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CONCEPT OF A NOVEL HIGH-BANDWIDTH ARRIVAL TIME MONITOR FOR VERY LOW CHARGES AS A PART OF THE ALL-OPTICAL SYNCHRONIZATION SYSTEMS AT XFEL AND FLASH*

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Abstract

Numerous advanced applications of X-ray free-electron lasers require pulse durations and time resolutions in the order of only a few femtoseconds or better. The generation of these pulses to be used in time-resolved experiments require synchronization techniques that can simultaneously lock all necessary components to a precision in the range of 1fs only. To improve the experimental conditions at existing facilities and enable future development of seeded FELs, a new all-optical synchronization system at FLASH and XFEL was implemented, which is based on pulsed optical signals rather than electronic RF signals. In collaboration with DESY, Hamburg the all-optical synchronization system is used to ensure a timing stability on the 10-fs scale at XFEL.

For a future ultra-low charge operation mode, down to 1 pC at XFEL an overall synchronization of 5+1 fs rms. or better is necessary.

This contribution presents a new concept of an ultra-wideband pickup structure for beampipe-diameters down to 10mm for frequencies up to 80 GHz or higher and at the same time providing sufficient output signal for the attached EOMs.

INTRODUCTION

In order to investigate dynamical processes down to the femtosecond (fs) time scale, free electron lasers (FELs) are conducted to deliver ultrashort x-ray pulse for pump-probe experiments [1,2]. These time-resolved measurements require synchronization between an external pumping laser and the FEL pulse for probing lower than the pulse duration, i.e., a few femtoseconds. The FEL pulse timing can be determined by high-resolution arrival-time measurements of electron bunches at the undulators [3].

In recent years, the interest for ultrashort x-ray pulses is continuously rising which requires for the accelerator an ultra-low bunch charge operation down to a few pC only [4,5]. Different schemes for bunch arrival time measurements have been implemented so far allowing. for single-shot detection with a resolution of a few fs and below. [6-10].

At the free-electron lasers European XFEL and FLASH in Hamburg, pickup-based arrival-time monitors with electro-optical detection schemes have been implemented.

As part of a laser-based synchronization system, bunch arrival-time monitors (BAMs) measure the arrival time with a sub-10 fs time resolution for bunch charges higher than 500 pC [11]. A beam-induced signal modulates the amplitude of an external laser pulse in a Mach-Zehnder type electro-optic modulator (EOM). This laser pulse is delivered through a stabilized optical fiber link with a drift stability of around 10 fs=day. Thus, as a direct client of this highly stable optical reference, the BAM based on standard telecom EOMs at 1550 nm has an intrinsic low drift feature, in addition to the high resolution. The reference timing is the zero crossing of the pickup signal, where the sampling laser pulse has no modulation. The EOM DC bias is such that without an external rf modulation the amplitude of the sampling laser pulses is halved. Any deviation from the zero crossing of the pickup transient, i.e., bunch arrival-time jitter, results in an amplitude modulation of the reference laser pulse. With a proper calibration with a precession delay line, this amplitude modulation is directly converted to arrival-time information with a dynamic range corresponding to the linear part of the pickup slope. More details are given in [11-12]. The slope steepness at the zero crossing defines the modulation voltage which the laser pulse experiences in the presence of an arrival-time jitter. This determines the time resolution as well as the sensitivity of the BAMs. The slope steepness reduces proportionally with the bunch charge leading to a BAM performance degradation for charges lower than 200 pC [3,13]. In order to achieve sub-10 fs time resolution for a low charge operation mode down to a few pC, the bandwidth of the current BAMs needs to be increased from 40 GHz up to 80 GHz or higher. As a part of the high bandwidth BAM, cone-shaped pickups were introduced in [14]. The cone shaped pickups are part of the synchronization systems at XFEL, FLASH and ELBE (Helmholtz-Zentrum Dresden- Rossendorf) [14-16].

This paper presents a new concept of an ultra-wideband pickup structure for beampipe-diameters down to 10mm for frequencies up to 80 GHz or higher with sufficient output signal for driving the attached EOMs.

CONE SHAPED PICKUP DESIGN

The rf properties of the pickup is defined by its shape, the material, the used connectors, and the cables connected to the pickup. However, the pickup shape has the largest influence on the performance of the system.

In [14] a tapered coaxial structure was proposed, which comprises a cone-shaped pickup electrode with the

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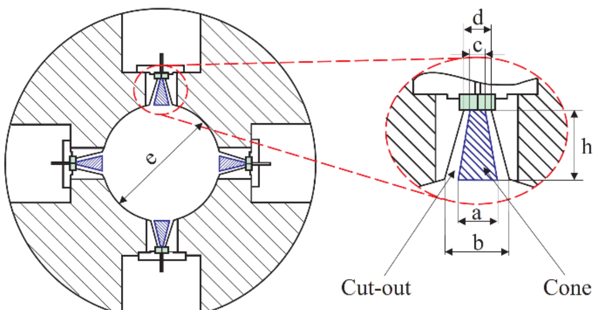
corresponding cut-out, as shown in Figure 1. Unlike the classical button-type pickup, the cone-shaped pickup avoids resonances within the pickup due to the tapered transition from the beam pipe to the connector having a constant line impedance of 50 Ω



a = 2.42 mm	c = 0.70 mm
b = 5.60 mm	d = 1.62 mm
e = 40.50 mm	h = 6 mm

Figure 1: Cross section of the current cone-shaped pickup with dimensions [14].

The cone shaped pickups are installed in XFEL, FLASH which allows for the detection of the arrival time with fs resolution for the low charge operation mode with 20 pC bunch charge in FLASH II and XFEL. Figure 1 shows a sketch of the cross-section of four cone shaped pickups integrated in the housing with corresponding dimensions for FLASH II and XFEL.

The simulation results of one pickup in time domain and the respective normalized frequency spectrum is shown in Figure 2.

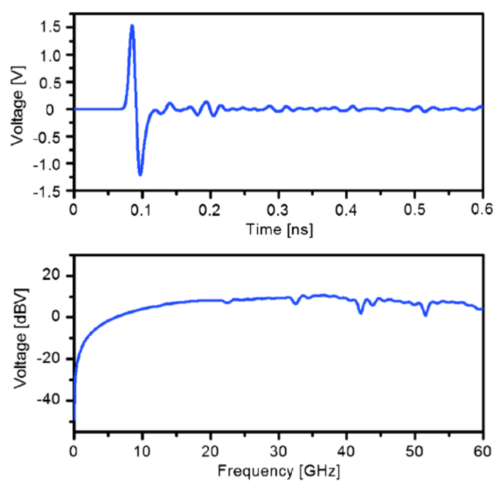


Figure 2: Simulation results of one pickup in time domain (top) and the respective frequency spectrum normalized by the spectrum of the particle beam (bottom) [14].

It can be seen that the spectrum of the voltage is resonance-free up to 40 GHz except small kinks in the spectrum around 23, 33, and 43 GHz.

The ultra-low-charge mode down to 1 pC or less requires a system bandwidth of at least 80 GHz to 100 GHz from the pickup to the attached EOM. In order to increase the bandwidth of the pickup for a constant line impedance, the pickup dimensions need to be reduced. Figure 3 shows the simulation results of a pickup structure filled with a glass ceramic having a relative permittivity of $\varepsilon_r = 3.75$ a radius of the inner conductor $r_{in} = 0.226$mm and the outer conductor radius $r_{out} = 0.5$ mm tapered to a outer conductor radius of $r_{out,cone} = 1{,}13$ mm.

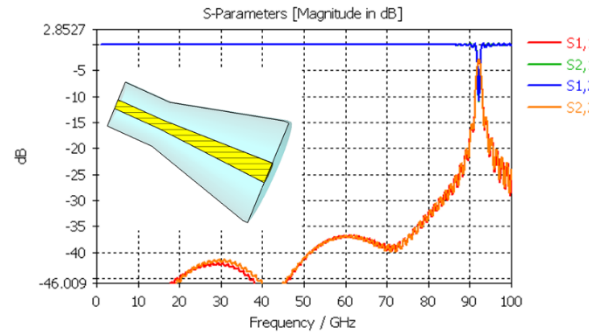


Figure 3: Cross section of the proposed pickup structure and corresponding s-parameter simulation result.

It can be seen, that the pickup structure is resonance free up to 90 GHz. 100 GHz can be reached by further reduction of the pickup diameter.

In order to increase the output voltage at the attached EOM and to reduce the orbit dependency, several pickups need to be arranged in a circle around the beamline. Figure 4 shows a sub-circuit of two pickups and an impedance matched combiner structure.

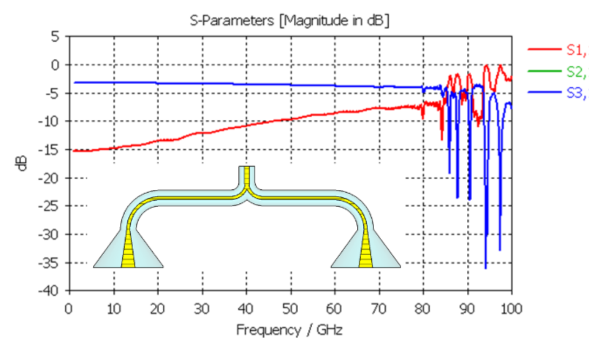


Figure 4: Combination of two pickup structures using an impedance matched combiner structure

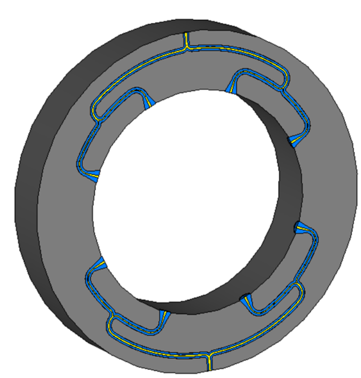


Figure 5: Exemplified pickup arrangement: 8 pickups, 4 pickups each were combined to an integrated sub-circuit with two connectors only.

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The simulated s-parameters exhibit resonances above 80 GHz that need to be improved within the project. A further combination is required to connect 4 pickups to s sub-circuit. Figure 5 shows a model of a pickup circuit containing 8 pickups equally spaced around the beamline.

Further research efforts need to be carried out to optimize the pickup circuit for the ultra-low-charge mode down to 1 pC and to provide sufficient output voltage for subsequent EOMs.

CONCLUSION

A high bandwidth cone-shaped pickup for the BAMs for free-electron lasers is introduced A new concept of an ultra-wideband pickup structure for beampipe-diameters down to 10 mm for frequencies up to 80 GHz is presented.

This makes it suitable for enabling a sub- 10 fs time resolution for high and low bunch charge operation down to 1 pC of the FELs.

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