

TEST OF THE FRONT-END ELECTRONICS AND ACQUISITION SYSTEM FOR THE LIPAC BPMS*

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Abstract

Non-interceptive Beam Position Monitors pickups (BPMs) will be installed along the beamlines of the IFMIF/EVEDA linear prototype accelerator (LIPAC) to measure the transverse beam position in the vacuum chamber in order to correct the dipolar and tilt errors. Depending on the location, the BPMs response must be optimized for a beam of 175 MHz bunch repetition, an energy range from 5 to 9 MeV, a current between 0.1 and 125 mA and continuous and pulse operation. The requirements from beam dynamics for the BPMs are quite stringent, aiming for the position an accuracy below 100 μm and a resolution below 10 μm , and for the phase an accuracy below 2° and a resolution below 0.3°. To meet these specifications, the BPM electronics system developed by ESS-Bilbao has been adapted for its use with the BPMs of LIPAC. 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. The electronics system has been tested at CIEMAT with a wire test bench and a prototype BPM. In this contribution, the tests performed will be fully described and the results discussed.

INTRODUCTION

Inside the new ESS-Bilbao (ESSB) linac facility [1], a BPM electronics and acquisition system has been developed by ESSB in collaboration with the Electricity and Electronics Department of the UPV-EHU University. The BPM system developed consists of the analog front-end electronic (FEE) boards [2], the digital processing board [2] and also the corresponding control system [3].

Although this system has been designed in order to meet the ESSB linac requirements [2], it has been adapted for its use with the LIPAC BPMs [4]. In order to validate the system, extensive measurements have been carried out at CIEMAT, using the CIEMAT BPM wire test bench [5]. The use of the ESSB electronics and the CIEMAT test bench will allow the full characterization of the Linear IFMIF Prototype Accelerator (LIPAC) BPMs in the future, before its final installation in the machine.

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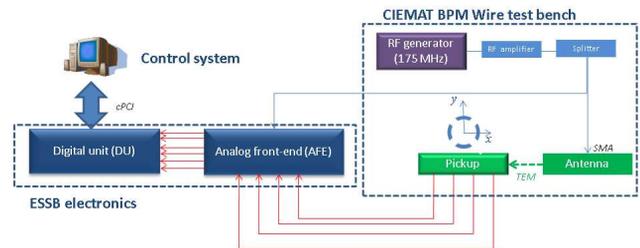


Figure 1: Picture of the experimental setup in the CIEMAT, showing the test bench and both the AFE and the DU.

SYSTEM DESCRIPTION

The experimental setup used consists of the following main parts (see Fig. 1):

- The wire test bench. A real LIPAC BPM is tested with a movable thin wire that simulates the beam.
- The electronics system. It is divided into two parts, the Analog Front-End (AFE) where the signals will be filtered, conditioned and converted to base-band and the Digital Unit (DU) to sample the baseband signals and calculate the beam position, amplitude and phase.
- The control system. It is based on the high performance FPGA of the DU, connected to a Host PC which works as an EPICS (*Experimental Physics and Industrial Controls System* [6]) server. The communication between both parts is made by a register bank implemented in the FPGA, being accessible using a Compact PCI bus (cPCI). However, to make more flexible the operation during these tests an alternative MATLAB based acquisition system has been used.

Wire Test Bench

A thin wire is used to create a TEM field in the coaxial formed by the wire and a real LIPAC BPM. This signal is used to simulate the beam excitation at different frequencies. In our case the frequencies of interest are 175 MHz and 350 MHz. The excitation signal at those frequencies is generated with an RF generator. To overcome the power limitation of the generator, an amplifier is placed downstream the generator, feeding the antenna with 25 dB more.

A prototype BPM [5] of the one that will be installed inside the superconducting RF (SRF) linac is installed, being similar to the one used in the cold areas of the LHC. Since

this BPM is well characterized and the results can be compared [7]. Two micromovers in perpendicular directions displace the wire along x and/or y directions, allowing to locate the wire with a repeatability smaller than $1 \mu\text{m}$.

Analog Front-End Unit

The Analog Front-End (AFE) unit [2] (see Fig. 1) is where the RF BPM signals will be filtered, conditioned and converted to base-band. This design is based on the ESSB *Low Level RF* (LLRF) system [8], due to its easy and versatile implementation.

The AFE unit is based on two different boards. One is a 4-channel high dynamic range logarithmic amplifier (log amp AD8310) board for measuring the position, being its bandwidth from DC up to 440 MHz. And the other is an IQ demodulator (AD8348) fed by the sum of the four signals provided by the buttons measuring the amplitude and phase of the beam. First each signal is converted from differential to single-ended and then it is sent to the Digital Unit.

Digital Unit

The Digital Unit [2] (Fig. 1) includes the FPGA and the Analog to Digital Converters (ADC) boards in a high performance cPCI VHS-ADC board from Lyrtech with an additional ADC card (8 channels, 14 bits resolution sampling up to 105 MHz) based on a Xilinx [9] Virtex-4 FPGA.

The output signals of the AFE unit will be sampled by the ADCs and processed by the FPGA. The FPGA includes the linearization (non-linear correction to measure properly non-centered beams) and calibration of the signals to compensate the effect of several errors which can degrade the precision of the measurements. This unit includes the offset compensation and different blocks to obtain both the beam phase ($\arctan(Q/I)$) and the position (Δ/Σ algorithm [10]).

PRACTICAL RESULTS

Sensitivity of the BPM

The test bench has been used in order to measure the relation between the variation of measured position signal and real position movement. The signal generator supplied a sinusoidal signal of either 175 or 350 MHz, working always in CW mode. In the center region of the pickup, the position is related to the measured button signal as:

$$x = k_x \frac{\Delta_x}{\Sigma'}, \quad y = k_y \frac{\Delta_y}{\Sigma''} \quad (1)$$

where k_x and k_y are the pickup sensitivities (inverse). The normalized differential buttons responses for each direction are then calculated as:

$$\frac{\Delta_x}{\Sigma'} = \frac{U_{right} - U_{left}}{U_{right} + U_{left}} \quad (2)$$

$$\frac{\Delta_y}{\Sigma''} = \frac{U_{up} - U_{down}}{U_{up} + U_{down}} \quad (3)$$

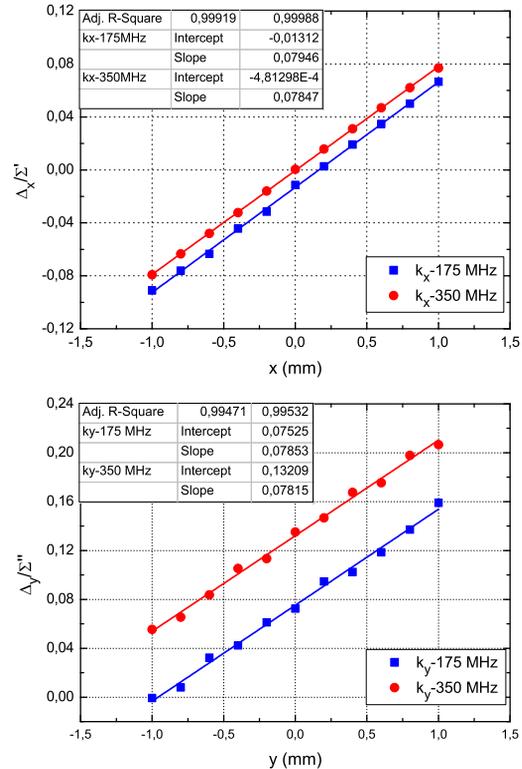


Figure 2: Sensitivity of the BPM for both directions (x and y). Up: $k_x=12.58 \text{ mm}$ (175 MHz) and $k_x=12.74 \text{ mm}$ (350 MHz). Down: $k_y=12.73 \text{ mm}$ (175 MHz) and $k_y=12.79 \text{ mm}$ (350 MHz).

where U_{right} , U_{left} , U_{up} and U_{down} are the voltages measured at each of the four electrodes.

Fig. 2 presents the sensitivity of the wire test bench. Upper figure shows the sensitivity in x direction, obtaining a $k_x=12.58 \text{ mm}$ (inverse) for a frequency of 175 MHz and $k_x=12.74 \text{ mm}$ (inverse) for 350 MHz. The lower figure shows the sensitivity in y direction, obtaining a $k_y=12.73 \text{ mm}$ (inverse) for a frequency of 175 MHz and $k_y=12.79 \text{ mm}$ (inverse) for 350 MHz. A previous measurement process showed a sensitivity of 12.8 mm [5]. The discrepancy in the measurement of k_x at 175 MHz could be a problem from the calibration of the log amp of the FEE.

Resolution and Stability

The minimum position change that could be detected with the ESSB electronics system has been analyzed in two ways. The first measurement was carried out by observing the standard deviation of a series of position data acquired at the center position. In a similar way, the long-term stability [11] has been measured using long-term data (around an hour). The resolution is then affected by drifts in the electronics due to the temperature change (8°C). The results of these measurements are summarized in Table 1. The data sampled at 105 MHz is integrated each $10 \mu\text{s}$.

The measurements have proved that the obtained resolution is better than the requirement one for both frequencies.

Table 1: Resolution and stability for position and phase. f represents the frequency of the excitation signal and P_{in} the power of the signal at the input of the electronic board.

CW mode, $f=350$ MHz, $P_{in}=-25.7$ dBm		
Parameter	Measure	Requirement
X position resolution	4.33 μm	10 μm
Y position resolution	6.19 μm	10 μm
X position stability	13.70 μm	100 μm
Y position stability	20.78 μm	100 μm
Phase resolution	0.1°	0.3°
CW mode, $f=175$ MHz, $P_{in}=-31.7$ dBm		
Parameter	Measure	Requirement
X position resolution	5.48 μm	10 μm
Y Position resolution	6.86 μm	10 μm
X position stability	-	100 μm
Y position stability	-	100 μm
Phase resolution	0.2°	0.3°

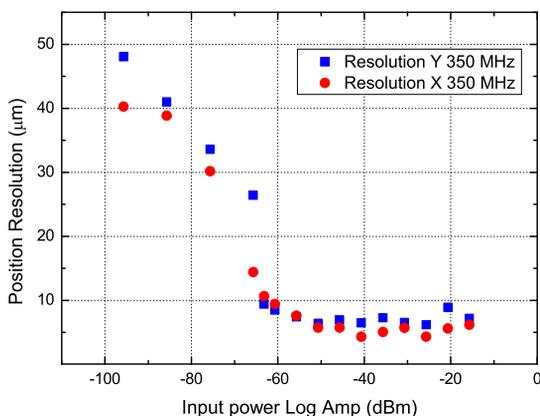


Figure 3: Position resolution at 350 MHz for x (red) and y (blue) directions, showing a position resolution better than 10 μm for signals higher than -60 dBm at the AFE input.

In order to test as well the dependence of the resolution on the signal power, the measurements have been repeated at different input powers (see Fig. 3). The resolution required (10 μm) is achieved for signals higher than -60 dBm, providing a dynamic range of more than 60 dB.

Finally, the minimum position resolved has been analyzed by changing the position in small steps (5-10 μm) during a long acquisition run. As it can be seen in Fig. 4, these microsteps can be easily detected, being in good agreement with the previous analysis.

SUMMARY AND CONCLUSIONS

The ESSB BPM acquisition system has showed that it is able to handle the stringent position and phase require-

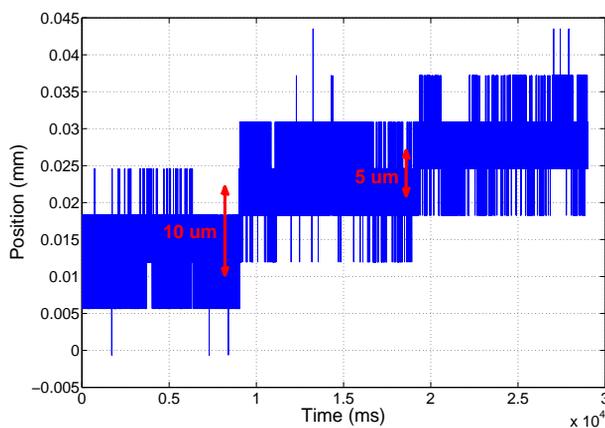


Figure 4: Sensitivity of the BPM electronics (up to 5 μm).

ments of the LIPAC BPMs with an integration time of only 10 μs . Future developments will include an automatic calibration system for the balance in gain and phase of the four acquisition channels (including cables between the BPM sensors and the electronics front-end). Furthermore, new measurements will be carried out including the EPICS control system, mapping tests to characterize the linearity and beam-like signal excitation -instead CW signals- to validate the response of the electronics with a more real signal.

REFERENCES

- [1] ESS-Bilbao Team, “ESS-Bilbao light-ion linear accelerator and neutron source: design and applications”, Journal of Physics CS (in press), 2011.
- [2] D. Belver et al., “Overview of the BPM system of the ESS-Bilbao”, MOPD21, Proceedings of DIPAC’11, Hamburg, Germany, May 2011.
- [3] P. Echevarria et al., “Multipurpose Controller Based on a FPGA with EPICS Integration”, WEOBN4, Proceedings PAC’11, New York, USA, March 2011.
- [4] A. Mosnier et al., “The accelerator prototype of the IFMIF/EVEDA project”, Proceedings of IPAC10, MOPEC056, p.588, Kyoto, Japan, May 2010.
- [5] I. Podadera et al., “Developments for IFMIF/EVEDA LIPAC Beam Position Monitors: the sensors at the MEBT and the wire test bench”, TUPD11, Proceedings of DIPAC’11, Hamburg, Germany, May 2011.
- [6] EPICS, <http://www.aps.anl.gov/epics>.
- [7] C. Boccard, private communication.
- [8] H. Hassanzadegan et al., “Design and Implementation of a Pulsed Digital LLRF System for the RAL Front End Test Stand”, TUPEA055, Proc. of IPAC’10, Kyoto, Japan (2010).
- [9] Xilinx, http://www.xilinx.com/support/documentation/virtex-4_user_guides.htm.
- [10] R. Shafer, “Beam Position Monitoring”, American Institute of Physics Proceedings, vol. 212, New York, 1990, pp. 2658.
- [11] G. Vismara, “Signal Processing for Beam Position Monitors”, AIP Conf. Proc. 546 (2000) pp.36-60.