Design and Beam Test Results of Button BPMs for the European XFEL

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### Abstract

The European X-ray Free Electron Laser (E-XFEL) will use a total of ~300 button BPMs along the whole accelerator, and additionally 160 cavity BPMs. The pickups for the button BPMs have been designed by DESY, whereas the electronics has been developed by PSI. This paper gives an overview of the button BPM system, with focus on the RF front end electronics, signal processing, and overall system performance. Measurement results achieved with prototypes installed at the DESY FLASH linac and at the SwissFEL Injector Test Facility (SITF) are presented. The single bunch position noise obtained with button pickups in a 40.5 mm aperture beam pipe is as low as ~11 µm at 20 pC bunch charge.

### Introduction

#### E-XFEL Machine Parameters

- 17.5 GeV superconducting linac
- Trains of 2700 bunches
- ±222 nm bunch spacing
- 10 Hz train repetition rate
- 100 (20) pC to 1 nC bunch charge
- Arbitrary bunch patterns
- SASE undulators, 0.1 nm wavelength

#### BPM Types and Requirements

<table>
<thead>
<tr>
<th>BPM Type</th>
<th>F</th>
<th>Inter Pipe Diam.</th>
<th>Train Averaged / Single-Bunch Resolution</th>
<th>Drift per hour / per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Standard BPM (Button)</td>
<td>10 mm</td>
<td>50</td>
<td>10 µm / 50 µm</td>
<td>20 µm / 50 µm</td>
</tr>
<tr>
<td>Warm Standard BPM (Button)</td>
<td>10.5 mm</td>
<td>50</td>
<td>10 µm / 50 µm</td>
<td>20 µm / 50 µm</td>
</tr>
<tr>
<td>Precision BPM (Cavity)</td>
<td>10</td>
<td>50</td>
<td>1 µm / 10 µm</td>
<td>20 µm / 10 µm</td>
</tr>
<tr>
<td>Undulator BPM (Cavity)</td>
<td>117</td>
<td>50</td>
<td>±0.5 µm</td>
<td>±0.2 µm</td>
</tr>
</tbody>
</table>

#### Principle and Functions

- Pulse stretching, amplification, and amplitude detection
- Band limit from 1.5 to 2.3 GHz (machine RF is 1.3 GHz)
- Chirp filters stretches sub-ns pickup pulses to 6 ns FWHM
- Gain adjustment range >60 dB
- Temperature stabilized balanced diode detectors
- Hold circuit with reset and droop rate control
- Two modes: a) self-triggered, b) high performance
- Balanced ADC buffer amplifier with offset adjustments
- Test pulse for in-situ self-test and detector calibration

### Beam Pickup

- "cold" button pickups (linac cryo modules): 78 mm aperture, 20 mm buttons, k = 17 mm
- "warm" button pickups (beam transfer lines): 40.5 mm aperture, 16 mm buttons, k = 11 mm
- First order model of beam position from electrode voltage magnitudes (near origin):
  
### RF Front End

- 6 channels, 1.3 GHz BW, balanced inputs
- 12-bit, max. 500 MSa/s, Intersil KAD5512P
- Internal or external clock
- Adjustable clock PLL, divider, delays

### Firmware

- Digital Carrier Board
  - One "GPAC" digital carrier board with two 8-channel ADCs mezzanines serves 4 button BPMs
  - Two BPM FPGA Xilinx Virtex-V for ADC waveform acquisition and position/charge calculation
  - One Backplane FPGA for communication with RFFE
  - One System FPGA for beamline signals (interfaces to control, timing, ...) Interfaces: Multi-Gigabit (max. 5 Gbps) links to front (2 x SFP), rear (8 x) with custom or standard protocol (Ethernet, PCIe, ...)

### ADC Mezzanine

- 8-channels, 1.3 GHz BW, balanced inputs
- 12-bit, max. 500 MSa/s, Intersil KAD5512P
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### Ongoing Tests

- Resolution at higher charges
- Linearity w.r.t. Position
- Linearity w.r.t. Charge
- Temperature dependency
- Drift

### User Experiments

- Beam Tests at PSI SwissFEL
  - "warm" button pickup
  - 40 m pickup cable (loss 12 dB @ 2 GHz)
  - Split signals from one pickup to two RFFEs
  - Bunch trains
  - 4.5 – 50 pC equiv. bunch charge

- Beam Tests at DESY FLASH
  - "warm" button pickup
  - 40 m pickup cable (loss 6.1 dB @ 2 GHz)
  - Split signals from one pickup to two RFFEs
  - Bunch trains
  - 4.5 – 50 pC equiv. bunch charge

### Beam Test Results of Button BPMs for the European XFEL

- Single bunch position noise is <5 µm at 90 pC.

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  - 40 m pickup cable (loss 12 dB @ 2 GHz)
  - Split signals from one pickup to two RFFEs
  - Bunch trains
  - 4.5 – 50 pC equiv. bunch charge

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  - 40 m pickup cable (loss 6.1 dB @ 2 GHz)
  - Split signals from one pickup to two RFFEs
  - Bunch trains
  - 4.5 – 50 pC equiv. bunch charge

- Charge limited position noise is 200 pC µm below 40 pC.

- Measured position and relative charge resolutions
  - Solid: single bunch
  - Dashed: averaged train of 40 bunches

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