Paul Scherrer Institut

Vladimir Arsov, M. Dehler, S. Hunziker, M. Kaiser, V. Schlott

First Results from the Bunch Arrival-Time Monitor at the SwissFEL Test Injector
• Specification & Requirements
• Conceptual Design
• Prototype Results
• Summary and outlook
Design parameters of the two beamlines

- **Charge:** 10 .. 200 pC
- **Beam energy for 1 Å:** 5.8 GeV
- **Core slice emittance:** 0.18 .. 0.43 mm.mrad
- **Energy spread:** 250 .. 25000 keV (rms)
- **Peak current at undulator:** 1.6 .. 15 kA
- **Bunch length:** 0.3 .. 25 fs (rms)
- **Bunch compression factor:** 125 .. 5000
- **Repetition rate:** 100 Hz, 2 bunches @ 28 ns

- **Wavelengths:**
  - 1 .. 7 Å (linear polarization)
  - 0.1 .. 7 Å (linear/circular polarization)

- **Pulse lengths:** 0.06 .. 20 fs

- **Peak brightness:** < 1.3 \( \times 10^{33} \) phot/s·mm²·mrad²·0.1%BW
BAM Detection Principle

Stable (pulsed) optical reference

Pickup in the accelerator tunnel

Data Acquisition (e.g. GPAC ADC12FL) in the technical gallery

*Florian Löhl, DESY-THESIS-2009-031, March 2009
Layout of the Optical Synchronization and BAM

- **RF MO 1.5 GHz**
- **Phase Shift**
- **Phase Detector**
- **PID Controller**
- **Master Laser Oscillator 1652±20 nm, Mode Locked 214 MHz, ~200 fs**
- **PID Controller**
- **Piezo Driver**
- **Mot./T° Driver**
- **3 MHz Event Receiver**
- **High level control**

**Optical Reference**

**Synchronization Hutch**

- **Link Front End**
- **High level control**
- **Mot. Driver**
- **Pol. Contr.**

**BAM-Front End**

- **EDFA**
- **FRM**
- **EDFA**
- **fine delay, position encoder, ZG FB**

**Accelerator tunnel**

- **Bunch Compressor**
- **BAM pick-up**
- **e-beam**

**Rack technical gallery**

- **Mot. Drivers**
- **EDFA PS**
- **TEC**
- **T° read out**
- **EOM bias**

- **10 Hz Event Receiver**
  - **clock**
  - **ADC**
  - **ADC**
  - **500 MHz, 12 Bit**

- **BAM Photoreceiver**
  - **Ch1**
  - **Ch2**
  - **clock**
Highly Stable RF-Based Phase Detection
Highly Stable RF-Based Phase Detection

**Optimized Detector and Photodiode Performance**

- Peltier-stabilized phase detector (stability < 0.01° C)
- Use of T°- insensitive cables
- Fused fiber-optic power splitter with equal length arms
- Specially selected and T° stabilized PDs
- PD Operation at vanishing AM/PM conversion (sweet spot)
- Amplitude stability (forward/reverse) kept < 0.1 dB
- T° stabilized amplifiers, ceramic BP filters

**Phase control:** mot. delay line (330 ps) / fiber stretcher
  (19 fs/V → compensates 3.4° / 12.2% RH)

**Amplitude control:** EDFA 1 in the BAM-Box

**Laboratory test HF signal (no BAM, no EDFA):**

< 10 fs pk-pk stability
Highly Stable RF-Based Phase Detection

Phase detector error signal slope: 86 fs/mV

**Link power stability (forward):**
Mean: 2.05 V
Ripple pk-pk: 15.6 mV

**Link power stability (reverse):**
Mean: 2.05 V
Ripple pk-pk: 27.6 mV
The Resolution is limited through:

- Bandwidth of the pickup feedthrough (DC..20GHz, Meggit PN853872)
- Bandwidth of the EOMs (12 GHz)
- ADC resolution (12 bit), AC-Coupling
- Missing Signal Conditioning Front-end (DC-Offset)
BAM Button Pickup: orbit dependence

Cables to combiner: group delay compensated, ~50 fs accuracy

- Blue circle: button on EOM2 (normal), scan (-x,y)-(x,-y), 195pC
- Orange triangle: button on EOM2 (normal), scan (-x,-y)-(x,y), 195pC
- Red square: button on EOM1 (swapped), scan (-x,-y)-(x,y), 200pC
- Green square: button on EOM1 (swapped), scan (-x,y)-(x,-y), 200pC
- Purple diamond: button on EOM2 (normal), single ended, scan (-x,y)-(x,-y), 138pC; slope: 105fs/%mod/mm

Graph showing orbit position R vs. pickup slew rate, ps/ % modulation.
BAM: drift measurement

beam parameters (average): 130 pC, 245 MeV, ~3 ps
BAM resolution (average): 20 fs
Bunch arrival-time drift: 410 fs
Jitter: 110 fs (rms); 150 fs (peak)
BAM: gun phase scan

Bunch Arrival-Time Downstream the Bunch Compressor:

\[ \Delta t_{\text{beam}} = G_{\text{laser}} \cdot \Delta t_{\text{laser}} + G_{\text{gun}} \cdot \Delta t_{\text{gun}} + O_2 \left( G_{\text{ACC}} \cdot \Delta t_{\text{ACC}} \right) \]

\[ G_{\text{gun}} = \frac{dt_{\text{beam}}}{dt_{\text{gun}}} = 2\pi f^{(S)} \frac{dt_{\text{beam}}}{d\phi_{\text{gun}}} \]

\[ f^{(S)} \approx 3 \text{GHz} \]

\[ \frac{dt_{\text{beam}}}{d\phi_{\text{gun}}} = 310 \text{ fs/deg} \]

\[ \Rightarrow \text{Gun phase contribution: } \sim 34\% \]
Summary and Outlook

Milestones:
- 1 BAM operational downstream BC ✓
- 2 bunch operation □
- Resolution, charge: 10 pc: <10 fs □

Implementation of one BAM-Box upstream BC:
- 40 GHz Cables and Components
- 40 GHz EOMs

Implementation of 40 GHz pickups:
- Reduced ringing
- Operation below the cut-off of the X-Band

Improved Readout:
- GPAC 16 FL, 160 MHz, 16 bit,
- Increased sample length;
- DC coupling
- signal conditioning DAC (in progress)
Thank you for your attention!