, 1.3 GHz, 9.1 GHz
  - low phase noise, high precision versus small dynamic range
  - stabilising repetition rate (cavity length) of the external laser oscillator
two-color optical cross-correlation (sum or difference frequency generation), balanced detection scheme

- currently, still optical bread-board design
- engineered version in development
- sensitivity typically between 30 mV/fs and 5 mV/fs
- slightly different setups installed at FLASH lasers:
  - Injector Laser 2 (IR)
  - Injector Laser 1 (UV): in development
  - Seed Laser (28g)
  - Pump-Probe Laser (28c)
LbSynch@FLASH

FLASH accelerator facility & laser-based synchronisation system

Legend:
- actively stabilized link fibre
- passively stable fibre (PSOF)
- external laser beam
- pickup with RF cable

BAM: Bunch Arrivaltime Monitor
FSD: Free-Space Distribution
MLO: Master Laser Oscillator
L2RF: Laser-to-RF Conversion
OXC: Optical Cross-Correlator

M.K. Czwalinna
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BAM Applications at FLASH1

- Resolution about 15fs, down to 150 pC bunch charge
- Resolution below 10 fs (usually) above 500 pC bunch charge
- Slow FBs for drift compensation:
  1. BAM.1UBC2: RF gun phase
  2. BAM.3DBC2: ACC1 or ACC39 amplitude
  3. BAM.4DBC3: ACC23 amplitude
- Data always available from DAQ: e.g. “TTF2.SYNCH/BAM.SERVER/4DCB3”

FLOAT0 = arrival time spectrum in ps.
- currently, still breadboard design: engineered version in development
- low-maintenance, stable operation
- normally running slow arrival time FB: compensating slow timing drifts of Laser 2 oscillator pulses
Synchronisation of Pump-Probe Laser

- lately, upgraded and improved locking mechanism by firmware update
- server and firmware are capable of automatically finding locking position again after the low-jitter lock has been lost
- but, instabilities from laser oscillator can impede a stable locking state
  - OXC has high sensitivity, but small dynamic range
  - RF-Locking setup sensitive to EMI and vibration
- EMI problems in laser labs deteriorate the synchronisation performance
- lately, immense improvement of phase & amplitude noise of the TiSa oscillator
  - in turn, the jitter characteristic of the RF & lock improved by a factor of 2

![Graph showing SSB Phase Noise FLASH1 PP-Oscillator RF-locked](image1)

![Graph showing AM Noise and SSB Phase Noise](image2)
What comes next ... first of all, until mid of 2015

1 server updates
2 upgrade electronics & firmware
3 redundancy for master-laser
4 extension of stabilised fibre-links
5 upgrade & extension of BAMs
1. grown system ended up in non-uniform naming of DOOCS locations: update of all servers (in preparation)

2. redundancy of MLO: installation of 2\textsuperscript{nd} laser allows for fast & remote switching (requires 1 week of maintenance time)

3. in VME, all channels for digital control-loops occupied: need to install new electronics (MTCA.4) for 9th fibre-link to be operated (FLASHFwd)
Next Work to-be-done in Synch. Lab: Jan. 2015

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Dealing with the Inherited Problems ...

- **electronic racks:**
  - no rack space left for additional crates: to be place beneath optical table
  - additional accoustic noise from MTCA.4 crate fans

- **space constraints on optical table:** old “Link-Box” design
  - stacking of fibre-link boxes in two levels has been foreseen
  - **big disadvantage:** design impedes stability (temperature & vibration), maintainability and ease of commissioning
  - XFEL type of LSUs delivers **solution**:
    - need to re-organize all existing fibre-links on optical table:
      - requires a few & longer periods of down-time (1 week, each)
      - will be done step-wise, starting Jan.’15 with uncritical fibre-links
1. new electro-optical unit ("BAM-box"): in preparation/industrialisation

2. new RF-frontend: tested & demonstrated usability for down to 40 pC \[\text{Details: [Czwalinna et al.2014]}\]

3. new electronics for read-out & control
   - specialised electronics for readout: less electronic noise, improved resolution
   - general I/O control as replacement for "Beckhoff-Box"
   - on-going DOOCS server development
Number of stabilised fibre-links on optical table in synch. lab
- now, 6 fibre-links in permanent operation
- 2 more are prepared: to BAM.15ACC7 & BAM.1SFELC
- 2 are reserved: to REFMopt at LLRF stations ACC1 & ACC23

MTCA.4 electronics: on-going developments & debugging in test lab:
- firmware & server for fibre-link locking: control algorithms
- firmware & server for laser locking
- server for BAMs: first of all, for existing installations at FLASH1

Pump-Probe laser oscillator phase locking...
- to RF (from optical link): 30 fs (RMS) jitter
- all-optical lock: below 10 fs (RMS) jitter

existing BAMs@FLASH 1:
- relatively reliable
- slow FBs available: normally running stable
- accurate on-crest phase scans for ACC1/ACC39 available

OXC@injector laser 2:
- running reliably: low-maintenance
- slow FB (matlab version) permanently running
cleaned-up server structure
redundant MLO (master-laser) installed in synch. lab
BAM.3DBC2 read-out running on MTCA.4
  - intra-train FB (again) ready to be used with ACC1
new electronics in synch lab: link locking in MTCA.4
  - stabilised link to laser FLASHFwd (28m/OG2.005)
repair/upgrade of BAM.4DBC3 (new optics & mechanics)
commissioning of one more BAM (at 15ACC7): 40 GHz version
2 BAMs at FL2 ready for installation

