First Measurements of an Electro-Optical Bunch Arrival-Time Monitor Prototype with PCB-based Pickups for ELBE

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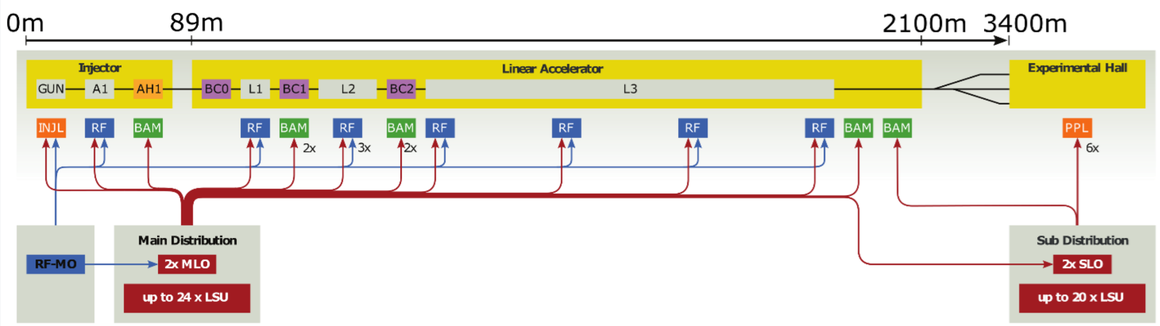
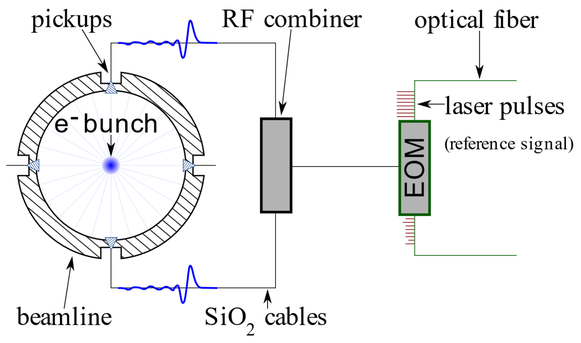
Abstract

A vacuum sealed prototype of an electro-optical bunch-arrival-time monitor has been commissioned in 2023. It comprises of a pickup-structure and a low-π-voltage ultra-wideband traveling wave electro-optical modulator. The stainless-steel body of the pickup structure is partially produced by additive manufacturing and comprises four pickups as well as an integrated combination network on a printed circuit board. This novel design aims to enable single-shot bunch-arrival-time measurements for electron beams in FELs with single-digit fs precision for low bunch charges down to 1 pC. The theoretical jitter charge product has been estimated by simulation and modeling to be in the order of 9 fs pC. The new prototype is tailored for validation experiments at the ELBE accelerator beamline.

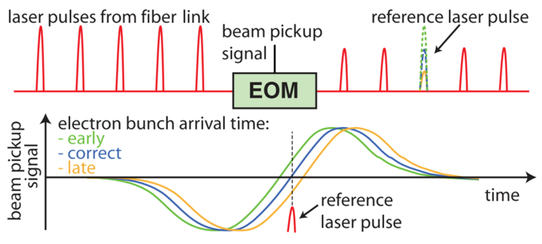
Optical Synchronization System



Schematic overview of the main building blocks of the optical synchronization system at EuXFEL [1].

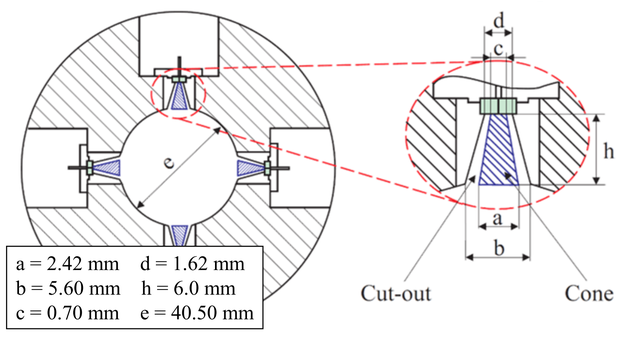


Basic cabling layout, adapted from [2].



BAM working principle [3].

Pickup Design

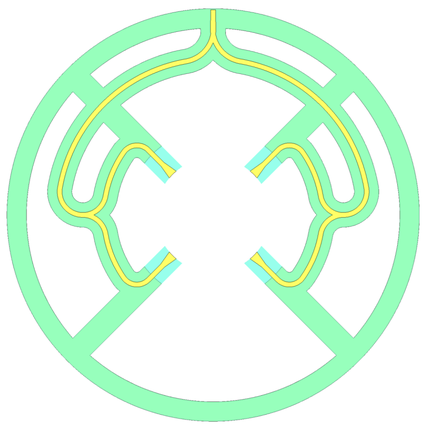


Pickup structure of the state-of-the-art BAM [4].

Slew rate at zero crossing (S_{ZC}):

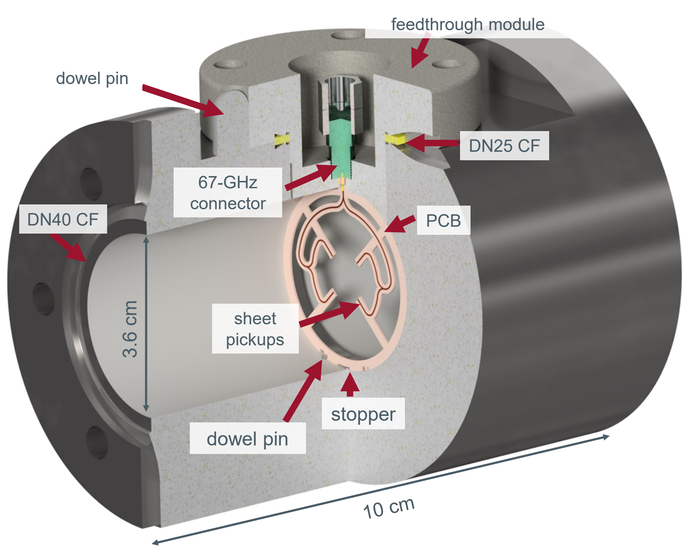
Cone-shaped: $S_{ZC} > 15.0 \frac{\text{mV}}{\text{ps pC}}$ [5]

Planar rPCB: $S_{ZC} \approx 187.7 \frac{\text{mV}}{\text{ps pC}}$ [6]

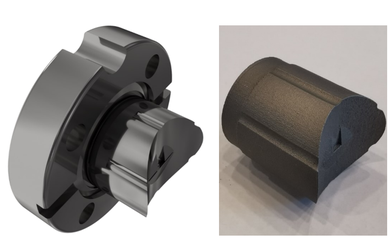


Tapered planar sheet pickups on a reduced substrate (rPCB), proposed in [6].

67-GHz PCB-BAM Prototype for ELBE



Manufacturing model (in Inventor®) of the first vacuum-sealed prototype for ELBE at HZDR.



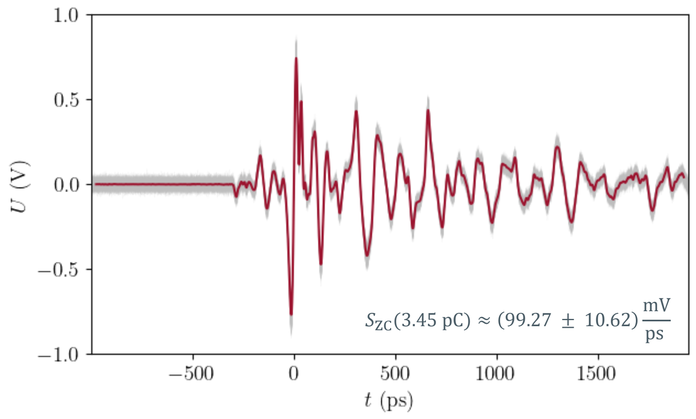
Model of the feedthrough module (left) & raw additive manufactured part without flange (right).

Printed Circuit Board (PCB):
- Substrate: 380 µm TMM® 10i
- Cladding: 35 µm Copper
- In-house fabrication at THM

Vacuum sealed body:
- Stainless steel 1.4301
- Feedthrough module (DN25 CF)
- Manufactured by NTG

Measurements

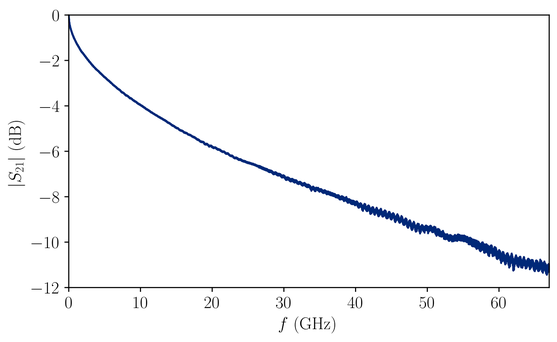
- THz-beamline of ELBE @HZDR
- Repetition rate: 0.41 MHz CW-mode
- 1.4 m of v-cables
- 110 GHz real-time oscilloscope (UXR1102A)



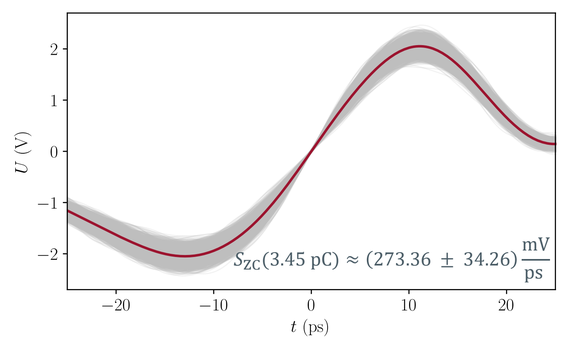
Set of 1024 measured pulses (gray) & average signal (red)

Measurement setup at ELBE

Discussion



Scattering parameter of the cable assembly

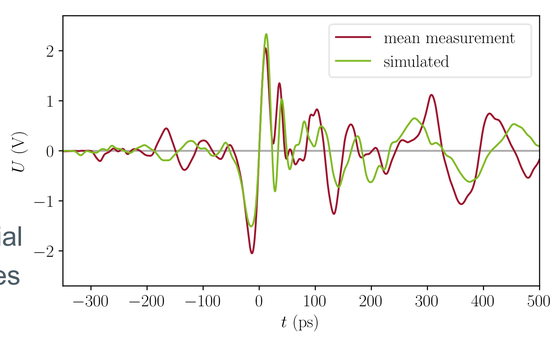


De-embedded measured pulses (gray) & average (red)

- High attenuation by coaxial cables
  → De-embedding necessary:

$$U_{PU}(t) \approx \text{IFFT}\left\{\frac{U_{meas}(f)}{|S_{21}(f)|}\right\}$$

- $S_{ZC} \approx 79.9 \frac{\text{mV}}{\text{ps pC}}$
- Slew rate below simulation with optimal material
- Close to the bunch, the measurement coincides with a simulation using the same substrate



De-embedded & simulated signal

Conclusions and Outlook

- Successful proof-of-concept for PCB-based arrival-time measurement
- Results promise fs precision down to 2 pC
- 1 pC with desired resolution possible: Thin fused-silica substrate
- In-depth evaluation of the measurements
  - Bunch charge & length, beam position
- Measurements with new and old EOM
- Design of an improved prototype
- Final BAM design for FLASH & EuXFEL

References

[1] T. Lamb et al, in Proc. IPAC'19, pp 3835 - 3838. doi:10.18429/JACoW-IPAC2019-THPRB018
[2] H. Dinter et al., in Proc. FEL'15, pp. 478–482. doi:10.18429/JACoW-FEL2015-TUP049.
[3] F. Löhl et al., Phys. Rev. Lett., Vol.104, No.14, 2010. doi: 10.1103/PhysRevLett.104.144801
[4] A. Angelovski et al., Phys. Rev. ST Accel. Beams 15, 2012. doi:10.1103/PhysRevSTAB.15.112803
[5] A. Angelovski et al., IBIC'2013, pp. 778-781. paper WEPC40
[6] B. E. J. Scheible et al., IPAC'23, pp. 4828-4831. doi:/JACoW-IPAC2023-THPL190 (pre-press)

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NTG *here at booth 10* · KEYSIGHT · Bundesministerium für Bildung und Forschung

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