PICKUP DESIGN FOR HIGH RESOLUTION BUNCH ARRIVAL TIME MONITOR FOR FLASH AND XFEL*

A. Angelovski[#], A. Penirschke, R. Jakoby, Institut fuer Mikrowellentechnik und Photonik, TU Darmstadt, Darmstadt, Germany
A. Kuhl, S. Schnepp,Graduate School Computational Engineering ,TU Darmstadt, Darmstadt, Germany
M.K. Bock, M. Bousonville, P. Gessler, H. Schlarb, DESY, Hamburg, Germany
T. Weiland, Institut fuer Theorie Elektromagnetischer Felder, TU Darmstadt, Darmstadt, Germany
J. Rönsch-Schulenburg, J. Roßbach, Institut fuer Experimentalphysik, Hamburg University, Hamburg, Germany

Abstract

The Free Electron Laser in Hamburg (FLASH) is currently equipped with four Bunch Arrival time Monitors (BAMs) which are part of the optical synchronization system [1]. For the low bunch charge regime operation, the bandwidth has to be increased substantially.

This paper shows a new design of a high frequency button pickup that can operate in a frequency band from DC up to 40 GHz. The performance of the designed model is analyzed for fabrication tolerances. A full wave simulation with CST PARTICLE STUDIO® is performed in order to prove the concept.

INTRODUCTION

At FLASH four bunch arrival time monitors (BAM) are currently installed, one more is scheduled to be commissioned until the end of this year. The BAM comprises a RF-pickup, an electro-optical front-end and specially designed read-out electronics, based on fast 108 MHz, 16 bit ADCs and an optical clock generation.

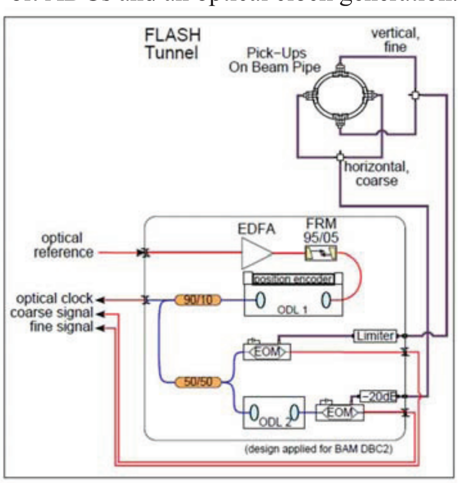

Figure 1: BAM electro-optical front-end.

The BAM measures the arrival time jitter of each individual electron bunch within a macro pulse, relative to an optical timing reference supplied by the pulsed optical synchronization system [2].

One component of the arrival time detection is a commercial electro-optical modulator (EOM), which translates the bunch timing information, given by the zero crossing of the pickup's voltage signal, into an amplitude modulation of ultra short laser pulses [3]. The slope steepness at the zero crossing defines the resolution of the BAMs [1]. For a high resolution the slope needs to be as steep as possible, and this requires a higher bandwidth.

In the current design, both the EOM and the RF-pickup are optimized to a voltage signal bandwidth from DC up to 10 GHz.

BEAM PICKUP SIGNAL

An ultra-relativistic electron bunch which travels in the center of a beam pipe induces a voltage signal into the four radial arranged pick-up electrodes as shown in Figure 2 [4]. The image charge in the pickup has the same longitudinal profile as the bunch charge due to the Lorentz contraction of the field, as defined in [5].

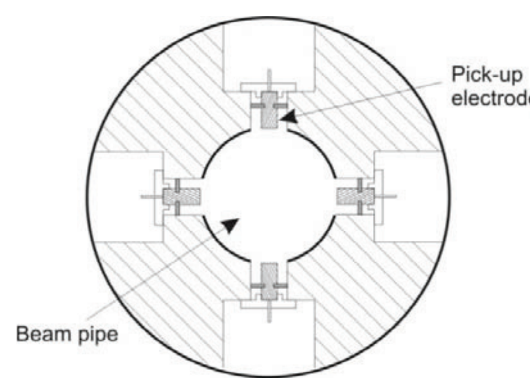

Figure 2: Cross-section of a button type beam pick-up for a BAM.

The longitudinal bunch distribution is assumed to be Gaussian with a temporal standard deviation of $\sigma_t = 0.05$ ps . The bunch charge may vary from 1 nC down to 20 pC within the bunch train, requiring the BAMs to equally

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angelovski@imp.tu-darmstadt.de

work for low and high charges. The dependency of the pickup's signal zero crossing on the bunch charge and the bunch profile is described in [1].

As bunches of low charge induce lower voltages the steepness at the zero crossing is reduced. In order to maintain the signal steepness, the duration of the voltage response needs to be shorter, which requires increasing of the bandwidth. The current system bandwidth does not allow for recovering the required slope steepness for low charge operation.

Additionally, the ringing requires attention, as in the actual system it lasts for several hundred nanoseconds. This causes an interference of the electron bunches within the bunch train. After detecting the first bunch, the output signal of all following bunches experience a shift in the energy level due to ringing [1]. In order to avoid interferences of signals excited by different bunches, the ringing is required to decay to less than 0.1 % of the peak amplitude after 220 ns, which corresponds to the bunch spacing foreseen for the European XFEL.

CONE-SHAPED PICKUP DESIGN

The designing procedure of the cone-shaped pickup focuses mainly on achieving steep slope at the zero crossing and reducing the ringing of the signal. The smooth cone transition prevents reflections and reduces the parasitic effects.

Design Analysis

In order to meet the requirements we propose a cone-shape pickup electrode, depicted in Fig. 3. A similar design was proposed in [6] for recovering a signal from a strong wake-field background. To avoid discontinuities and sharp edges in the transition between the button and the pin, we have substituted the button with a continuous cone-shaped pin. This design provides smooth transition between the beam pipe and the feedthrough.

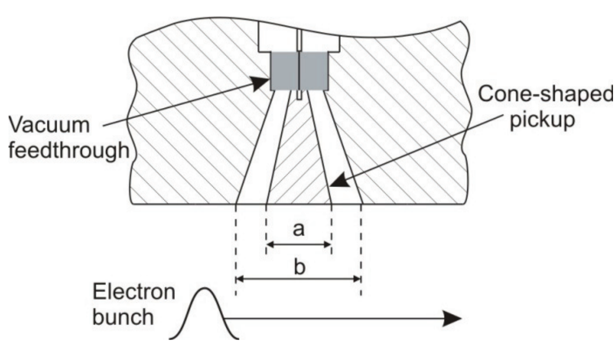


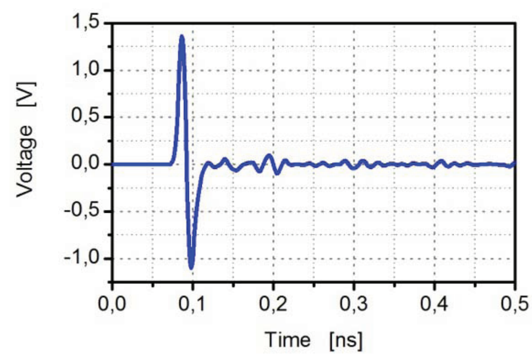
Figure 3: Cross-section of the cone-shaped pickup electrode for the BAM.

For maximizing the signal transmission while avoiding reflections, the pickup is matched to the impedance of 50 Ω. Thus, the ratio b / a is a constant with value of 2.3, where a = 2.428 mm and b = 5.6 mm. The radius of the pickup is $a / 2$, and the radius of the housing is $b / 2$. The length of the pickup is 6 mm. For our simulations we are using commercially available vacuum feedthroughs from Advanced Technology Group, Inc. These feedthroughs are sealed with glass with a relative permittivity $\varepsilon_r \sim 4.7$ and impedance of 50 Ω. The feedthroughs are used for K-connectors which can operate up to 40 GHz.

Simulation Results

The pickup electrodes are designed and simulated in CST PARTICLE STUDIO® for a beam pipe diameter of 40.5 mm, bunch length of σ_b = 1 mm (σ_t = 33 ps) and bunch charge of 20 pC. Since the simulation duration depends on the computational power, the voltage signal is recorded only for the first 0.5 ns. In near future, the simulation will run on a supercomputer and we will have more precise results about the ringing of the signal.

The output voltage is shown in time domain in Fig. 4 (top), and in frequency domain in Fig. 3 (bottom).



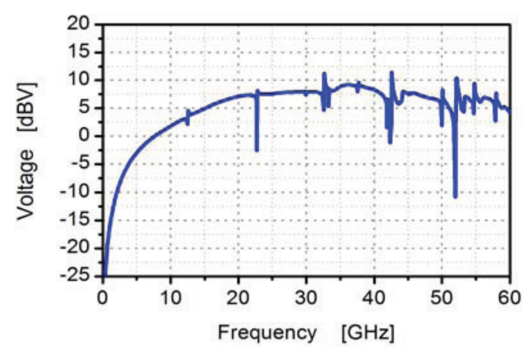


Figure 4: Beam pickup signal: Top: time domain, Bottom: frequency domain.

From the voltage response in time domain one can determine a slope at the zero crossing of 382 mV/ps with peak to peak voltage of 2.5 V. The amplitude of the ringing signal after 0.5 ns is less than 1% of the peak amplitude. We expect that the ringing will be reduced to less than 0.1% from the peak of the signal due to the losses in the material. The Fourier transform of the pickup signal shows that we have approximately flat characteristics up to 40 GHz. We assume that the sharp peaks around 12 GHz, 22 GHz and 33 GHz are result of a simulation inaccuracy and by investigating this problem we came to the conclusion that they are connected to the time resolution of the simulation. The other peaks in the spectrum for frequencies higher than 40 GHz are due to the ripples in the pickup signal and the mismatch of the feedthrough for these high frequencies.

Tolerances Analysis

For the manufacturing process of the pickup system it is very important to know what is the influence of the variation of the dimensions over the system performance. Commercially available vacuum feedthroughs that we are using have constant dimensions, as well as the flanges they are placed in. The upper bases of the pickup and the housing cut cones are predefined by the dimensions of the vacuum feedthrough as well. The dimensions of the lower bases of the pickup and the housing are free parameters and the change of these dimensions was subject of analysis.

Fig. 5 shows the dependency of the slope at the zero crossing versus the change of the radius of the pickup and the housing respectively.

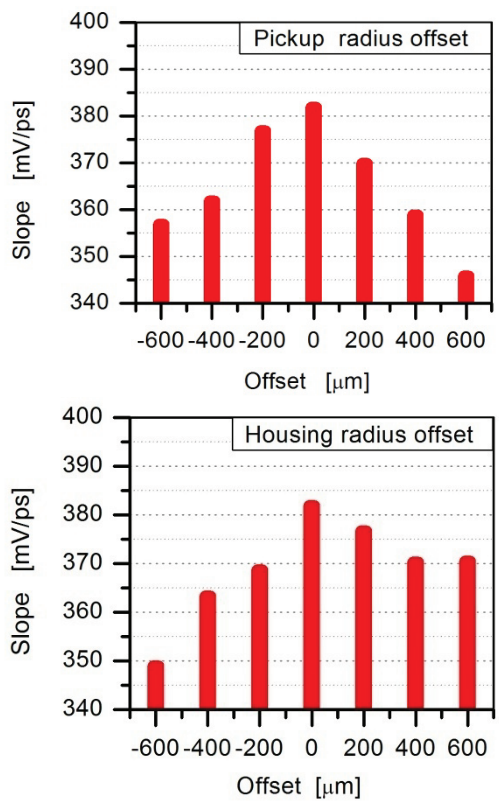


Figure 5: Top: pickup radius, Bottom: housing radius.

From the plots in Fig. 5 one can see that for the calculated values for the radius of the pickup and the housing, the slope has a peak value of 382 mV/ps. By increasing or decreasing the radius in both cases, the value of the slope decreases in Gaussian-like manner with mean value in the nominal one. The decrease of the slope is due to the mismatch and the change of the parasitic capacitance, both defined by the radius of the pickup and the radius of the housing. The change of the pickup radius has the strongest impact on the slope steepness. This is expected because this radius defines the amount of image charge in the pickup. However, changing the radius by ±600 μm in both cases causes the slope to decrease less than 8%. One should notice that the change of ± 600 μm for the pickup radius means change of ± 50% and for the housing radius it means 22% of the nominal value.

CONCLUSION

A cone-shaped pickup for BAM is introduced which fulfils the requirements of more than 300 mV/ps slope steepness and a bandwidth up to 40 GHz. The ringing of the signal is investigated only to 0.5 ns due to the lack of computational power. At this time, however, it has already decayed to less than 1% of the signal peak amplitude.

The slope steepness at the zero crossing was evaluated for different values for the pick-up and the housing radius. The decrease of the slope steepness due to the dimension variations in the range of ± 600 μm is less than 8%. It is shown that the highest values of the slope steepness are obtained for the nominal dimensions.

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