Evaluation of a Novel Pickup Concept for Ultra-Low Charged Short Bunches in XFEL

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IBIC'20 International Beam Instrumentation Conference
WEPP21

MOTIVATION

The all-optical synchronization systems used in various X-ray free-electron lasers (XFEL) such as the European XFEL depend on transient fields of passing electron bunches coupled into one or more pickups in the Bunch Arrival Time Monitors (BAM). The extracted signal is then amplitude modulated on reference laser pulses in a Mach-Zehnder type electro-optical modulator. With the emerging demand of the experimenters for future experiments with ultra-short FEL shots, fs precision is required for the synchronization systems even with 1 pC bunches. Since the sensitivity of the BAM depends in particular on the slope of the bipolar signal at the zero crossing and thus, also on the bunch charge, a redesign with the aim of a significant increase by optimized geometry and bandwidth is inevitable. **In this contribution a possible new pickup concept is simulated and its performance is compared to the previous concept. A significant improvement of slope and voltage is found. The improvement is mainly achieved by the reduced distance to the beam and a higher bandwidth.**

BAM WORKING PRINCIPLE

Pickup structure
- Passing bunches generate RF signal

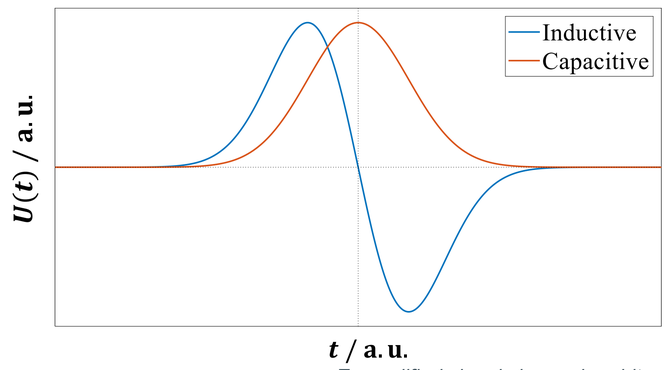
Electro-optical modulator (EOM)
- Signal voltage used as input
- Reference laser at target arrival time (samples instantaneous voltage)
- Amplitude modulation ∝ temporal offset

Data acquisition system
- Measured amplitude ⇒ timing information
- Input for the feedback loops

RF Signal

Bipolar signal if close to the inductive case [1]

$$\Rightarrow U(t) \propto \dot{Q}_{\mathrm{im}}(t) \propto \mathrm{Q_{Bunch}}/\mathrm{R_{PU}}$$

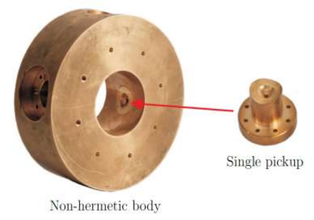


Exemplified signal shapes in arbitrary units.

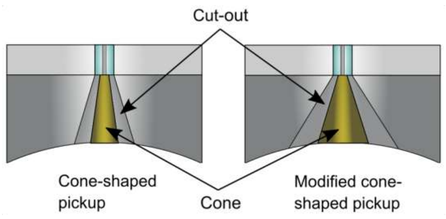
BAM SENSITIVITY

Proportional to signal slope: $S \propto \dot{U}(t)\big|_{t_{\mathrm{ref}}}$

⇒ Bunch charge: $S \propto \mathrm{Q_{Bunch}}$
⇒ BAM aperture: $S \propto \mathrm{R_{PU}^{-1}}$
⇒ Pickup size: $S \propto W_{\mathrm{PU}} \cdot l_{\mathrm{PU}} \quad (l_{\mathrm{PU}} \ll \sigma_{\mathrm{z}})$
$S \propto W_{\mathrm{PU}} \quad (l_{\mathrm{PU}} \gg \sigma_{\mathrm{z}})$

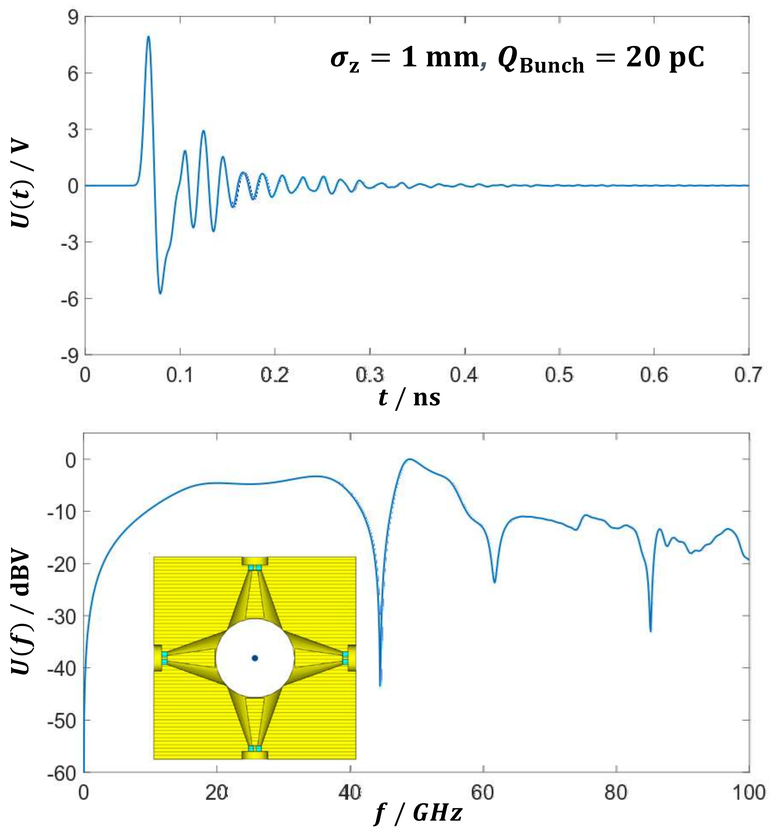


Nonhermetic prototype reprinted from [2].



Cross section of 1st & 2nd gen. pickups adapted from [2].

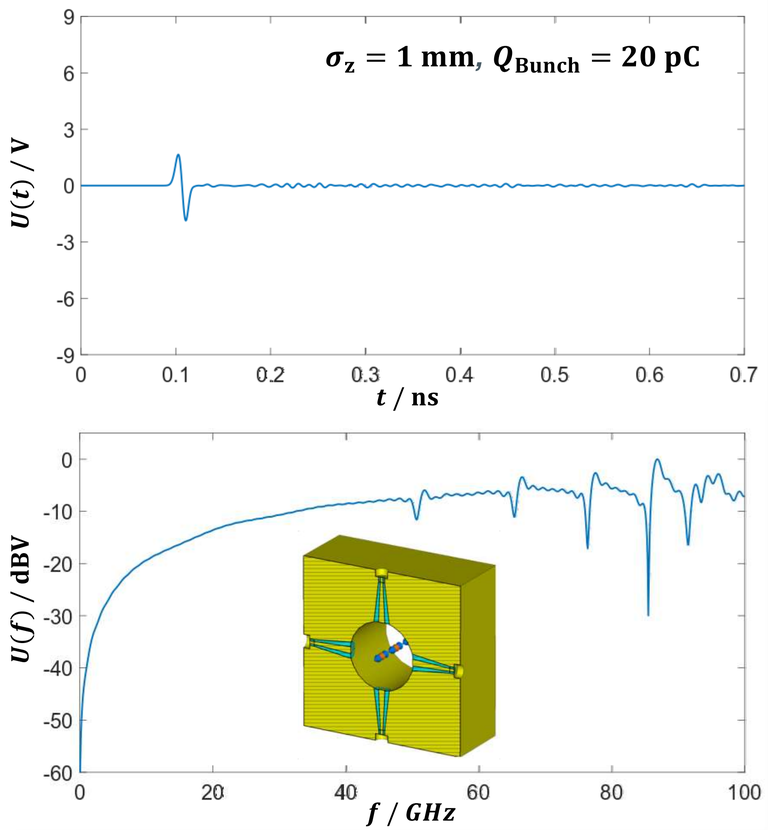
Aperture Reduction



Simulated voltage signal in time domain and normalized signal in frequency domain calculated by CST Particle Studio™.

1st Generation pickups,10 mm aperture
- ▶ Slope 1746 mV/ps (≈ 4 pC possible)
- ▶ Voltage 13.7 V
- ▲ Strong ringing (> 40%), fast decay to ≪ 1%

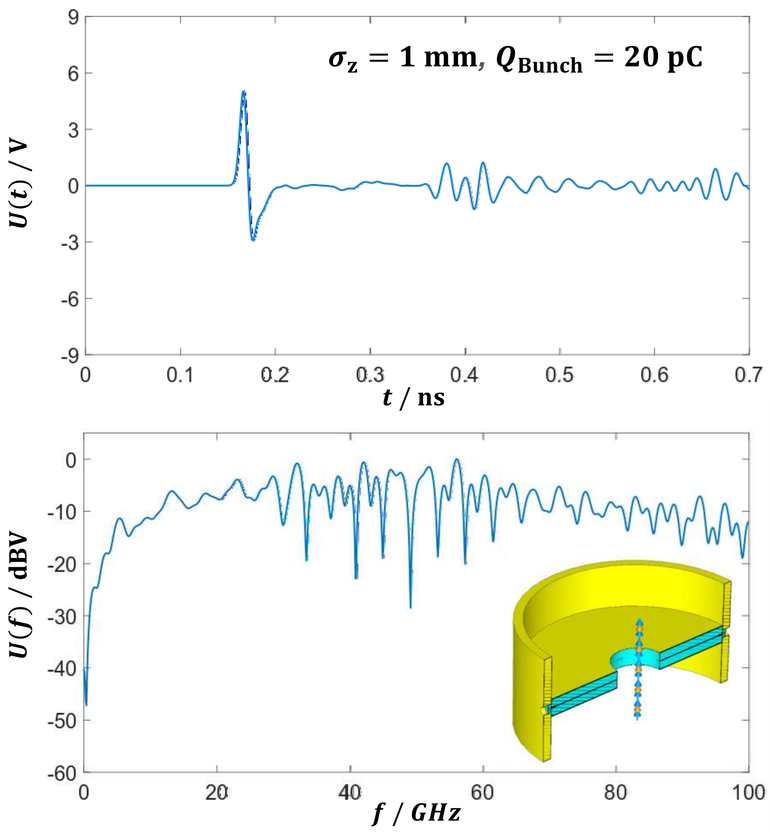
Ultra High-Bandwidth Pickup [3]



Simulated voltage signal in time domain and normalized signal in frequency domain calculated by CST Particle Studio™.

Ultra-high bandwidth pickups, 10 mm aperture
- ▼ Slope 722 mV/ps (≈ 10 pC possible)
- ▶ Voltage 3.5 V
- ▶ Never above 7% but still > 1% after 0.6 ns

Printed Circuit Board (PCB) - BAM



Simulated voltage signal in time domain and normalized signal in frequency domain calculated by CST Particle Studio™.

PCB (50 Ω stripline) pickups, 10 mm aperture
- ▶ Slope 1270 mV/ps (≈ 5 pC possible)
- ▶ Voltage 7.9 V
- ▼ Strong (> 30%), delayed ringing

CONCLUSION AND OUTLOOK

Comparison of three simulated design concepts
- Increased slope, but far from target (≈ 3000 mV/ps)
- Voltage probably too low for 1 pC and to high for 1 nC operation
- Two designs have ringing above the limits of earlier design studies
- Increase by aperture reduction proves effective
- High bandwidth must be reached without drawbacks of size reduction
  → Potentially by planar pickups as a PCB (for ultra-short bunches)
- Signal combination necessary

Outlook
- Check for further improvements or alternative designs
- Examine materials and signal combination for PCB-type solutions
- Consider passive machine protection

REFERENCES AND FURTHER READINGS

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ACKNOWLEDGMENTS

This work is supported by the German Federal Ministry of Education and Research (BMBF) under contract no. 05K19RO1.

Bundesministerium für Bildung und Forschung

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