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CHARACTERIZATION TESTS OF A STRIPLINE BEAM POSITION MONITOR FOR THE CLIC DRIVE BEAM

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INTRODUCTION

CLIC, an electron-positron linear collider proposed to probe the TeV energy scale, is based on a two-beam scheme where RF power 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 operating close to the Power Extraction and Transfer Structures (PETS) and the accuracy requirements are demanding (20µm). They must be compact, inexpensive and operate below waveguide cut-off to ensure locality of position signals, ruling out processing at the natural 12GHz bunch spacing frequency. Also wakefields, and hence longitudinal impedance, must be kept low. A compact conventional stripline BPM with signals processed below 40MHz was found to meet requirements. Laboratory characterization of the manufactured prototype and the designed analog readout chain is needed before testing the system with beam at the 3rd CLIC Test Facility (CTF3). We have focused on electronics performance, system linearity and sensitivity parameters.

SYSTEM DESIGN

Stripline BPM

The designed model is compact, built into the quadrupole vacuum chamber, each electrode with an angular coverage of 45º, a characteristic impedance of 50Ω and electrode length L, of 25mm. The transfer function of the BPM has nulls at multiples of c/(2L), including at the natural bunch spacing frequency of 12GHz. L is chosen so that the response to a multi-bunch train only shows the first and last pair of bunches, being the rest cancelled (Fig. 1). Other relevant design parameters are summarized in Tab. 1.
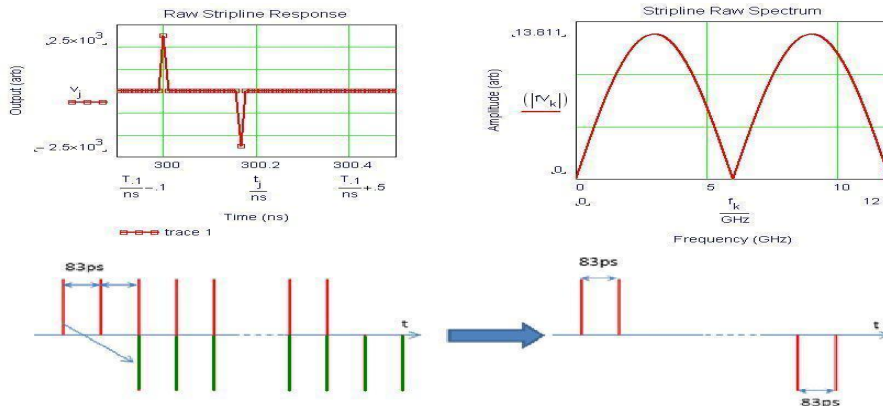

Figure 1: Impulse response, transfer function and train response of the CLIC Drive Beam Stripline BPM.

Table 1: Drive Beam Stripline BPM Parameters

Parameter	Value	Comment
Diameter	24 mm	Stripline ID
Stripline length	25 mm	
Width	12.5 %	of circumference
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, between 4 and 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 for a full multi-bunch train is estimated in a stripline BPM as x=(r/2)Δ/Σ, being r the pipe radius and Δ and Σ the difference and sum of opposed electrode signals. Further details of the design can be found in [1].

Readout Electronics

An analog shaping circuit, mainly an integration/low-pass filtering, is needed to perform a correct acquisition of the electrode signals, since the pulses at the output doublet are expected to be very intense and narrow in the presence of a beam with a 240ns train of bunches and 10ps bunch length. The resulting electrode signal should reflect beam position and intensity during the passage of a multi-bunch train, but should return to zero in time to allow acquisition of the next train.

The combination of filters found in simulations to perform an optimal shaping is the following: a 4MHz 1st order low-pass filter, a 20MHz 1st order low-pass filter and a 35MHz 2nd order low-pass filter. A scheme of the BPM readout chain is presented in Fig. 2.

In order to guarantee a good impedance matching in the processing bandwidth, the 2nd-order filter has been implemented as an input diplexer crossing at 35MHz, the 20MHz filter as a bridged-T structure and the 4MHz filter as the feedback loop of the Analog-to-Digital-Converter (ADC) driving amplifier stage, which performs single-ended to differential conversion.

A 14-bit digitizer of up to 125MS/s has been selected, with a ±1V differential input range, from ± 0.4V to ±1.4V. For testing purposes the sampling rate has been set to 96MS/s, synchronized with CTF3 acquisition. With an Effective Number of Bits (ENOB) of 11.8, the ADC noise for the maximum signal in the described input range is about 162μVrms, above 5 times the integrated noise for the analog chain, 30μVrms. Under these conditions, the analog chain will not degrade the acquisition, with the ADC noise being the main contributor to the total noise.

In order to enable acquisition of the lowest charge beams considered for commissioning [2], the inclusion of a programmable attenuator and a Low-Noise Amplifier (LNA) between the 20MHz filter and the ADC driving stage is currently needed, although next generation ADCs with higher dynamic range and better resolution might eliminate this requirement.
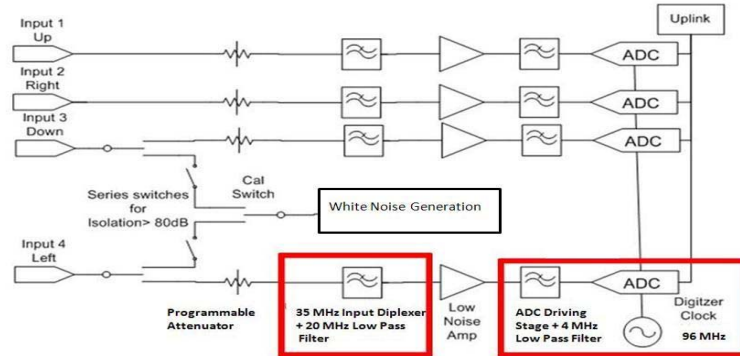

Figure 2: Analog readout chains for each position channel. Only highlighted parts have been implemented for testing.

The extraction of the position signal is done by deconvolution of the theoretical impulse response of the full system, BPM and readout chain, with the acquired multi-bunch train response.

Calibration

Calibration must be performed online and transparently to operations. The selected procedure consists of implementing a 1-bit Digital-to-Analog Converter (DAC) to inject white noise in the processing bandwidth. One electrode of each plane will be used as calibration input for the other plane (Fig. 2).

Resolution

For small deviations around the centre, the expected resolution for a full train is 1.22μm and, for small deviations around the half pipe aperture is about 2.5μm. Resolution measurements are planned with beam, considering the full system noise, not only the contribution of the ADCs. Further improvements are expected with oncoming generations of digitizers.

WIRE CHARACTERIZATION TEST

The full BPM system has been tested in laboratory to check the performance of the electronics and evaluate the linearity, sensitivity, electrical offset and overall precision parameters for each coordinate plane. A 0.2mm diameter wire has been used to emulate the beam passing through the BPM. As it is not currently possible to emulate the CLIC Drive Beam 10ps bunches, a 240ns long pulse has been used as excitation, acting as a multi-bunch train. A stripline BPM behaves as a differentiator at low frequencies, where its transfer function (Fig. 1) can be linearly approximated. The expected output signal of the BPM is then a pair of pulses present during the rise and fall time intervals of the input signal.

As the electronics performs a time integration, any signal shape having the same area provokes the same output signal, as long as it does not spread beyond the time constant of the highest-frequency filter in the chain (4.5ns for the 35MHz filter). Each of the pulses at the electrode output can then emulate, for electronics testing purposes, the positive- and negative-polarity pair of bunches present at the beginning and end of the real multi-bunch train response (Fig. 1).

A fast 10A current generator with 4ns rise time was used to feed an input signal into the test setup, although after impedance matching the current going into the BPM was 1.87A. The acquisition was performed at 96MS/s with 8192 points and an 83μs acquisition window.

The ADC output signals for a centered wire are shown in Fig. 3, having an amplitude maximum of approximately 130mV and performing the required pulse shaping, being able to return to zero at the end of each test pulse.
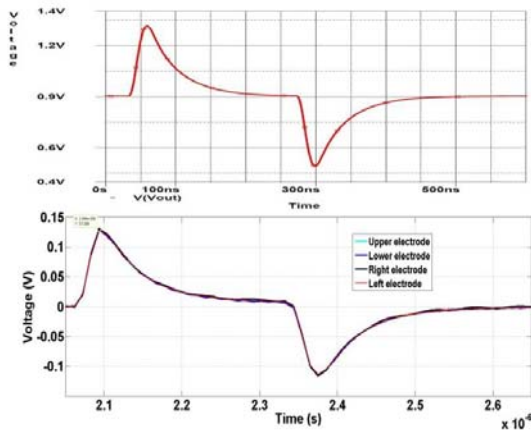

Figure 3: Simulated output signal for a centered multi-bunch beam (top) and measured ADC output signals for a centered wire (bottom).

For linearity tests, the wire was moved in 1mm steps in both planes and measurements were taken in the different positions. Due to limitations of the setup, it was not possible to move the wire further than 4mm in the vertical plane. A linear fit was done for both planes to obtain the sensitivity, the electrical offset, the linearity error (Fig. 4)

and the nonlinearity contribution to the overall precision, giving the uncertainty in the position measurements (Tab. 2).

Table 2: Sensitivity and Linearity Parameters

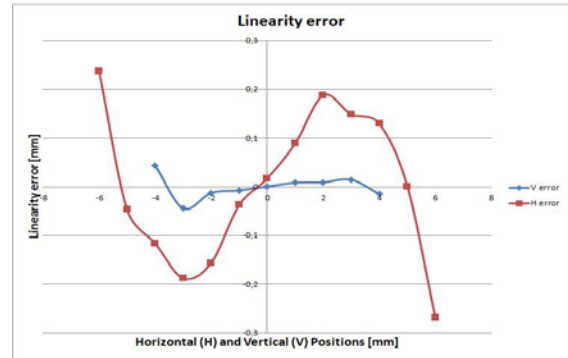| $x_{H,V} = (S_{H,V}^{-1})\Delta/\Sigma + EOS_{H,V}$	
Parameter	Value
V Sensitivity S_V	(119.43 ± 0.40) m^{-1}
H Sensitivity S_H	(114.29 ± 1.37) m^{-1}
V Electrical Offset EOS_V	(0.16 ± 0.01) mm
H Electrical Offset EOS_H	(-0.21 ± 0.05) mm
V overall precision σ_V ($\pm$4mm)	22.89 μm
H overall precision σ_H ($\pm$6mm)	148.84 μm

Figure 4: Linearity error for both planes.

The difference in linearity error between both planes, as well as the lower than expected sensitivity, 166m^{-1} for $\pm$ 6mm, are both currently under study. Gain mismatch between electrodes can be ruled out as the cause after the latest checks, leaving other possible reasons such an improperly centered wire in one of the planes or other setup limitations. Further study is needed to improve these results.

CONCLUSIONS AND FUTURE WORK

The performance of the electronics is satisfactory as the signal shaping and levels are within the expected ones. Tests have also been performed for linearity in the half-aperture range, sensitivity and nonlinearity contribution to the overall precision. Another test is foreseen to align the BPM with the magnetic center of the quadrupole using the same wire to eliminate the alignment error. The longitudinal impedance of the BPM and possible high-frequency effects on the electrode response will be measured using the test bench and method proposed in [3]. These results will have to be confirmed with beam tests in CTF3, scheduled for summer 2012.

REFERENCES

[1] S. Smith, et al., "CLIC Drive Beam Position Monitor", DIPAC'11, Hamburg, May 2011, TUPD13.

[2] CLIC Conceptual Design Report (CDR), Volume I, Section 5.16.7.1, Geneva, 2012.

[3] J.J. García-Garrigós, et al., "High Frequency Measurements of the Beam Position Monitors for the TBL Line of the CTF3 at CERN", DIPAC'11, Hamburg, May 2011, TUPD16.