DESIGN AND MEASUREMENTS OF THE STRIPLINE BPM SYSTEM OF THE ESS-BILBAO

D. Belver*, F.J. Bermejo, J. Feuchtwanger, N. Garmendia, P.J. Gonzalez, L. Muguira, S. Varnasseri, ESS-Bilbao, Leioa, Spain
V. Etxebarria, J. Jugo, J. Portilla, University of the Basque Country, UPV/EHU, Leioa, Spain

Abstract

A new design for the Beam Position Monitors (BPMs) diagnostics of ESS-Bilbao, consisting of a whole block of stripline sensors, has been designed and manufactured. The design is based on travelling wave principles to detect the position of the beam in the vacuum chamber. The length of the stripline is 200 mm and the coverage angle is 0.952 rad. The position of the internal tube simulating the beam can be changed with respect to the outer tube within a range of 20 mm approximately for both X and Y axis, with a resolution less than 10 μm. The characteristics of the block with and without beam are measured and evaluated at frequencies of 175 and 352 MHz, using the electronics system developed for the BPM capacitive pick-ups. This electronics system is divided in an Analog Front-End (AFE) unit, where the signals are conditioned and converted to baseband, and a Digital Unit (DU) to sample them and calculate the position and phase of the beam. In this contribution, the performed tests will be fully described and the results also discussed.

INTRODUCTION

In the framework of the future ESS-Bilbao (ESSB) [1] accelerator facility, the Control and Diagnostics group of ESSB is developing several activities in collaboration with the Department of Electricity and Electronics of the University of the Basque country (UPV/EHU). The project of Beam Position Monitors (BPMs) is one of the open issues within the development of the diagnostics system. The BPMs system includes both the already tested capacitive pick-ups design [2] and also the new stripline one. This stripline design and the validation measurements are presented in the next sections.

The implementation of this BPM system includes the pick-ups and stripline BPMs, the test stand for simulating beam conditions, the analog and digital electronic units and the control system [2]. The control system integrates the BPM system into the *Experimental Physics and Industrial Controls System* (EPICS) [3] network of the accelerator.

EXPERIMENTAL SETUP

In order to validate and characterize the stripline BPM design, different types of measurements have been carried out using the BPM test stand at 175 and 352 MHz to compare with previous results [2, 4]. The experimental setup consists of two main parts:

- A 4-electrode stripline BPM assembled in our test stand, where the relative position of the internal tube simulating the beam can be changed with respect to the outer tube.
- The electronic system, divided in two parts. An Analog Front-End (AFE) where the signals will be filtered, conditioned and converted to base-band and a Digital Unit (DU) to sample the base-band signals and calculate the beam position, amplitude and phase.

For the tests with the stripline BPM, a local PC connected to a FPGA board from Lyrtech [5] was implemented in order to control and monitor the system in a MATLAB®-Simulink environment.

Stripline BPM Design

A stripline BPM was designed and fabricated at ESSB and UPV/EHU. The design is based on travelling wave electrodes principles to detect the transverse position of the beam in the chamber with a delta-over-sigma (Δ/Σ) algorithm [6]. In the design of the stripline, it has been considered to keep the comparison conditions to pick-up assembly [2] as similar as possible, since one of the objectives was to compare the functionality of stripline and pick-ups.

The stripline is designed for the rf frequency of ESSB, 352 MHz. However it can function on a wide range of frequencies out coming from the measurement results. Striplines in general have well defined behavior even for low beta and low intensity beams, as well as functionality at low and high frequencies [6]. Using the SUPERFISH code [7], the electromagnetic behavior of the whole stripline set is analyzed in order to find the optimum physical dimensions of the strips along the tube. Furthermore, the dimensions and physical property of the feedthrough and transition from strips to the outside N-type connector are simulated in the electromagnetic code.

The tube chamber inner diameter of the stripline set is 57 mm, and the length of electrodes is 200 mm. The transverse plane of the stripline is rotationally $\pi/2$ symmetric and in ideal case the response of all electrodes are identical. The coverage angle for the four-electrode configuration is 0.952 rad per electrode. Increasing the angular coverage could deteriorate the signal integrity due to coupling between adjacent electrodes. The whole assembly is fabricated with a $\pi/4$ radians rotation, in order to fit easily on the test stand. Figure 1 shows a picture of the stripline BPM, showing the four electrodes and the position of the N-type connectors.

* dbelver@essbilbao.org

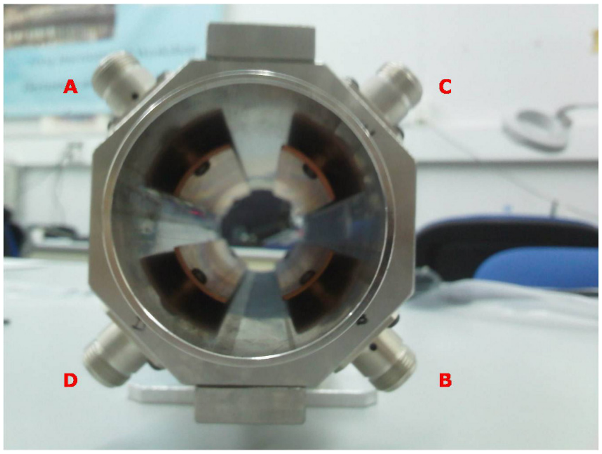

Figure 1: Internal view of the assembled stripline in the laboratory, showing the position of the 4 electrodes.

BPM Test Stand

In order to test the BPMs system, a test stand [2] has been developed by ESSB and UPV/EHU for assembling both BPMs. With striplines an internal tube is assembled inside the four electrodes. The relative position of the internal tube simulating the beam can be changed with respect to the outer tube within a range of ~20 mm for both X and Y axis with a positioning resolution less than 10 μm.

BPM Electronics System

The AFE unit is where the RF BPM signals will be filtered, conditioned and converted to base-band. It is based on the ESSB *Low Level RF* (LLRF) system [8], including two in-house modules. One is a 4-channel high dynamic range logarithmic amplifier (AD8310) board measuring the position of the beam, with a bandwidth up to 440 MHz. The other is an IQ demodulator (AD8348) board fed by the sum of the four signals provided by the electrodes measuring the amplitude and phase of the beam.

The DU is used to sample the base-band signals, providing the beam parameters through different blocks: the phase (arctan(Q/I)) and position (Δ/Σ algorithm). It includes the FPGA and the Analog to Digital Converters (ADC) in a cPCI VHS-ADC board from Lyrtech [5] (14 bits resolution sampling up to 105 MHz) with an extra 8-channel ADC card, based on a Xilinx [9] Virtex-4 FPGA.

PRACTICAL RESULTS

The stripline BPM system has been tested using the described test stand and the electronic units, measuring the sensitivity of the stripline, its position and phase resolution and the stability. The test stand is connected to the AFE unit. Some RF equipments are required to simulate the beam at 175 and 352 MHz, working always in CW mode.

Sensitivity of the Stripline BPM

The Δ/Σ method is used for the interpretation of the signals from the four electrodes. However, it is possible to have different expressions to interpret the estimated electrode signals. The beam pipe polar symmetry would have a positive impact on the linearity of the sensitivity curves. The electrical beam position of center-of-mass is given by:

$$X = \frac{\Delta_x}{\Sigma} = \frac{(U_a + U_d) - (U_b + U_c)}{U_a + U_b + U_c + U_d} \tag{1}$$

$$Y = \frac{\Delta_y}{\Sigma} = \frac{(U_a + U_c) - (U_b + U_d)}{U_a + U_b + U_c + U_d} \tag{2}$$

where U_a, U_b, U_c and U_d are the voltage measured at the four electrodes (see Fig. 1). The physical beam position (x,y) is derived from a polynomial function of the electrical beam position (X,Y) by the following equations:

$$x = F_x(X, Y) = k_x \cdot X + \delta_x \tag{3}$$

$$y = F_y(X, Y) = k_y \cdot Y + \delta_y \tag{4}$$

The monitor constants $k_{x,y}$ are a characteristic value of a stripline and they are related to the sensitivities $S_{x,y}$:

$$k_{x,y} = \frac{1}{S_{x,y}(0,0)} \tag{5}$$

Table 1 shows the sensitivities $S_{x,y}$ for both frequencies. No major differences in sensitivities are found for the stripline, obtaining values between $0.07 < S_{x,y} < 0.08$ mm^{-1}.

Table 1: Stripline Sensitivities at 352 and 175 MHz

f (MHz)	S_x [mm^{-1}]	S_y [mm^{-1}]	δ_x	δ_y
352	0.0716	0.0703	11.96	11.25
175	0.079	0.075	12.36	11.814

Resolution and Stability

The position resolution of the stripline system is extracted from several input signal levels of the log amp ranging from -90 to -20 dBm. This was done for both 175 and 352 MHz. Fig. 2 shows the results for a frequency of

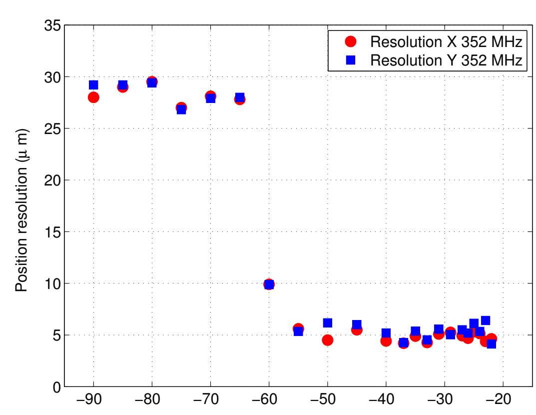

Figure 2: Position resolution $\sigma_{x,y}$<6.4 μm for signals higher than -55 dBm at the AFE input, at 352 MHz.

352 MHz, providing a rms stability of less than 6.4 μm in both planes for log amp inputs higher than -55 dBm. This corresponds to -43 dBm at the input of the stripline block. The required resolution (10 μm) is achieved for a wide dynamic range of more than 60 dB. The position resolution has been extracted from 10k continuous samples in a similar environment condition.

Table 2 shows the results for the position and phase resolution and the position stability. f represents the frequency of the excitation signal and P_{in} the power of the signal at the input of the electronics. These results are similar at both frequencies, fulfilling our requirements. The resolution and accuracy indicate that with this solution the effect of several errors such as temperature variations and nonlinearities are minimized through temperature regulation and system calibration.

Table 2: Resolution and Stability for Position and Phase

CW mode, f=352 MHz, P_{in}=-24 dBm

Parameter	Measure	Requirement
X position resolution	6.4 μm	10 μm
Y position resolution	5.7 μm	10 μm
X position stability	23 μm	100 μm
Y position stability	23 μm	100 μm
Phase resolution	<0.1°	0.3°

CW mode, f=175 MHz, P_{in}=-24 dBm

Parameter	Measure	Requirement
X position resolution	5.7 μm	10 μm
Y Position resolution	6.3 μm	10 μm
X position stability	12 μm	100 μm
Y position stability	14.4 μm	100 μm
Phase resolution	<0.1°	0.3°

For the position and phase resolution data at both frequencies, the rms values are less than 6.4 μm for the position and less than 0.1 ° for the phase (see Table 2). The input power of the stripline block was -6 and -12 dBm at 175 and 352 MHz, respectively, just because the impedance matching is different for both frequencies. These levels correspond in both cases to -24 dBm at the log amp input.

For the long-term stability measurements [10] at both frequencies, the system was tested continuously for several hours monitoring the temperature but without any air temperature control. No meaningful correlation between temperature variation (4.5°C) and position stability readings was found. The results of these measurements at both frequencies are summarized in Table 2, showing rms values for the position stability less than 25 μm for both planes.

The minimum position resolved has been also analyzed by changing the position in small steps (5-10 μm). Figure 3 shows that these microsteps can be easily detected, being in good agreement with the previous analysis.

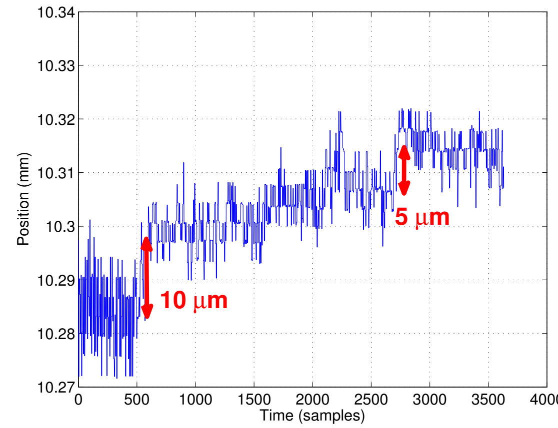

Figure 3: Sensitivity of the stripline system (up to 5 μm).

SUMMARY AND CONCLUSIONS

The design, fabrication and characterization of the stripline BPM developed by ESSB in collaboration with the Electricity and Electronics Department of the UPV/EHU have been presented. The new design has been characterized with extensive measurements, fulfilling our requirements at both frequencies. The whole beam positioning system measurements using the BPM test stand and the electronic units show good stability and position resolution which are less than 25 μm and 6.4 μm, respectively, for both frequencies. The phase resolution is less than 0.1°.

REFERENCES

[1] ESS-Bilbao Team, "ESS-Bilbao light-ion linear accelerator and neutron source: design and applications", Journal of Physics: Conference Series 325 (2011), 012003.

[2] D. Belver et al., "Overview of the BPM system of the ESS-Bilbao", MOPD21, Proceedings DIPAC'11, Hamburg, Germany, May 2011, pp. 89-91.

[3] EPICS, `http://www.aps.anl.gov/epics`.

[4] D. Belver et al., "Test of the Front-End Electronics and acquisition system for the LIPAC BPMs", TUPC125, Proceedings IPAC'11, San Sebastian, Spain, September 2011, pp. 1311-1313.

[5] Lyrtech, `http://www.lyrtech.com/`.

[6] R. Shafer, "Beam Position Monitoring", American Institute of Physics Proceedings, vol. 212, New York, 1990, pp. 2658.

[7] SUPERFISH, `http://laacg1.lanl.gov/laacg/services/download_sf.phtml`.

[8] H. Hassanzadegan et al., "Design and Implementation of a Pulsed Digital LLRF System for the RAL Front End Test Stand", TUPEA055, Proceedings IPAC'10, Kyoto, Japan, May 2010.

[9] Xilinx, `http://www.xilinx.com/support/documentation/virtex-4_user_guides.htm`.

[10] G. Vismara, "Signal Processing for Beam Position Monitors", AIP Conf. Proc. 546 (2000) pp. 36-60.