PLANAR TRANSMISSION LINE BPM FOR HORIZONTAL APERTURE CHICANE FOR XFEL

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Abstract

In order to obtain ultra short bunches in the Free Electron Laser FLASH at DESY, the electron beam is compressed in magnetic chicanes. Precise knowledge of the beam position in the chicane allows for non-destructive energy measurements of each individual bunch in the beam. In the current implementation, the Energy Beam Position Monitor (EBPM) pick-ups are coaxial pick-up striplines mounted perpendicularly to the beam. One can determine the horizontal beam position by measuring the phase difference of the beam induced signal at opposite ends of a pick-up. Due to the different electrical and mechanical requirements for the European XFEL a new EBPM has to be developed.

In this paper, we present the design and analysis of a planar transmission line structure which is planned to be used as an EBPM in the European XFEL. The planar design of the pick-ups can provide for a proper impedance match to the subsequent electronics as well as sufficient mechanical stability along the aperture when using alumina substrate.

INTRODUCTION

The European XFEL will need a zoo of diagnostic tools for the study of the longitudinal properties of the electron beam. The Electron Beam Position Monitor (EBPM) will be used as part of longitudinal diagnostic tools for the European XFEL. It is composed of the pick-up structure and detection electronics.

The EBPM is an instrument used for bunch energy measurements [1] and it will be used at three different locations along the European XFEL LINAC. The energy measurement is done by means of position measurements, where the transformation from position to bunch energy is defined by the formalism of the bunch compressor [2]. As opposed to a standard BPM, the energy BPM measures phases to define the absolute position of the bunch in the dispersive section of the bunch compressor. Figure 1 shows the current EBPM installed at FLASH and the principle of phase detection [1]. Two coaxial pick-up striplines are mounted perpendicular to the beam. At both ends of the pick-up ceramic disks are placed for mechanical support and the pick-ups are tapered towards the connectors. The difference between the measured phases of the pulses coming from the left and from the right side of the pick-up is proportional to the position (dx in Fig. 1) of the bunch.

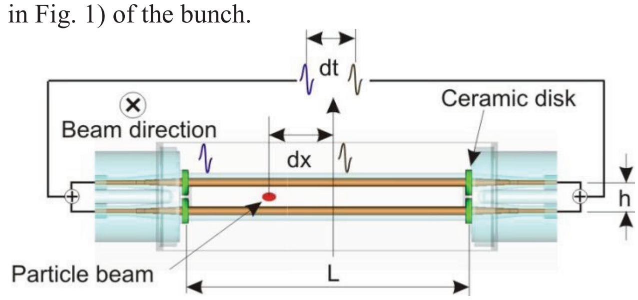

Figure 1: CAD model of the EBPM installed in the second bunch compressor at FLASH.

The measurement resolution of the bunch position, hence energy, depends on the frequency of the detection. Therefore it is advisable to have the phase detection at a rather high frequency. The upper limit is defined by the manufacturing limitations of the pick-up, limitations of the detection electronics and size of the chicane which imposes the wavelength, below which the phase detection might become ambiguous [3]. The resolution of the instrument also depends on the signal spectral density that the pick-up structure transfers from the beam to the output connector.

As the requirements for the future EBPM at the European XFEL (mechanical and electrical) differs significantly from the ones at FLASH, a new EBPM needs to be designed. Table 1 summarizes a comparison between the design parameters for FLASH and the European XFEL.

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Table 1: Design Parameters of the EBPM for FLASH and the European XFEL

	FLASH	XFEL
L [mm]	183	400
H [mm]	8	40.5
Detection freq. [GHz]	1.3	3
Bunch charge [pC]	> 200	20

This paper presents the design of planar pick-ups for the XFEL EBPM monitor. Two planar structures are proposed and their performances are compared. For the simulation of the EBPM pick-ups CST PARTICLE STUDIO® is used.

DESIGN OF PLANAR TRANSMISSION LINE PICKUPS FOR THE EBPM AT XFEL

In order to fulfill the electrical as well as the mechanical requirements for the new EBPM, we propose the planar pick-up electrodes. The pick-ups need to have a resonance-free spectrum up to 6 GHz. To fulfill this, the pick-ups need to be matched to the subsequent electronics. Although, for now the detection frequency is determined to be 3 GHz we design the pick-ups with higher bandwidth in order to leave margin for future upgrades to higher frequencies. The connectors are planned to be perpendicular to the transmission line. With such a structure the pick-ups will be independent from the chicane and can be mounted or dismounted without removing the entire chamber. However, this is one of the critical points which influences the bandwidth of the pick-ups. Optimization of the transition from the connector to the transmission line is still in progress. The use of "hard" substrate (Alumina, Glass, etc.) can provide for sufficient mechanical stability. Figure 2 shows the sketch of this structure.

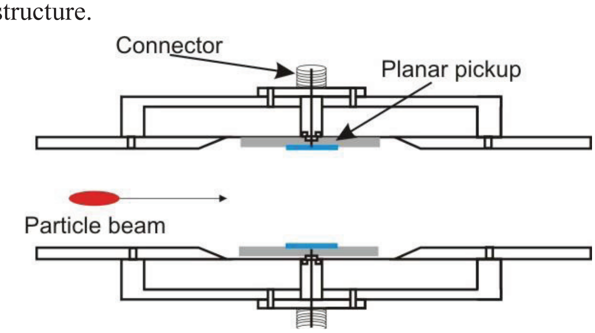

Figure 2: Cross-section of planar transmission line pick-ups for the EBPM.

Two planar structures are investigated in this paper: The microstrip transmission line and Grounded Co-planar Waveguide (GCPW) transmission line. Details of the design and analysis are presented in [4]. Planar structures used as pick-up/kicker electrodes for stochastic cooling are described in [5,6]. Figure 2 shows the CAD design of the planar structures.

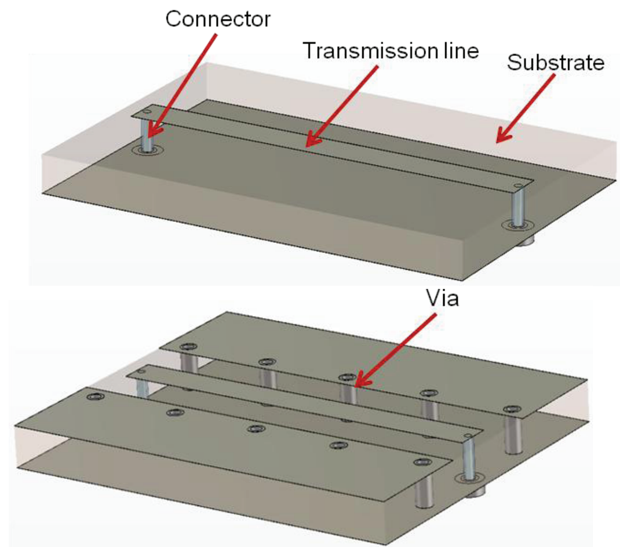

Figure 3: Microstrip transmission line (top). GCPW transmission line (bottom).

The connectors for both structures are perpendicular to the transmission line. In the case of GCPW, vias are placed in order to short-cut the field. Alumina with $\varepsilon_r = 9.8$ is used as a substrate and copper as metallization layer for both structures. The design parameters are shown in Table 2.

Table 2: Design Parameters for the Planar Transmission Lines

	Microstrip	GCPW
Substrate height [mm]	1.3	1.5
Line thickness [mm]	0.006	0.006
Line width [mm]	1.55	1.3
Line gap [mm]	/	20
Loss [dB/m]	2.4	3.6

Using the planar transmission lines (microstrip and GCPW) two rectangular chambers are built (as shown in Fig. 2) and simulated. The simulation is performed with CST PARTICLE STUDIO® with a beam charge of 100 pC and a beam width of 1.8 mm. Figure 4 shows the results of the simulation.

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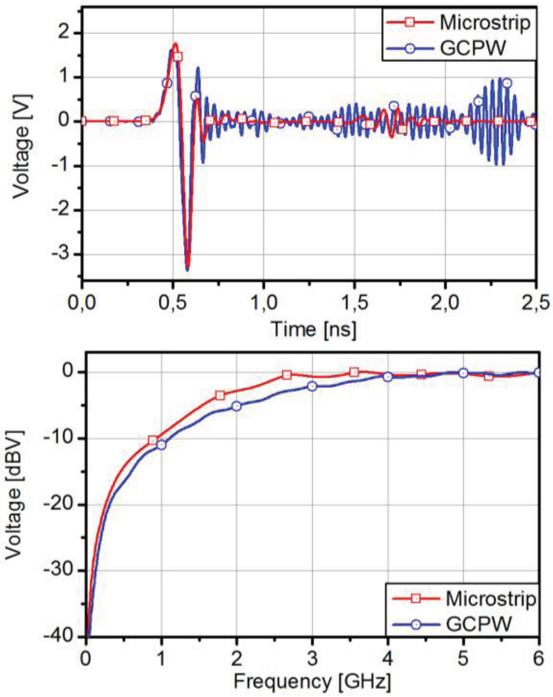

Figure 4: CST PARTICLE STUDIO simulation of the planar pick-ups. Voltage in time domain (top), voltage in frequency domain (bottom).

The simulation shows that both planar transmission lines have similar performance. However, the output signal for the GCPW transmission line rings longer and with higher amplitude. As a Figure of Merit (FoM) we use the voltage level at 3 GHz. The microstrip transmission line has -0.7 dB/Hz and the GCPW line has -2.175 dB/Hz. The lower FoM for the GCPW line corresponds to the higher losses and the higher ringing compared to the microstrip line. Based on the simulation results as well as on the fabrication complexity, for producing the pick-ups we have selected the microstrip transmission line pick-ups to be the candidate for the EBPM at the European XFEL.

In order to assess the output signal of the microstrip transmission line pick-ups we have compared it to the signal obtained from the coaxial pick-ups (see Fig. 1). The dimensions of the chamber are the same for both scenarios. Figure 5 shows the spectra for the planar and coaxial pick-ups.

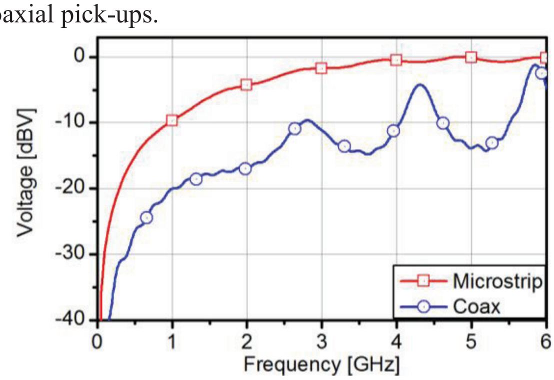

Figure 5: Comparison of the spectrum for microstrip transmission line and coaxial pick-ups.

From the results we can see that the coaxial pick-ups become resonant at 2.7 GHz. The resonant peaks in the spectrum are due to the miss-match (the ceramic discs in Fig. 1) and correspond to twice the length of the pick-up. The FoM for the coaxial pick-ups is -11.17 dB/Hz and is lower (-0.7 dB/Hz) compared to that of the microstrip line.

CONCLUSION AND FUTURE WORK

In this paper we have presented the design of planar transmission line pick-ups for the EBPM to be installed at the European XFEL. Two types of planar structures are proposed and analyzed. Based on the obtained simulation results the microstrip transmission line pick-ups were selected as a candidate for the new EBPM. The microstrip transmission line pick-ups show the best FoM compared to the GCPW and the current coaxial pick-up design.

A non-hermetic prototype of the EBPM with planar pick-ups is planned to be built in near future for measurement purposes and prove of concept. Optimization of the transition from the connectors to the mictrostrip line is in progress as well as analysis for maximizing the signal for different substrate thickness.

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