

# ANALYSIS OF NEW PICKUP DESIGNS FOR THE FLASH AND XFEL BUNCH ARRIVAL TIME MONITOR SYSTEM<sup>#</sup>

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## Abstract

New pickup designs for the Bunch Arrival time Monitor (BAM) at the Free Electron Laser in Hamburg (FLASH) have been developed and simulated with CST PARTICLE STUDIO®. All presented designs fulfill the specifications of an output voltage slope greater than 300 mV/ns for a wide range of bunch charges from 10 pC to 3 nC.

## INTRODUCTION

The Free Electron Laser in Hamburg (FLASH) is equipped with Bunch Arrival time Monitors (BAM) [1], which provide for a time resolution of less than 10 fs for bunch charges higher than 0.2 nC. The timing information is obtained by mixing the pickup signal with the pulses of a reference laser in an Electro Optical Modulator (EOM) [2]. This information is coupled back to the first accelerating module, for stabilizing the arrival time jitter of the electron bunches to less than 25 fs. The sensitivity of the measurement system is defined by the slope of the pickup signal at the zero crossing and scales close to linear with the bunch charge. For future experiments lower bunch charges down to 10 pC are of interest. In this case the requirements on the time resolution will no longer be fulfilled. The slope can be increased either by increasing the output signal voltage or its frequency. Due to a technical limitation of the maximum signal voltage a new pickup has to be developed, which has a bandwidth of 40 GHz or higher.

## SIMULATION SOFTWARE

For the design and simulation of new pickups we used the CST PARTICLE STUDIO® software package, which allows for computing the time dependent voltage along user defined paths as one feature. To determine the voltage gradient at the zero crossing (slope) and the amplitude of the ringing an automatic analysis has been developed and implemented as a postprocessing step by means of VBA macro scripts. The integrated optimizer can employ these

results in order to tune design parameters for the next simulation run. Furthermore, the peak-to-peak voltage are determined. In order to distinguish whether the slope is influenced by the amplitude or by the frequency bandwidth, considering its value alone is not sufficient. Thus, we assume a sine wave

$$U(t) = A \cdot \sin(2\pi f_e \cdot t)$$

$$S = \pm A \cdot 2\pi f_e \quad \text{with } S \text{ as Slope}$$

$$\Rightarrow f_e = \frac{|S|}{\pi \cdot U_{\text{peak to peak}}} \quad \text{with } U_{\text{peak to peak}} = 2 \cdot A$$

by using the slope and the peak-to-peak voltage, we compute its equivalent frequency ( $f_e$ )<sup>1</sup> with the available functions in CST. The ringing is calculated with the maximum absolute voltage in the time window between 0.3 ns after the zero crossing up to the end of the simulated time. This value is divided by half of the peak-to-peak voltage and given in percent. In the following, all simulations are carried out using Gaussian bunches with a longitudinal standard deviation of  $\sigma = 1$  mm and 20 pC bunch charge.

## CURRENT PICKUP

In order to compare new pickup designs, the currently installed pickup was modeled in CST to serve as a reference. This pickup consists of four rotationally symmetric arranged pins. The signals of both horizontal and vertical pins are combined and conducted to the EOM. This arrangement minimizes the influence of beam offsets. The simulation results show the signal of one pickup only. This type of pickup was built for a bandwidth of 10 GHz using a vacuum feedthrough made from alumina (see Fig. 1). The analysis shows a mismatch of the impedance, which causes a high level of ringing. The dimensioning of the structure is not suited for a bandwidth up to 40 GHz resulting in higher order modes in the pickup signal. Alumina has a high relative dielectric constant ( $\epsilon_r$ ) of approximately 9.6, which increases the reflections and thus also the ringing. The results of the simulation show a slope of 69.7 mV/ps, a ringing of more than 67 % after 0.3 ns, a peak-to-peak voltage of 2.52 V and an equivalent frequency of 8.78 GHz.

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<sup>1</sup>A finite time signal requires a bandwidth around this frequency.

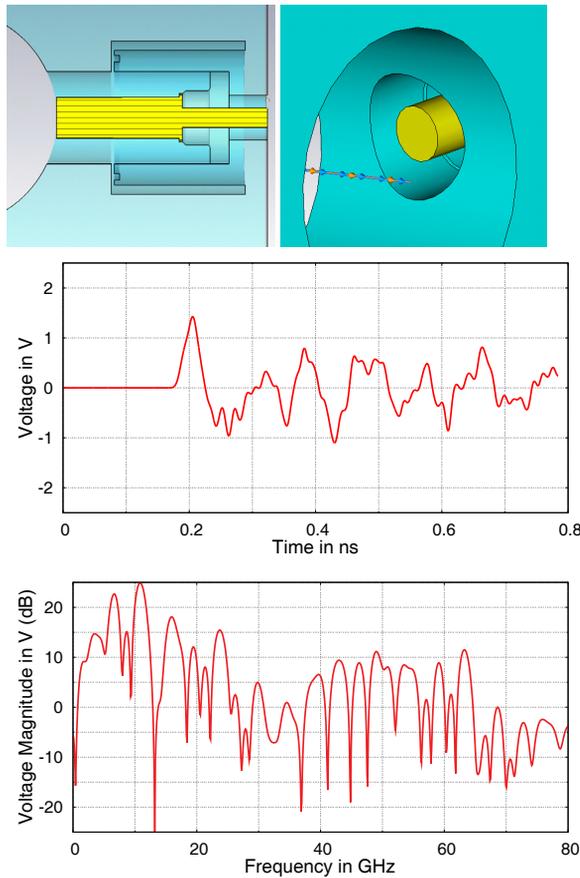


Figure 1: Current pickup and the simulation results.

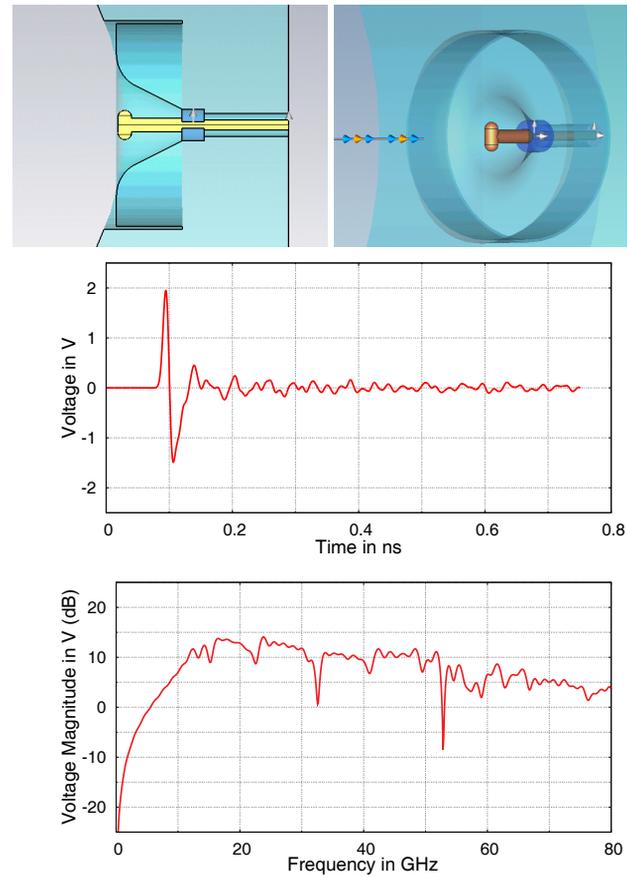


Figure 2: T-shaped design with horn-shaped expansion and the simulation results.

## NEW PICKUP DESIGNS

Three new pickup designs have been developed. The arrangement of four symmetrically arranged antennas was kept for all designs. All new designs have the same coaxial dimensions. The connector has an inner conductor diameter of 0.6949 mm and an outer conductor diameter of 1.6 mm. It is, therefore, adapted to an impedance of 50  $\Omega$ .

### *T-Antenna Design*

The first design is a T-shaped pickup, which is a combination of a pin pickup and the commonly used button pickup [3] (see Fig. 2). The horn-shaped expansion increases the sensitivity of the antenna. An investigation revealed that orienting the T-antenna perpendicularly to the beam direction yields the best results regarding slope and ringing. Employing the automatic evaluation of the slope and ringing with the integrated optimizer of the CST software for determining optimal dimensions, this pickup achieves a slope of 479 mV/ps, a ringing of 6.39 % after 0.3 ns, a peak-to-peak voltage of 3.44 V and an equivalent frequency of 44.4 GHz.

### *Short Circuit V-Antenna Design*

The second design is the short circuit V-antenna (see Fig. 3). Short-circuiting the antenna wire with the housing efficiently damps the ringing. The angle  $\beta$  of the V-antenna (see marks in Fig. 3) influences the ratio of the first to the second maximum in the voltage signal but it has only a small influence on the slope. The best results are obtained for an angle of  $\beta = 160^\circ$ . The simulation results show a slope of 499.7 mV/ps and a maximum ringing of 2.32 % after 0.3 ns. Furthermore, a peak-to-peak voltage of 4.01 V and, thus, an equivalent frequency  $f_e$  of 39.7 GHz are determined.

### *Double Notch T-Antenna Design*

The third design is the double notch T-antenna (see Fig. 4), where the notches improve the coupling of the electromagnetic field to the antenna. The results of the simulation show a very high slope of 604.4 mV/ps and a maximum ringing of less than 4.8 % after 0.3 ns. The value of the peak-to-peak voltage is 3.41 V yielding an equivalent frequency  $f_e$  of 56.45 GHz.

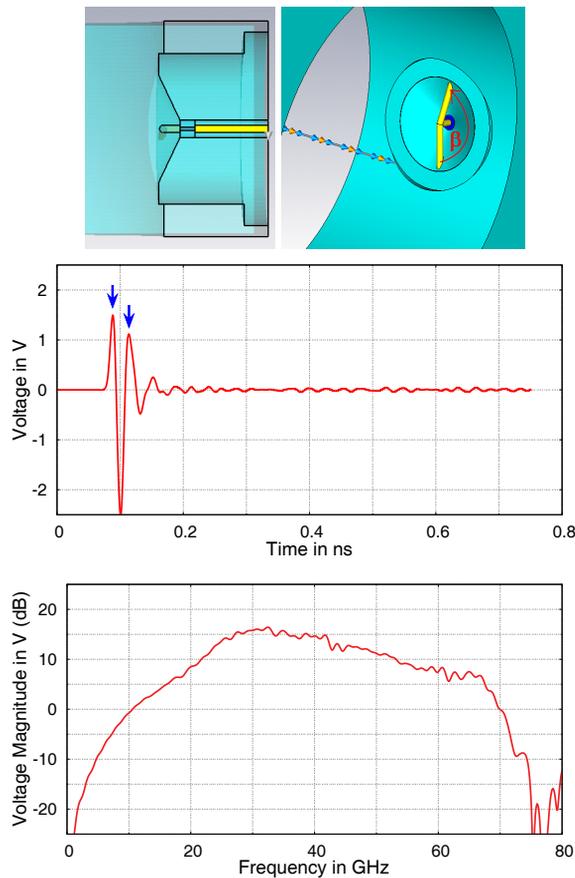


Figure 3: Short circuit V-antenna and the simulation results.

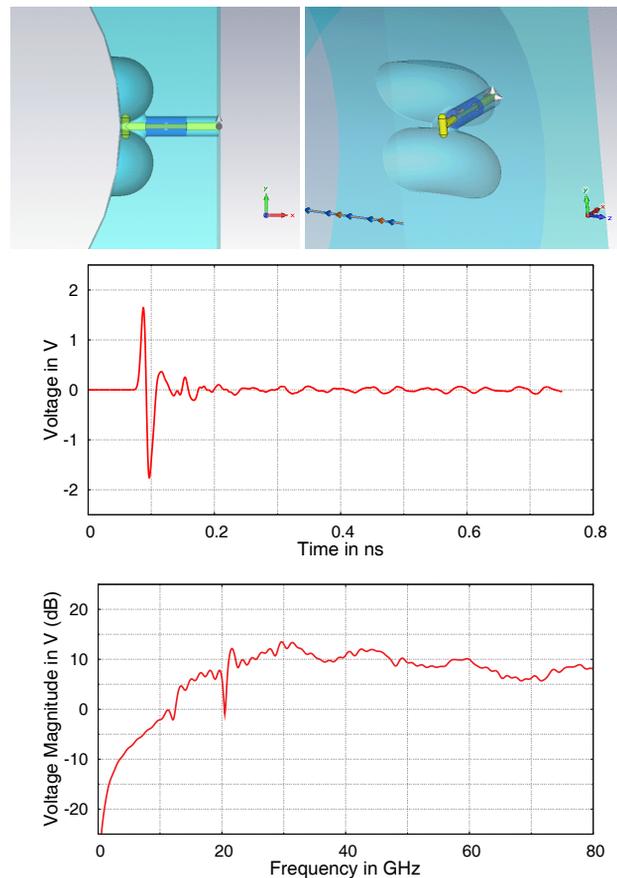


Figure 4: Double notch T-Antenna design and the simulation results.

### CONCLUSIONS

The specifications of the new pickup are a slope greater than 300 mV/ps and a ringing below 0.1 % after 220 ns. It is possible but not practicable to run the simulations up to 220 ns for checking the ringing at this point as the respective simulations consume about 30 hours time. Sporadic long term simulations were made and showed that the ringing has decayed to about 0.1 % after 10 ns already. It was demonstrated that several new pickup designs are able of fulfilling the requirements regarding slope and ringing of the output voltage signal. This will enable time measurements down to 10 fs even when operating with bunch charges as low as 20 pC. Furthermore, all designs show a substantially reduced ringing of less than 7 % after 0.3 ns in comparison to the currently installed pickup (Fig. 1).

One difficulty we encountered during the design process are the opposing aims of obtaining a high slope value while keeping ringing at a low level. If the slope is increased, the ringing usually also increases. Since ringing appears not to be a severe problem, we introduced a weighting factor into the optimization goal, which takes care of the trade-off between these two aims.

### OUTLOOK

Future works will include a sensitivity analysis, which is necessary for determining production tolerances for all dimensions relevant to the functionality of the pickup. Furthermore, one selected design [4] will be built as a non-vacuum compatible prototype at the Microwave Engineering Laboratory at TU Darmstadt. This prototype will be measured and compared with simulation results. Eventually, a vacuum compatible prototype will be built and installed in the FLASH facility.

### REFERENCES

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