DESIGN AND CHARACTERIZATION OF A PROTOTYPE STRIPLINE BEAM POSITION MONITOR FOR THE CLIC DRIVE BEAM*

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Abstract

The prototype of a stripline Beam Position Monitor (BPM) with its associated readout electronics is under development at CERN, in collaboration with SLAC, LAPP and IFIC. The anticipated position resolution and accuracy are expected to be below 2µm and 20µm respectively for operation of the BPM in the CLIC drive beam (DB) linac. This paper describes the particular CLIC DB conditions with respect to the beam position monitoring, presents the measurement concept, and summarizes electromagnetic simulations and RF measurements performed on the prototype.

INTRODUCTION

CLIC, a Compact electron-positron LInear Collider proposed to probe high energy physics (HEP) in the TeV energy scale, is based on a two-beam scheme. RF power, required to accelerate a high energy luminosity beam is extracted from a high current Drive Beam (DB), whose decelerator requires more than 40000 quadrupoles, each holding a BPM. These BPMs face several challenges, as they will be operated in close proximity to the Power Extraction and Transfer Structures (PETS), while the accuracy requirements are demanding (20µm). They have to be compact, inexpensive and operate below the waveguide (WG) cut-off frequency of the beam pipe to ensure locality of the position signals, which rules out the signal processing at the 12GHz bunch frequency. Also wakefields, and hence the longitudinal impedance, must be kept low. This first proposed solution is a compact, conventional stripline BPM utilizing a signal processing scheme operating below 40MHz. Before installation into the CLIC Test Facility (CTF3), the manufactured prototype has been characterized in detail on an RF bench setup. In parallel, the design of a readout system is progressing.

CONCEPTUAL BPM PICKUP DESIGN

The CLIC DB stripline BPM pickup is compact and fits into the quadrupole vacuum chamber. Each of the four electrodes spans an angular coverage of 45º, having a characteristic impedance of 50Ω and a physical electrode length of L=25mm. As of the proximity of 12GHz high power accelerating structures (PETS), L was chosen to utilize one of the notches in the transfer function (*nc/2L*, *n*=2, where *c* is the speed of light in vacuum) to be at 12GHz, which is also the bunch frequency. Therefore, in the time domain, the idealized response to a multi-bunch train will only show the first and last pair of bunches, all other bunches in-between will be cancelled (Fig. 1). Other relevant design parameters are listed in Table 1.

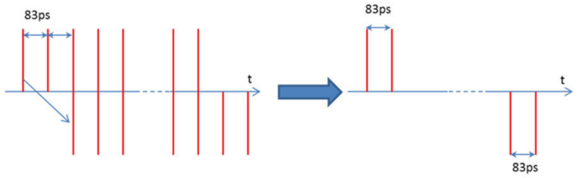

Figure 1: Idealized BPM multi-bunch train response.

Table 1: Drive Beam Stripline BPM Parameters

Parameter	Value	Comment
Diameter	24 mm	stripline ID
Stripline length	25 mm	
Width	12.5 %	of circumference (45^0)
Ch. Impedance	50 Ω	
Duct aperture	23 mm	In decelerator
Resolution	2 µm	Full train
Accuracy	20 µm	
Temporal resolution	10 ns	BW > 20 MHz

The signal processing will be performed at baseband frequencies ranging 4 to 40MHz, to avoid non-local confounding signals, mainly coming from the PETS, starting at 7.6GHz, the cut-off frequency of the TE_{11} mode for a circular waveguide of 23mm pipe aperture.

The position signal sensitivity of a stripline BPM detector is based on the image charge model, and is approximately $pos=(r/2)\Delta/\Sigma$, being r the beam pipe radius, Δ and Σ the difference and sum of the opposite electrode signals, and *pos* the horizontal (x) or vertical (y) beam position. A thorough description of the readout electronics and further details of the design can be found in [1] and [2].

PROTOTYPE CHARACTERIZATION

Position Characteristics and Linearity

The full system was tested using the procedure described in [2] to check its performance. The position characteristic was analysed using a stretched wire fed by an RF excitation signal, while being moved in 1mm steps in the range ±6mm. Table 2 shows the results for the position sensitivity at the origin, the electrical offset and the RMS linearity error for both planes. Although the performance of the electronics was satisfactory, showing the expected signal shape and levels, [2], the obtained

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sensitivity was lower than computed using the simplistic formula above: $166m^{-1}$.

In order to rule out inadequacies of the setup due to the adjacent vacuum chambers to the pick-up being much smaller than the wavelength of the excitation signal (4-40MHz), a brief measurement was performed at 3GHz, without electronics. This result (value raw in Table 2) is almost equivalent to a numerical simulation (EM PIC solver), which gives $137m^{-1}$ as pickup sensitivity.

Table 2: Sensitivity and Linearity Parameters

$x_{H,V} = (S_{H,V}^{-1})\Delta/\Sigma + EOS_{H,V}$		
Parameter	**Value (Full System)**	**Value (Raw)**
V sensitivity S_V	$(115.19 \pm 2.32)\ m^{-1}$	$(130.44 \pm 2.59)\ m^{-1}$
H sensitivity S_H	$(115.17 \pm 1.98)\ m^{-1}$	$(130.28 \pm 2.37)\ m^{-1}$
V offset EOS_V	(0.03 ± 0.08) mm	(-0.51 ± 0.08) mm
H offset EOS_H	(0.02 ± 0.07) mm	(-0.30 ± 0.07) mm
V RMS linearity error	251.07 µm	247.71 µm
H RMS linearity error	214.07 µm	225.83 µm

Transfer Function Measurements

The transfer function of the BPM was analysed with a coaxial transmission-line setup, [3]. An inner rod, traversing the BPM, serves as center conductor of the coaxial structure, which has conical transitions towards the SMA connectors at both ends, providing a constant characteristic impedance of 50Ω. A sine wave stimulus signal was swept in the range 0.003-20GHz to measure the magnitude of the transfer function (Fig. 2). We observed major differences between measured and ideal (theoretical) transfer functions, e.g. the first notch frequency was found at 4.5GHz, while expecting 6GHz, which hints to an electrical length of 33mm.

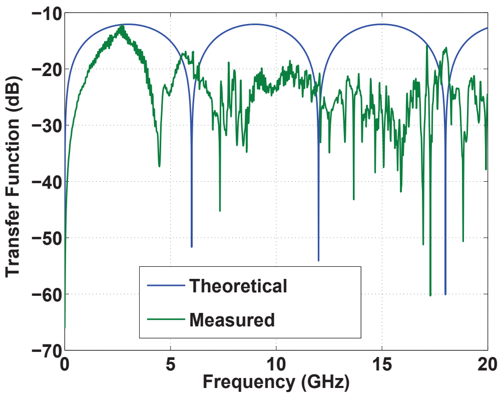

Figure 2: Transfer function of the stripline BPM prototype.

Time Domain Measurements

The frequency domain result was verified by a S21 time domain measurement, using a 50ps full width at half maximum (FWHM) Gaussian stimulus pulse passed on the wire conductor, emulating a single bunch. A 210ps time difference was measured between the two opposite-polarity pulses out of one pickup electrode, confirming an effective electrode length of ~32mm.

EM SIMULATIONS AND DISCUSSION

Effects of a SiC HOM Damping Ring

A strong resonance peak of the transverse wake impedance of the striplines was observed around 12GHz in simulations [1]. A ring of SiC RF damping material was placed at the downstream end of the electrodes to absorb this, and other higher-order modes (HOM). However, while successfully damping HOMs, the dielectric ring also shifts the transfer function to lower frequencies, i.e. causing an extension of the effective electrical length of the striplines, as Fig. 2 indicates. Therefore, the pick-up can no longer behave as a notch filter for 12GHz, which unfortunately prevents the “bunch cancellation” scheme (see also Fig. 6).

Geometric Issues

Despite the extended electrical length, the measured magnitude response (Fig. 2) hints for other design issues, which we tried to understand by empirical EM simulations.

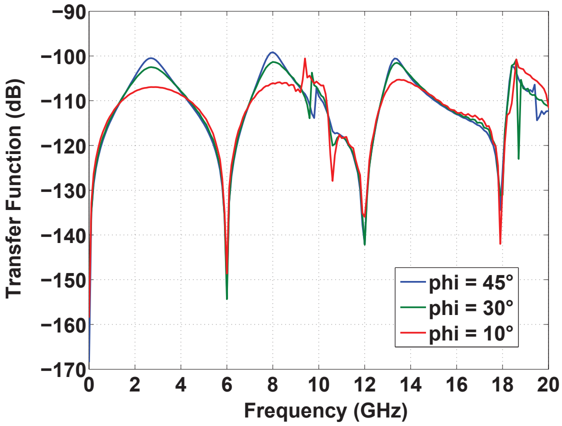

Figure 3: Transfer function for different electrode angular coverages, without SiC damping ring.

The width of the 45^0 stripline electrodes is large with respect to its length, causing non-TEM fields. Simulations of the transfer function towards more narrow, TEM-like electrodes reduce some of the spurious resonances (Fig. 3). Particularly, the 10^0 electrodes approximate the theoretical magnitude response quite well, except for one resonance around 10GHz.

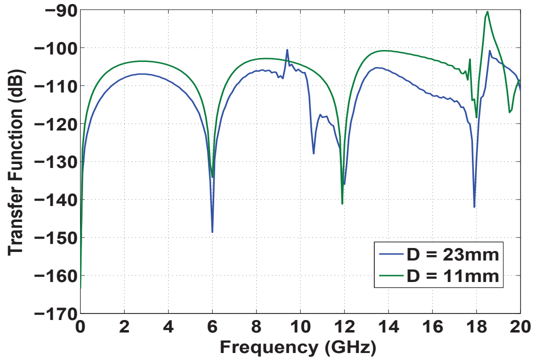

Figure 4: Transfer functions for different pipe apertures.

This unavoidable resonance seems to be caused by the TM_{01} waveguide mode of the vacuum chamber. A simulation with an 11mm aperture shifts the effect well above 15GHz (Fig. 4).

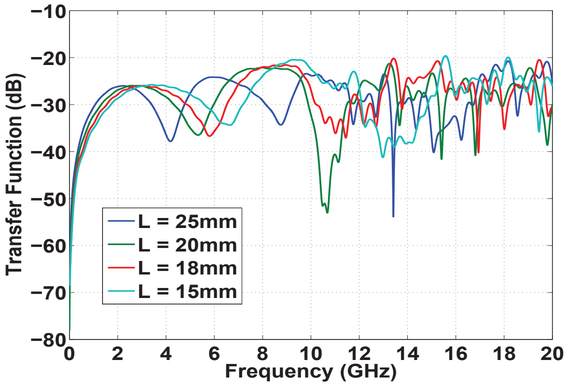

Figure 5: Transfer function for different electrode lengths with SiC ring.

Figure 5 shows the simulation efforts to compensate the length extension effects caused by the SiC damping ring. Evidently, also the notch effect is damped, so relocating the notch to 12GHz will only be of minor benefit.

A 2D EM analysis of the prototype geometry showed furthermore, that the characteristic impedance of the stripline electrodes is ~40Ω, not 50Ω as anticipated. Some corrections on electrode thickness (3.1 → 1.37mm) and a gap (2.4 → 0.63mm) would be required.

Expected Beam Signals

As the transfer response of the prototype BPM (Fig. 1) has some drawbacks with respect to the design intentions, we analysed the expected signal response to a CLIC-like beam with an EM simulation, based on the CST Studio Particle-in-Cell (PIC) solver. As stimulus signal, a relativistic beam of 20 Gaussian bunches spaced by 83.33ps, each one with 8.4 nC charge and 1 mm length (RMS), was supplied. As expected, the time domain output signal does not show any bunch cancellation (see Fig. 6). The raw waveform recorded by a voltage monitor at the output feedthrough port shows strong high frequency signal contents, particularly at 12GHz.

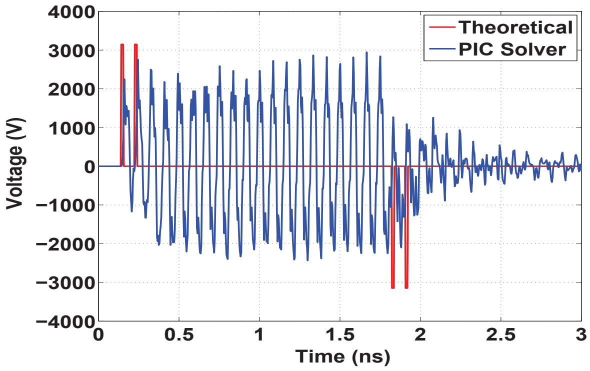

Figure 6: Stripline BPM raw output.

However, passing this pickup signal through an ideal 40MHz low-pass network, similar to that of the read-out electronics, returns the expected baseband waveform (Fig. 7). This is not surprising, as the ideal low-pass filter in the simulation is perfectly attenuating all high frequencies, including 12GHz. In practice, the prototype BPM can be still made operational, a dedicated external 12GHz notch filter will be mandatory however.

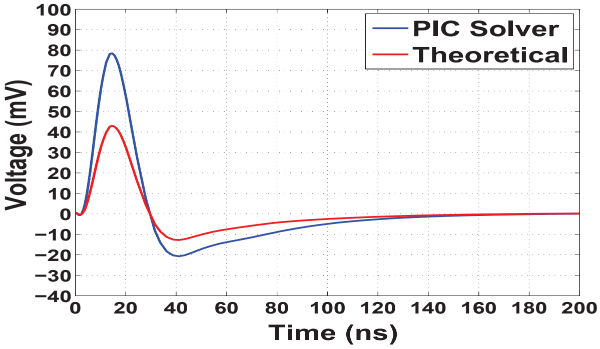

Figure 7: Filtered signals at the output of the readout electronics for simulated (blue) and ideal (red) cases.

CONCLUSIONS AND FUTURE WORK

Due to the described geometry constraints and the frequency shift caused by the damping material, the tested prototype is conceptually not behaving close to an ideal stripline BPM at high frequencies. We do not expect a sufficient filtering of 12GHz CLIC DB beam harmonics by this first DB stripline BPM prototype. However, the pickup may still operate very well as BPM, assuming we will be able to provide a sufficient external 12GHz notch filter solution.

The presented results have to be confirmed by beam tests in CTF3, foreseen for late 2012. More studies, including other BPM pickup solutions will be performed in the future.

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