DEVELOPMENT OF A MODIFIED SIX-PORT DISCRIMINATOR FOR PRECISE BEAM POSITION MEASUREMENTS

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Outline

- Motivation - Energy BPM for FLASH and XFEL
- Six-Port Reflectometer
- System Measurements
- Conclusion & Outlook
New Energy Beam Position Monitors for FLASH and European XFEL

- EBPM: Energy Beam Position Monitor in the dispersive section of a bunch compressor chicane for energy measurements

- Position measurement proportional to bunch energy \( dx \sim \frac{dE}{E} \)

- Current implementation at FLASH
New Energy Beam Position Monitors for FLASH and European XFEL

- Upgrade of EBPMs at FLASH and European XFEL necessary

- Design parameters for FLASH and the European XFEL

<table>
<thead>
<tr>
<th></th>
<th>FLASH</th>
<th>XFEL</th>
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</thead>
<tbody>
<tr>
<td>L [mm]</td>
<td>183</td>
<td>400</td>
</tr>
<tr>
<td>H [mm]</td>
<td>8</td>
<td>40.5</td>
</tr>
<tr>
<td>Frequency [GHz]</td>
<td>1.3</td>
<td>3</td>
</tr>
<tr>
<td>Bunch charge [pC]</td>
<td>&lt;200</td>
<td>20</td>
</tr>
</tbody>
</table>

- Improved, mechanical stable design of the pickup structures necessary
New Energy Beam Position Monitors for FLASH and European XFEL

Planar transmission line pickups

- Microstrip transmission line as a Baseline design\(^1\) for FLASH and XFEL

- Grounded coplanar waveguide transmission line as an Improved option\(^2\) for FLASH and XFEL

\(^1\)Angelovski et al. MOPA47, IBIC 2012, Tsukuba, Japan
\(^2\)Penirschke et al. TUPC29, IBIC 2013, Oxford, UK
New Energy Beam Position Monitors for FLASH and European XFEL

- Taper of substrate height improves the input reflection
- Complicated structure; fabrication with standard substrate hardy possible
  - Substrate made of melted glass in cavity

E-field distribution @ 1.3 GHz and 3 GHz
New Energy Beam Position Monitors for FLASH and European XFEL

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Pickup voltage signal @ 20pC

E-field distribution @ 1.3 GHz and 3 GHz
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Six-Port Reflectometer for Phase Difference Measurements

Pickup

Readout electronics

- Band pass filter
- Band pass filter
- Six-port reflectometer
- Detector diodes
Six-Port Reflectometer for Phase Difference Measurements

- Pickup
- Readout electronics
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Pickup

Readout electronics

band pass filter  band pass filter

six-port reflectometer

detector diodes
Six-Port Reflectometer
Operation principle

Branch line coupler
\[ a_1 \rightarrow (-a_2 - ja_1)/\sqrt{2} \]
\[ a_2 \rightarrow (-a_1 - ja_2)/\sqrt{2} \]

Rat race coupler
\[ a_2 \rightarrow -j(a_1 + a_2)/\sqrt{2} \]
\[ j(a_1 - a_2)/\sqrt{2} \rightarrow \lambda/4 \]
\[ \lambda/4 \rightarrow 3\lambda/4 \]
\[ \lambda/4 \rightarrow \lambda/4 \]
\[ a_1 \rightarrow \lambda/4 \]
Six-Port Reflectometer
Operation principle

Port 1: $2a$

Port 2: $2b$

Port 3: $\frac{\sqrt{3}}{2}a - \frac{\sqrt{3}}{\sqrt{2}}b$

Port 4: $\frac{\sqrt{3}}{2}a$

Port 5: $\frac{\sqrt{3}}{2\sqrt{2}}a + j\frac{\sqrt{3}}{2}b - j\frac{\sqrt{3}}{2\sqrt{2}}a$

Port 6: $\frac{\sqrt{3}}{2\sqrt{2}}a - j\frac{\sqrt{3}}{2}a - j\frac{\sqrt{3}}{2}b$
Six-Port Reflectometer
Operation principle

[Diagram showing the operation principle of a six-port reflectometer with annotations for ports 1 to 6 and a graph showing power vs. phase for ports 3, 4, 5, and 6.]
Six-Port Reflectometer Design

Agilent ADS layout

Rogers RT/Duroid® 6010LM

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Dielectric constant</td>
<td>10.2</td>
</tr>
<tr>
<td>Substrate thickness</td>
<td>1.27 mm</td>
</tr>
<tr>
<td>Conductor thickness</td>
<td>18 µm</td>
</tr>
</tbody>
</table>

CST simulation model

Realized circuit
Six-Port Reflectometer Design

comparison between ADS and CST simulations
Six-Port Reflectometer Design
Comparison between ADS simulations and Measurements

![Graphs showing comparison between ADS simulations and measurements.](image)
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band pass filter  band pass filter

six-port reflectometer

detector diodes
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Measurement Setup

Six Port Reflectometer

Microstrip EBPM Pickup

Coupling loop (not to scale)
Beam induced excitation modeled with a small coupling loop in the vicinity of the transmission line

Non-hermetic TL Pickup  Coupling loop

Six Port Reflectometer  Phase stable Semi-Rigid cables

3D Micro-Positioner (not shown)
Measurement Results

Detection range: 43 mm (1mm step size)

Power measurements

Port 4: 3 dBm variation due to
- mismatch &
- TL-losses

Port 3: 15 dBm periodic variation

Port 5: 35 dBm periodic variation

Phase ambiguity, leads to multiple solutions, when position is calculated
- Lower operation frequency needed for coarse detection
Measurement Results

Detection range: 3 mm (100µm stepsize)

A standard power meter fulfills the requirements of 0.1dBm typically down to -70dBm.

<table>
<thead>
<tr>
<th>Port #</th>
<th>Variation [dBm]</th>
<th>Sensitivity [dBm/µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>0.0025</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Motivation - Energy BPM for FLASH and XFEL
Six-Port Reflectometer
System Measurements
Conclusion & Outlook
Conclusion

- A simple and passive read out scheme the EBPM Pickup structures for energy measurements of free-electron lasers such as FLASH or XFEL was introduced.

- The EBPM requires a high dynamic range over the sensor length of 183 mm and high resolution of less than 20 \( \mu \text{m} \).

- The proposed design provides a sensitivity of more than 5dBm/mm beam offset for a mean value of -60dBm for the non hermetic test setup.

- For the high resolution of less than 20 \( \mu \text{m} \) a sensitivity of 0.1dB at the given power level is sufficient.
Conclusion and Outlook

Conclusion

- A simple and passive read out scheme the EBPM Pickup structures for energy measurements of free-electron lasers such as FLASH or XFEL was introduced
- The EBPM requires a high dynamic range over the sensor length of 183 mm and high resolution of less than 20 µm
- The proposed design provides a sensitivity of more than 5dBm/mm beam offset for a mean value of -60dBm for the non hermetic test setup
- For the high resolution of less than 20 µm a sensitivity of 0.1dB at the given power level is sufficient

Outlook

- Realization of a Six-Port Spectrometer @ 1.3GHz to prevent phase ambiguity
- Further investigations about the detector circuit is needed
Outlook
Diode Detector Circuit

- Power detection using Zero-Bias Schottky diodes

- dBm linear rectifier circuit based on a combination of a Villard circuit and a voltage divider
Outlook
Diode Detector Circuit

- Sensitivity needs to be improved
- Adaption to input and output impedance necessary
- Integration to six-port discriminator

Detector circuit
Thank you for your attention