TIME DOMAIN PICKUP SIGNAL CHARACTERISATION FOR LOW CHARGE ARRIVAL-TIME MEASUREMENTS AT FLASH*

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Abstract

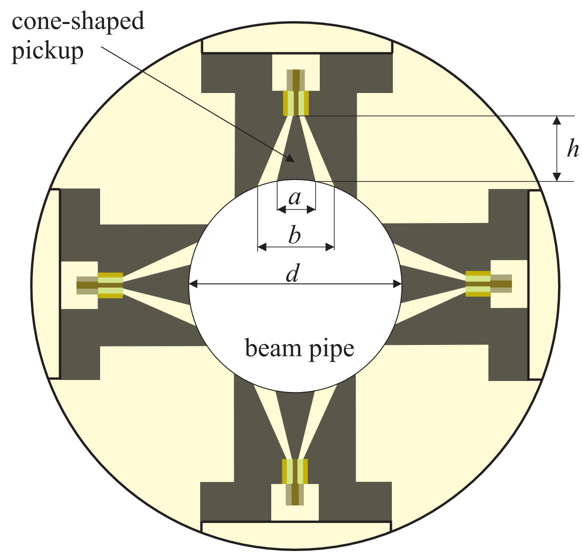
For the low charge operation mode at the European XFEL, high bandwidth cone-shaped pickups were developed as a part of the Bunch Arrival-time Monitors (BAMs). The simulation showed that the signal parameters of interest, the signal slope and bandwidth are improved by more than a factor of six compared to the state of the art pickups. The pickups are installed at FLASH for verification. In this paper, time domain measurements of the cone-shaped pickups at FLASH are presented. The pickup signal is recorded with a high bandwidth sampling oscilloscope. Two channel measurements are conducted with a single and a combined pickup signal in order to analyse the orbit and charge dependence. The measured time domain pickup signal wave form is compared with the full wave CST PARTICLE STUDIO as well as with the Agilent Advanced Design System (ADS) simulation.

INTRODUCTION

In order to measure the arrival-time of the electron bunches at FLASH, Bunch Arrival-time Monitors (BAMs) are installed as an integral part of the laser-based synchronisation (LbSyn) system [1,2]. A BAM comprises RF pickups, electro-optical and RF front-end and read-out electronics. The beam induced pickup signal modulates the amplitude an external laser pulse train in the Mach-Zender type electro-optical modulator (EOM). The reference timing is determined by the laser pulse sampling the pickup signal at the zero-crossing resulting with a zero amplitude modulation at the output of the EOM. An arrival-time jitter of the electron bunch and thus of the transient signal translates into a laser amplitude modulation. The arrival-time is deduced by comparing the amplitude of the modulated laser pulse to the adjacent ones. The sensitivity of the BAMs depends on the pickup signal slope steepness. This detection scheme provides for a time resolution of the arrival-time measurements of less then 10 fs for bunch charges above 500 pC. For the new European - XFEL a low charge operation mode is planed with bunch charges of 20 pC. As the bunch charge reduces below 200 pC, the time resolution of the BAMs decreases significantly [3]. For improving the time resolution for low charges the bandwidth of the BAMs is increased from the current 10 GHz to 40 GHz. The high bandwidth system provides for a beam induced signal with steeper slope compared to the low bandwidth one.

Cone-shaped Pickups

The cone-shaped pickups were developed in [4] as a part of the 40 GHz BAMs for low bunch charge operation of the European-XFEL. Figure 1 shows the cross-section of the pickups with dimensions.



$a = 2.42$ mm	$h = 6$ mm
$b = 5.60$ mm	$d = 40.50$ mm

Figure 1: Cross section of the cone-shaped pickup with dimensions [4].

The simulated slope steepens at the zero-crossing is 417 mV/ps and it is by a factor of six higher compared to signal slope of the current 10 GHz pickups [4]. The pickups are installed in FLASH for testing and evaluation as part of the BAMs for low charges.

In this paper we present the time domain measurements of the cone-shaped pickups at FLASH. A comparison between the measured wave forms and simulations is performed for validation of the results. The signal slope is evaluated for different bunch charges and orbit displacements.

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TIME DOMAIN MEASUREMENTS OF THE CONE-SHAPED PICKUP SIGNAL

The measurements of the pickup signal are performed directly in the accelerator tunnel with a high bandwidth (50 GHz) sampling oscilloscope Tektronix DSA8300 with a 80E10 electrical sampling module. In order to avoid damages to the equipment due to radiation, the oscilloscope was enclosed in a lead box.

Measurement Setup

The beam induced pickup signal is recorded at the output of the RF signal path which includes RF coaxial cables, combiner and two attenuators. Figure 2 shows the measurement setup. In order to reduce the signal degradation due to the cable length, the oscilloscope is mounted inside the beam tunnel. The left and right pickups (horizontal branch) are fed into a power combiner and the output is connected to the oscilloscope via 40 GHz phase stable RF cables (Phasemaster 160, Teledyne-Storm Microwave) through 30 dB attenuator for an over voltage protection. The bottom pickup (vertical branch) signal is recorded as a single while the top signal is connected to the trigger input via 1.3 GHz bandpass filter. The result from the measurements are given in the next subsections.

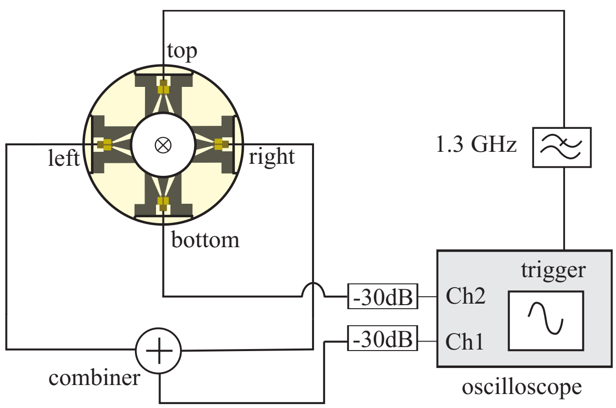

Figure 2: Measurement setup for the time domain measurements of the beam induced pickup signal.

Comparison between Measurements and Simulation

In order to validate the measurement results a comparison between them and the outputs of two different simulation packages is performed. A full wave simulation with CST PARTICLE STUDIO delivers the beam induced signal at the output of the pickup while an Advanced Design System (ADS) simulation shows the signal at the end of the RF path. The pickup signal from the CST PARTICLE STUDIO is used as an input parameter for the ADS simulation and the measured S-parameters of the cables and the combiner are embedded into the building blocks. Figure 3 shows the schematics of the RF path for the ADS simulation. A comparison between the measured pickup signal for a bunch charge of 20 pC and two simulation outputs is shown in Fig. 4. It can be seen that the measured curve and the ADS simulation are in a good agreement with decreased slope and peak voltage compared to the CST PARTICLE STUDIO simulation. The second zero crossing signal visible in the ADS simulation and in the measurement as well as the slope reduction are as a result of the signal degradation in the RF path. The extracted parameters from the wave forms are given in Table 1.

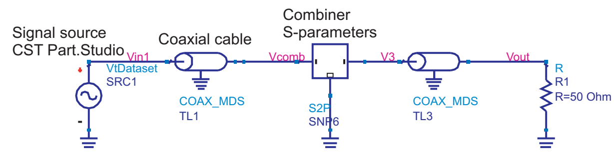

Figure 3: ADS schematics for the RF path simulation. The excitation signal is obtained with a CST PARTICLE STUDIO simulation.

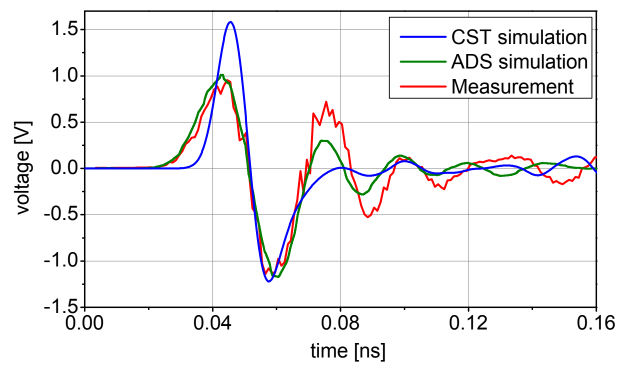

Figure 4: Simulation measurements.

Table 1: Comparison of the Pickup Signal Parameters for Measurement and Simulations

signal source	slope [mV/ps]	V_{pp} [V]
CST PARTICLE STUDIO	417	2.7
ADS	372	2.1
measurement	370	2.15

Bunch Charge and Orbit Sweep

The beam induced pickup signal is recorded for different bunch charges and orbit positions. Two channels of the oscilloscope simultaneously recorded the signals from the single pickup and the combined pickups. Figure 5 shows the pickup signal for a bunch charge sweep from 25 pC up to 215 pC. It can be seen that the peak voltage has a linear dependance from the bunch charge, i.e. 1.1 V for a bunch charge of 25 pC and 12.2 V for a bunch charge of 215 pC at both single and combined signal. The peak amplitude is the same for the single and the combined signal due to the

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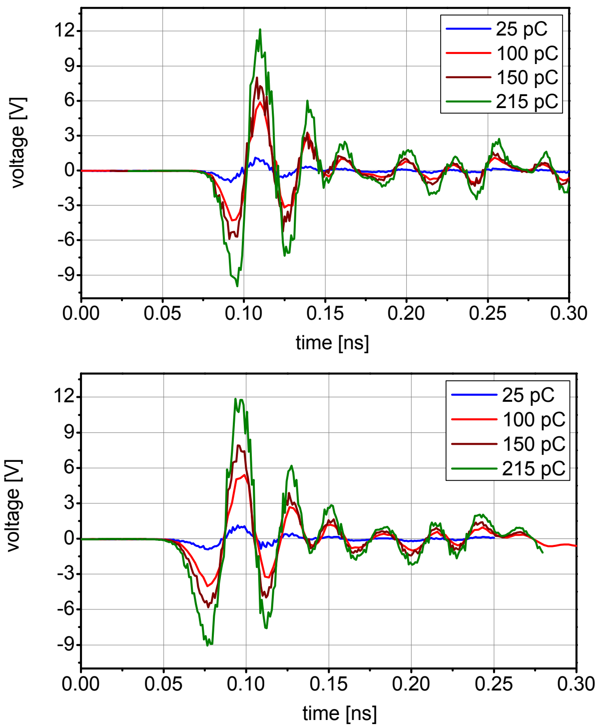

Figure 5: Measured beam pickup signal for bunch charge sweep from 25 pC to 215 pC. Top: Single pickup signal, bottom: combined pickup signal.

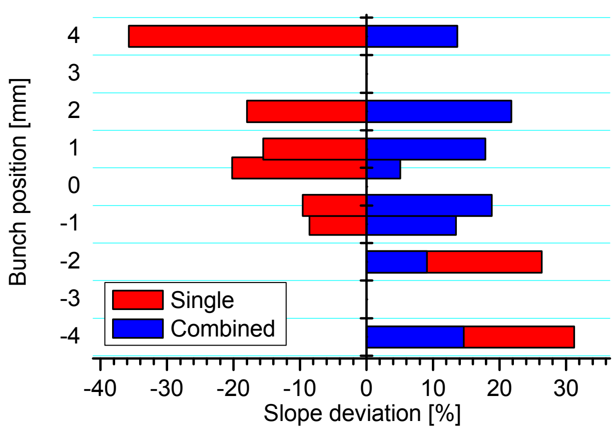

Figure 6: Simulation measurements.

losses of the power combiner at high frequencies (7 dB at 40 GHz).

Figure 6 shows the dependance of the signal slope from the bunch position. The pickup signal obtained from the single and the combined branch is recorded for a vertical orbit displacement measured with a BPM mounted behind the BAM pickups. As the electron bunch moves closer of further away to the pickups the induced voltage increases or decreases respectively as well as the signal slope. In case of a single signal the slope deviation is around 65 % in the full scan range compared to a centralised beam. The slope deviation decreases down to 20 % for the combined pickup signal. The voltage difference between the opposite pickups caused by the beam position change is compensated in the combiner resulting in a reduced slope dependance. This will decrease the uncertainty in the arrival-time detection of the BAMs.

CONCLUSION

The cone-shaped pickups for the high bandwidth low charge BAMs are installed at FLASH. The pickup signal is measured with an oscilloscope and the measurement data is compared to the simulations showing a good agreement between the wave forms. With a combination of the opposite pickups the slope dependance of the bunch position is significantly reduced which will lead to a decreased uncertainty of the bunch arrival-time measurements.

ACKNOWLEDGMENT

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