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SLS2 Fast Orbit Feedback: Photon BPM Integration Aspects

SLS2 Photon BPM Meeting, Feb. 25, 2020

SLS1: Present Fast Orbit Feedback (FOFB)

Objective:

- Stabilize photon beam position at the end stations

Method:

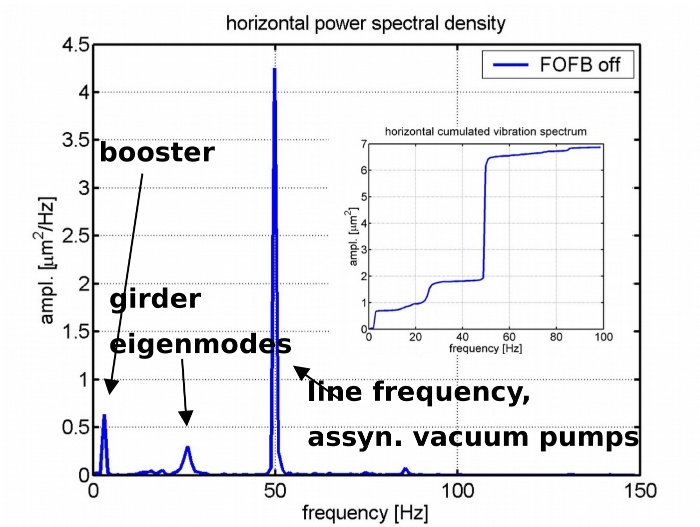
- Fast electron beam feedback:
  - Read data of 74 e-beam BPMs (4 kSamples/s data rate, ~500 Hz BPM bandwidth)
  - Calculate corrective kicks (12 DSP boards)
  - Apply corrective kicks to 74 vertical + 74 horizontal corrector magnets (4 kSample/s update rate, ~500 Hz corrector bandwidth)
  - Feedback stabilizes from DC to 100 Hz (=0dB point)
- Slow photon beam feedback:
  - Measure photon beam position at few beamlines (few samples/s)
  - Move e-beam (few times/second) to keep p-beam stable (bandwidth < 1 Hz)

Orbit motion damped < 100 Hz, but excited > 100 Hz -> optimal tuning depends on beam motion frequency spectrum!

SLS1 FOFB Performance

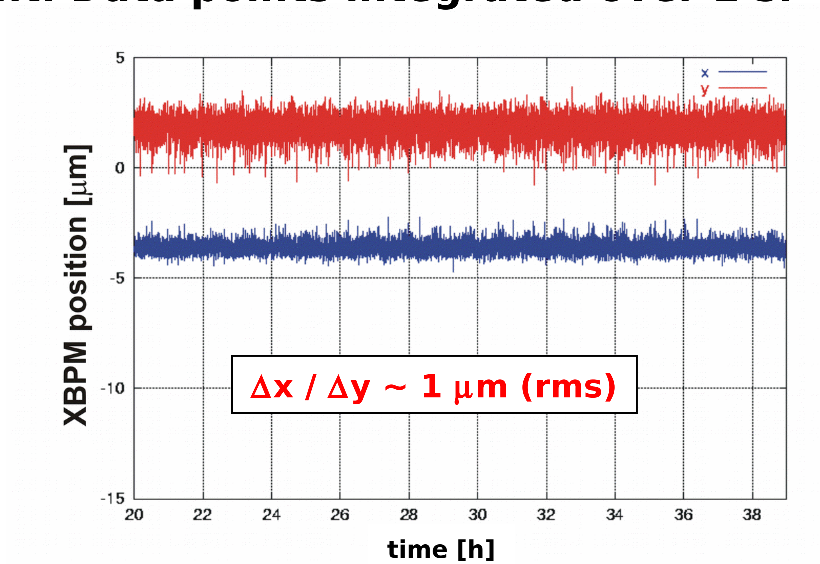
Power Spectral Density

Horizontal, measured at RF BPM outside of FOFB loop (β_x = 11 m).



Medium / Long Term Stability

Photon BPM signals at ID 06S, ~ 10 m from sou point. Data points integrated over 1 s.



SLS Orbit Stability with FOFB

- **Horizontally (1 - 100 Hz): 0.38 μm · $\sqrt{\beta_x}$**
- **Vertically (1 - 100 Hz): 0.27 μm · $\sqrt{\beta_y}$**

Examples: tune BPM (β_y = 18 m) ⇨ Δy = 1.2 μm

ID 06S (β_y = 0.9 m) ⇨ Δy = 0.25 μm

SLS2: Future Fast Orbit Feedback (FOFB)

0dB point can be changed digitally by choice of digital filters (limited by system latency), but optimal value depends on beam motion spectrum, higher is not always better (adds BPM/corrector noise to beam).

Objective:

- Stabilize photon beam position at the end stations from DC to ~300 Hz (=0dB point)

Digitally programmable data rate & bandwidth (MHz … Hz). 20 kHz = reasonable value for FOFB.

Method:

- Fast electron beam feedback:
  - Read data of 100+ e-beam BPMs (20 kSamples/s data rate, ~10 kHz BPM bandwidth)
  - Calculate corrective kicks (1 FPGA/SoC board)
  - Apply corrective kicks to 100+ vertical & 100+ horizontal corrector magnets (20 kSample/s update rate, ~5 kHz corrector bandwidth)
- Fast photon beam feedback (my wish, to be discussed …):
  - Measure photon beam position at most/all beamlines (20 kSamples/s, >10 kHz bandwidth)
  - Move e-beam to keep p-beam stable (corrector magnet update rate 20 kSample/s)

Electron & Photon BPMs: Possible Synergies

E-Beam BPM

- 4 button electrodes in beam pipe generate sub-ns pulses (DC-free)
- Electronics filters out 500 MHz component (=only dependent on beam current, not on filling pattern) & calculates beam position.
- Digital filters: BPM position data available simultaneously at different bandwidths and data rates:
  - 1 MSample/s, 500 kHz bandwidth (turn-by-turn)
  - 20 kSample/s, 10 kHz bandwidth (for FOFB)
  - 10 Sample/s, 5 Hz bandwidth (high-resolution drift study, ...)
- ADC raw data also available (16-bit, max. 500 MSamples/s, some GByte memory) for offline analysis

Electron & Photon BPMs: Possible Synergies

Photon BPM

- Photon beam is bunched, 2ns spacing, few 10 ps bunch length (like electron beam)
- Different detection methods:
  - Metal blades:
    - Usually lower bandwith of initial detector signal
    - Electronics usually reduces bandwith further, to 1-100 kHz / 1-100 kSamples/s (or less)
  - Diamond, SiC, ...:
    - Initial detector signal: Sub-ns pulses, GHz bandwidth
    - Two options for electronics:
      - Traditional: Use DC-component of signal, lowpass to 1-100 kHz. Drawback: Noise, ...
      - New: Use only 500 MHz component of detector signal + similar electronics like e-beam. Possible advantage: Lower noise, different bandwidths at same time (turn-by-turn, FOFB, few Hz, ...)

Activities at Other Labs

Fermi/Elettra:

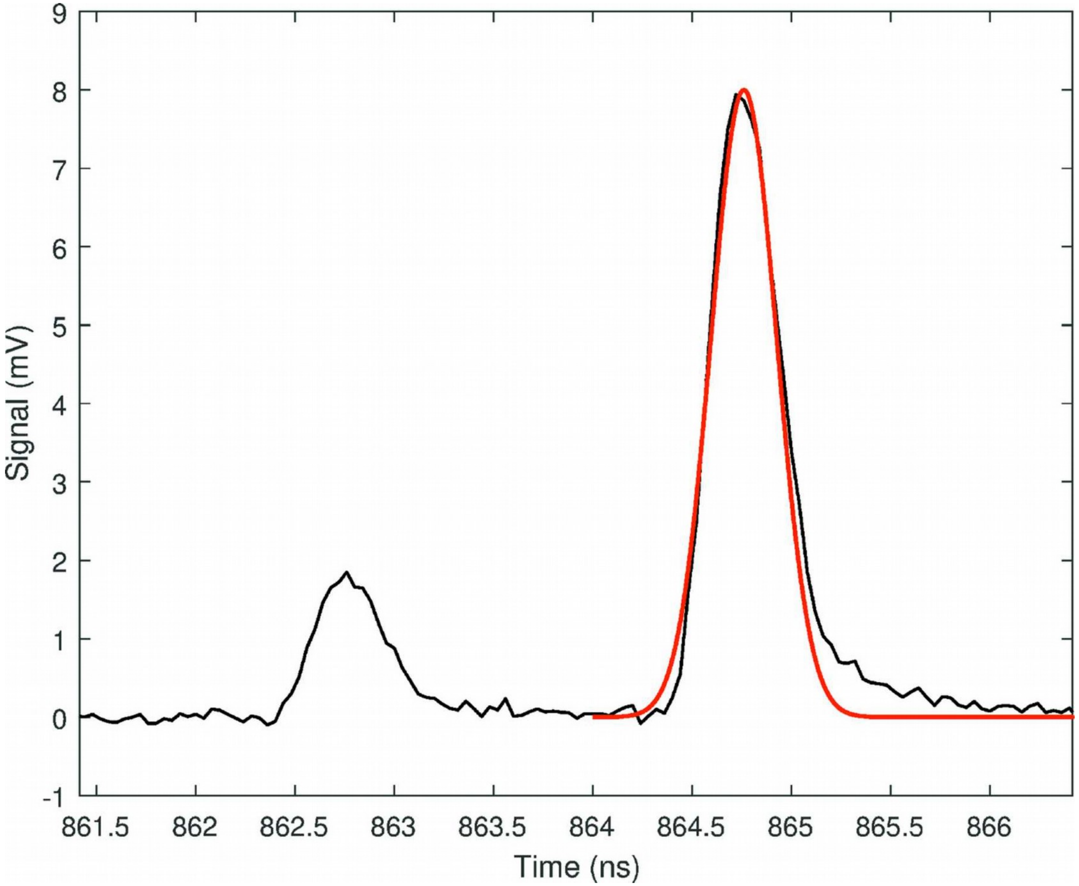
- Experimenting with high-bandwidth photon detector (intensity, position, ...). RF-matched connection to diamond detector, observed ns-scale pulses
  - http://journals.iucr.org/s/issues/2019/02/00/ve5098/

Diamond Light Source:

- Experimenting with fast photon BPM feedback
  - https://ibic2019.vrws.de/papers/mopp032.pdf
- Also observed ns-scale pulses of detector
- Started refining their photon BPM electronics & feedback loop

Activities at Other Labs: Elettra

Zoom in of Fig. 4 in the hybrid peak region (black) and Gaussian fit of the main peak (red). The best-fit value of the **FWHM is 389 ps**. A rise time of 186 ps has been estimated from the experimental ...



JOURNAL OF SYNCHROTRON RADIATION

- **Di Fraia *et al.***
- **Volume 26** | **Part 2** | March 2019 | Pages 386–392 | 10.1107/S1600577519000791

SLS2: FOFB Integration of Photon BPMs

<u>Requirements to Photon BPMs</u> (my wish, to be discussed):

- p-beam position data rate >20 kSample/s
- Bandwidth >10 kHz
- Interface: Multi-gigabit fiber optic link (ideally Xilinx FPGA integrated into photon BPM electronics, 5 GBaud, multimode fiber SFP+ transceiver). Data link protocol defined by AEK.
  - Comment: Integrating commercial electronis with different protocols may be feasible, but with some extra work & drawbacks -> pro/con to be discussed.

Challenges

Photon BPM Electronics

- In-house design feasible? Who has resources?
- If not: Effort to integrate commercial solution into FOFB?
- Concept? Traditional ("DC") vs. 500 MHz ("RF-AC")

FOFB Algorithm

- e-BPMs always see beam, p-BPMs not (shutter closed, gap open, ...). SLS1 FOFB must be stopped and reconfigured each time we add or remove an e-BPM. Try to avoid this for SLS2 (for e-BPMs & p-BPMs).
- Bandwidth: If e-BPM and p-BPM have different bandwidth and/or latency (= delay from detector to data arrival at FOFB): Dynamic behavior of FOFB is affected (stability, tuning of controller gains, ...) -> try to reach similar bandwidth & latency for e-beam and p-beam BPMs.

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Summary & Questions

- FOFB integration of new SLS2 photon BPMs is easiest & most robust if e-BPMs and p-BPMs are as similar as possible, regarding:
  - Interface to FOFB (multi-gigabit fiber link)
  - Bandwidth & latency
  - ...

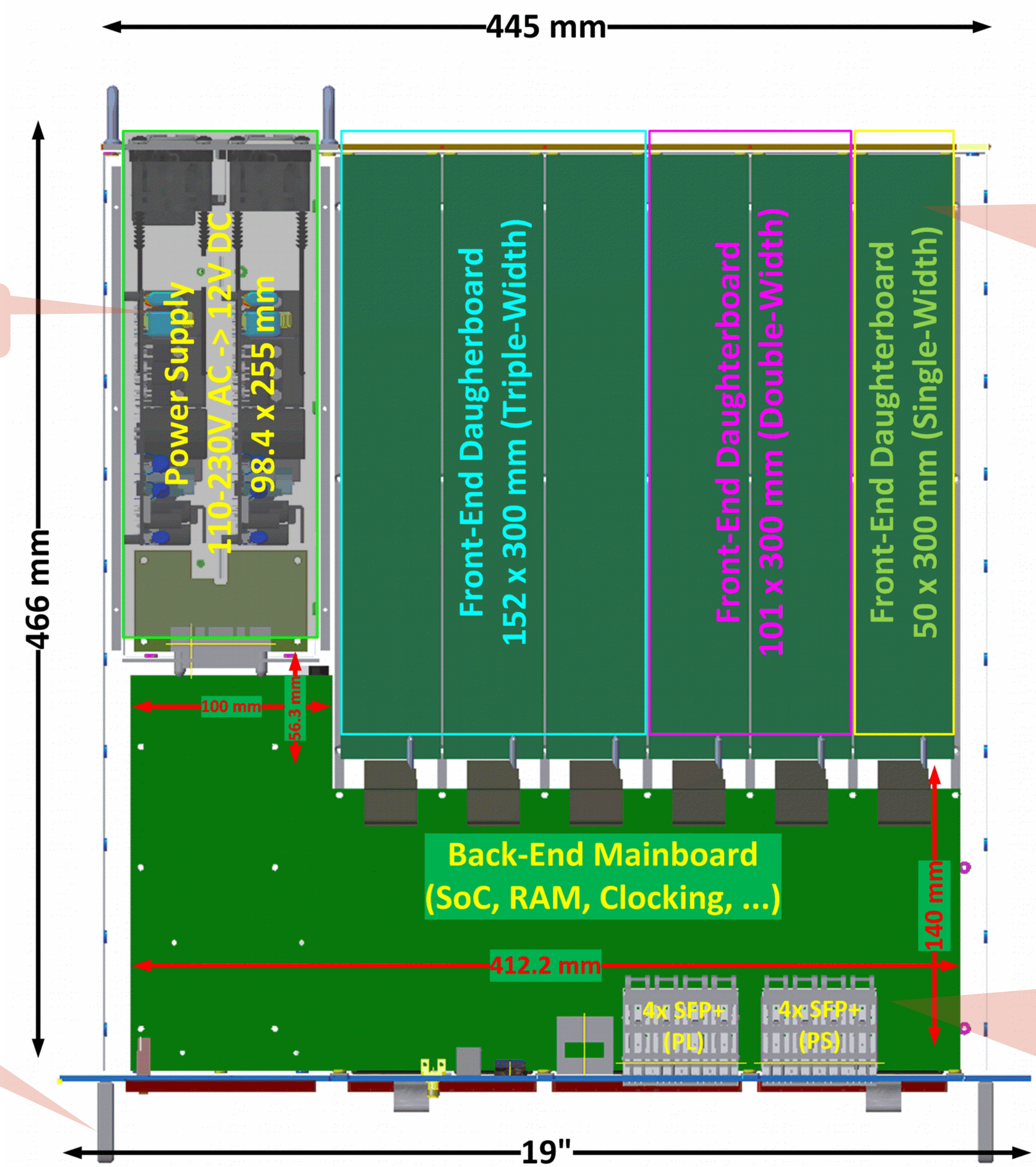
- e-BPMs and p-BPMs could use similar electronics.
  - e-BPMs: 16-bit 500 MSample/s ADCs. 19'' 3HE unit, 4 BPMs (a 4 buttons) per unit.

- Does PSI have the resources to develop an RF photon BPM that uses the 500 MHz component in the detector signal?
  - Requires sufficiently fast detector (diamond, SiC, ...)
  - Requires RF matching of detector signal connection (no long bonding wires, ...)
  - Integrate test/pilot signal for in-situ calibration?

Thank you for your attention!

Supplementary Slides

SLS2 BPMs: 19'' Unit (2D Top View)



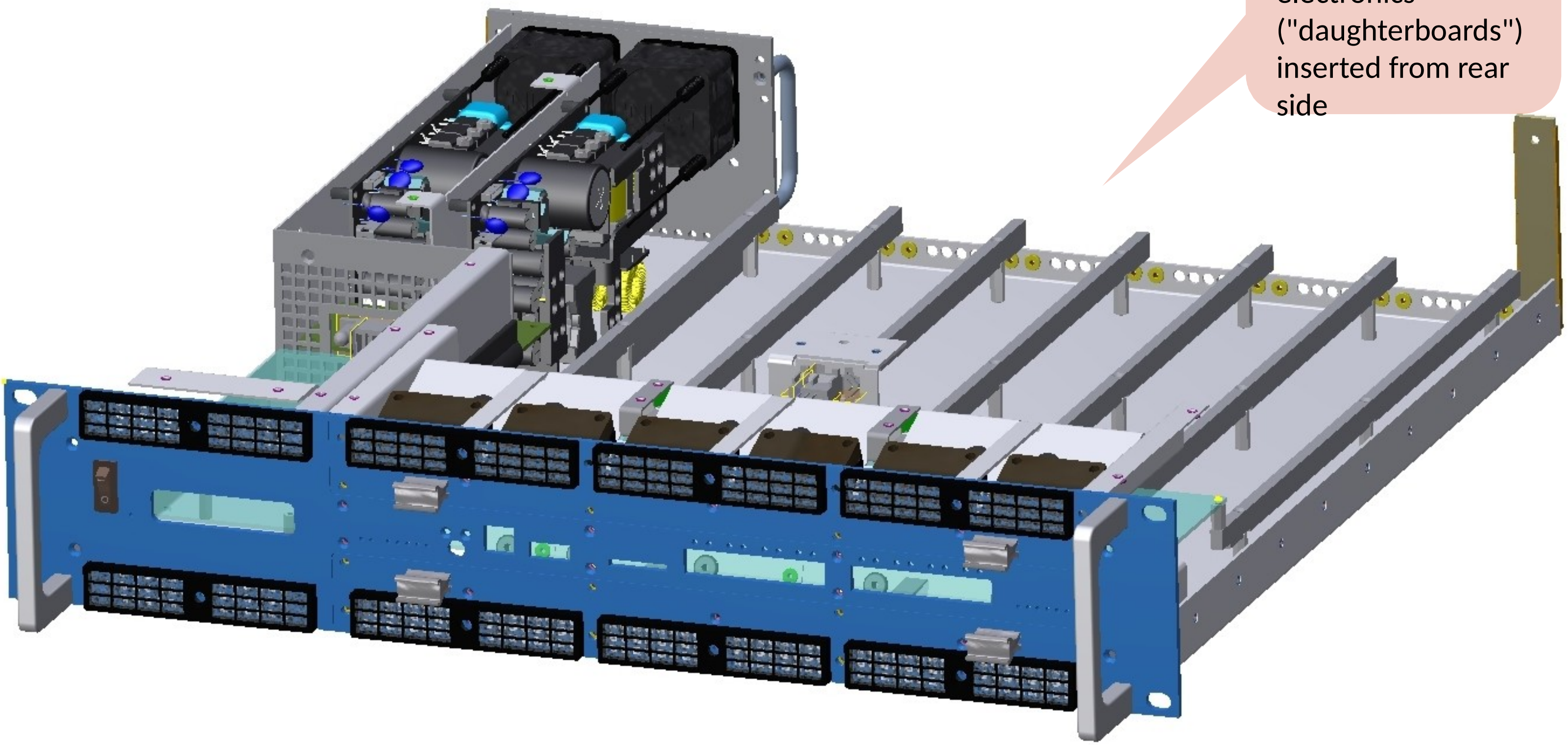
Power supply

BPM-specific front-end electronics ("daughterboards") inserted from rear side

Generic FPGA/MPSoC board used for all BPM types (with SFP+ fiber links to FOFB, timing, control system, ...)

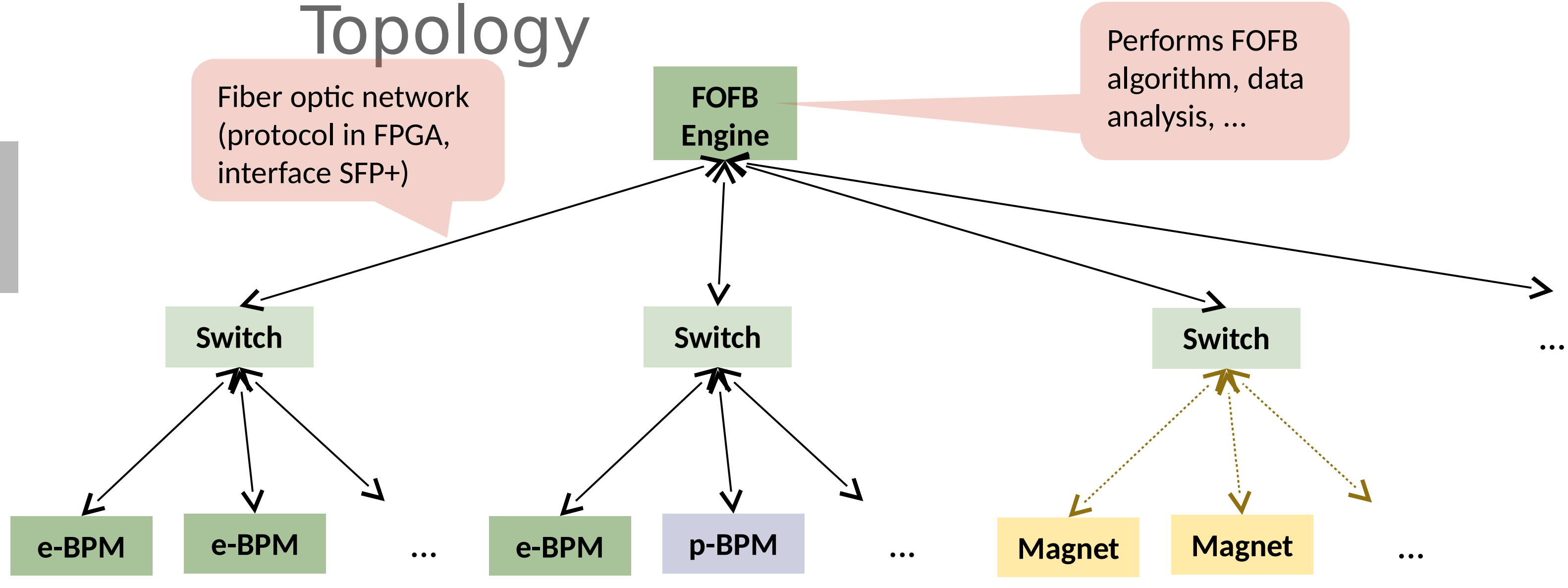
Front side

SLS2 BPMs: 19'' Unit (3D Front View, Cover & Daughterboards Removed)



BPM-specific front-end electronics ("daughterboards") inserted from rear side

SLS2 FOFB System: Fiber Link Tree Topology



<u>Data transfer from/to "FOFB Engine": Tree topology</u>

- Can be scaled/extended (size, performance)
- Allows mix of different monitors & actuators (e-BPM, <u>photon BPM</u>, magnet PS, ...)
- Uses fiber optic links (50MBaud POF for magnet PS, multi-gigabit SFP+ for everything else)
- e-BPM, Switch & FOFB Engine can use same FPGA board (Zynq U+ SoC).