DEVELOPMENT OF A HIGH DYNAMIC RANGE BEAM POSITION MEASUREMENT SYSTEM USING LOGARITHMIC AMPLIFIERS FOR THE SPS AT CERN

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Abstract

A new Front-End electronics, based on Logarithmic Amplifiers, is currently being developed for the CERN SPS Multi Orbit POsition System (MOPOS). The aim is to resolve the multi-batch structure of the beams and cope with their large intensity range (> 70 dB). Position and intensity signals are digitized in the Front-End electronics installed in the tunnel. The data are then transmitted over a serial fibre-optic link to a VME Digital Acquisition board located in surface buildings. A first prototype, equipped with a calibration system, has been successfully tested on the SPS under different beam conditions, including single bunch, 25 ns and 50 ns bunch trains. The system architecture and the first beam measurements are reported in this paper.

INTRODUCTION

The SPS currently accelerates proton and lead-ion beams. Proton bunch spacing extends from 5 ns up to 23 µs with a bunch charge dynamic range from 0.1 to 50×10^{10}. Pb^{82+} ion bunch spacing can change from 75 ns to 125 ns with bunch charge from 0.01 to 2×10^{10}. The Front-End electronics needs to cope with these dynamic ranges and it must be fast enough to resolve the 2 µs long multi-batch structure of these beams. Within a ±15 mm BPM-aperture, the required resolution should be 0.1 mm in orbit mode, averaging over 1 ms, and 0.4 mm for turn-by-turn acquisitions in trajectory mode.

THE SPS BPM SYSTEM

The MOPOS comprises 216 Beam Position Monitors (BPM) distributed along the SPS accelerator ring. Most of them are single plane shoe-box electrostatic pick-ups, based on linear-cut electrodes. However, in view of a future possible upgrade for two-plane BPMs, the Front-End electronics integrates two processing channels that are based on Logarithmic Amplifiers (Log-Amps). The Front-End board is designed to be located in the tunnel, where a radiation dose rate of 100 Gy/y is expected in the worst condition. For this reason, analogue components, such as Logarithmic Amplifiers, ADC-Drivers and Voltage regulators, as well as several families of Small Form-Factor (SFP) bidirectional optical transceivers have been tested and selected for radiation hardness [1].

Position Measurement Principle

Beam position x can be derived from the logarithmic difference of BPM signals on opposite electrodes A and B as follows:

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$$x = \frac{A-B}{A+B} \Leftrightarrow \frac{A}{B} = \frac{1+x}{1-x}$$

Consider the series expansion of the natural logarithm:

$$\ln\frac{1+x}{1-x} = 2\left(x + \frac{x^3}{3} + \frac{x^5}{5} + \cdots\right)$$

Converting to decibels and using the first term leads to:

$$\log\frac{A}{B} \cong 2\frac{x}{\ln 10}$$

Then, for small beam displacements, the log-ratio gives a good approximation of x:

$$x = \frac{\ln 10}{2}(\log A - \log B)$$

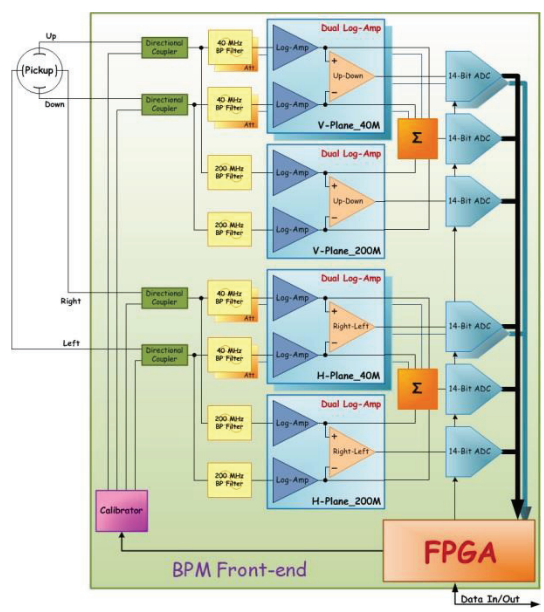

Figure 1: Front-End Prototype block diagram.

Front-End Prototype Architecture

The architecture of the Front-End Prototype is depicted in Figure 1. The signals from each electrode are split into three parallel detection chains with different input filters and gain stages to cover the high dynamic range and the different beam patterns possible in the SPS. Signals from opposite electrodes are processed by the same dual logarithmic amplifier. The resulting position and intensity information is digitized using an octal 14bit-10MSa/s ADC. Finally, the data are serialized and transmitted through an optical fibre link to the VME acquisition electronics located on the surface [2] [3].

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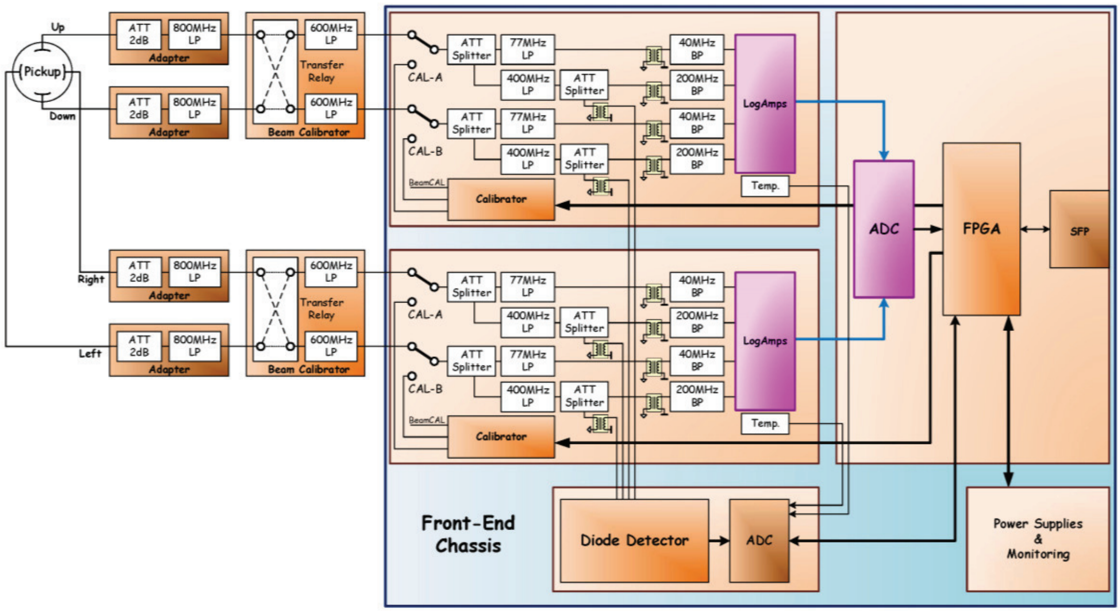

Figure 2: MOPOS Front-End electronics diagram.

MOPOS Front-End Electronics

Figure 2 shows the basic layout of the final Front-End electronics, for a dual-plane BPM. In order to reduce both power dissipation and bunch length dependence during beam acceleration, a low-pass filtering scheme has been distributed over three elements: the pick-up adapter that performs electrode impedance matching, the beam-based calibrator circuit and the input filters in the Front-End chassis. Matched pairs of 40 MHz and 200 MHz band-pass filters then generate suitable signals for the three Log-Amp channels (40 MHz Low and High Sensitivity and 200 MHz) that are required simultaneously to cover the high SPS intensity dynamic range. The sum of all the Log-Amps is used to detect the presence of the beam.

Optional diode detectors [4] are foreseen, in parallel to the logarithmic processing chain, to achieve even more accurate orbit measurements. The resulting digitized data is transmitted via optical fibres over long distances (up to 1 km) to the VME digital acquisition hardware, which is located in 6 auxiliary surface buildings.

The Front-End integrates both internal and beam-based calibration capabilities using RF switches, remotely controlled via the optical link.

FIRST BEAM MEASUREMENTS

A prototype has been assembled and tested on the SPS, with both proton and lead-ion beams, under different conditions, including single bunch, 25 ns and 50 ns bunch trains. The Front-End test setup, as presented in Figure 3, consisted of two Log-Amp boards, an octal-14bit-ADC commercial evaluation board, a calibrator and the FPGA-based acquisition board. Horizontal and vertical beam displacements were acquired from a stripline and a shoe-box BPM respectively.

To characterise the system, local beam displacements, usually called orbit-bumps, were introduced during the SPS machine cycle using dipolar magnetic correctors. An external beam-synchronous pre-pulse, which can be delayed in the FPGA, triggers the acquisition either at injection or during the orbit-bump.

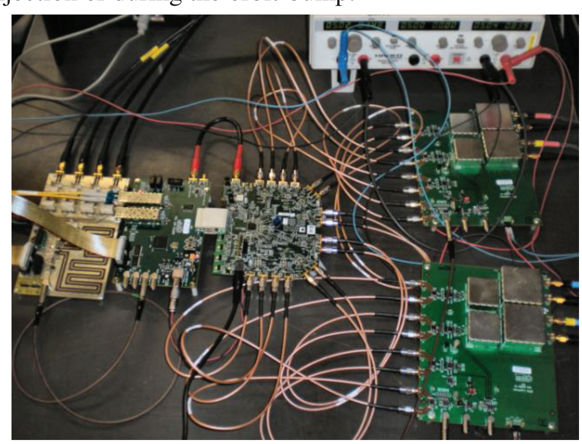

Figure 3: Hardware of the Front-End prototype, which includes 2 Log-Amp boards, 1 octal-ADC, 1 calibrator and 1 FPGA-based acquisition board.

Injection Oscillations

The batches of Pb^{82+} ion beams injected in the SPS contained two bunches with 200 ns spacing. Figure 4 presents the acquisition of a lead-ion beam of 10^{10} charges/bunch, when batch 11 is injected. Notice that batch 11 is off-centre while the others are already centred. For this kind of beam, only the 40 MHz High-Sensitivity channel provided useful data; the other channels were dominated by the noise of the Log-Amps and the associated ADC-Drivers.

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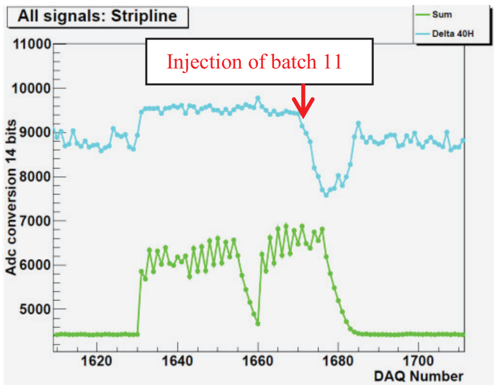

Figure 4: Lead-ion beam horizontal injection acquisitions.

Proton beam injection acquisitions have also been measured and are displayed in Fig. 5. The top plot presents typical single-bunch oscillations observed at injection on the stripline pick-up using the 40 MHz high sensitivity mode. These oscillations are usually damped within 1ms when the transverse damper is active. The bottom plot shows the beam position and intensity signals of 4 batches containing 36 bunches with 50 ns bunch-spacing and 1.4×10^{11} protons/bunch. The measurement was done during the injection of the 4th batch, which is clearly off-centre with respect to the other batches.

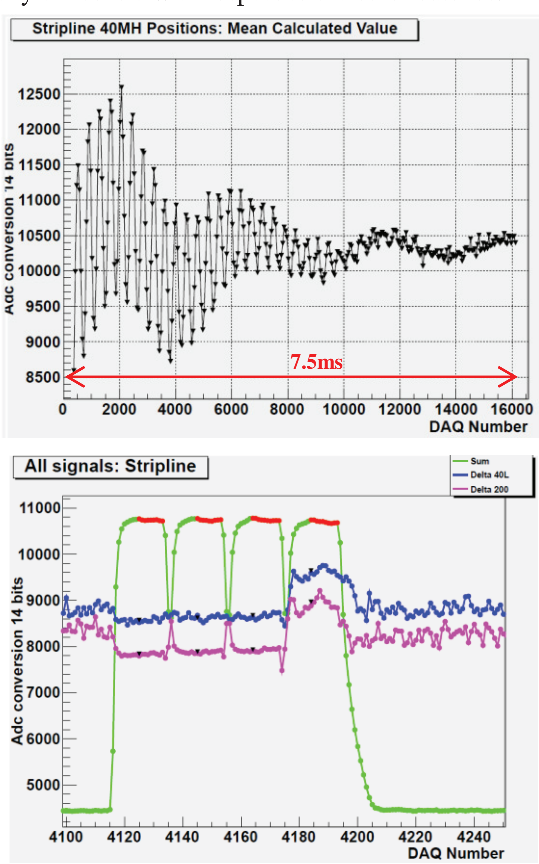

Figure 5: Proton beams. (Top) Single-bunch horizontal injection oscillations. (Bottom) Intensity and position signals of 36 bunch-batches with 50 ns-spacing, during the 4th batch injection.

Local Beam-Bumps

In order to characterise the sensitivity of the system, local beam displacements of ±1 mm, ±2.5 mm and ±5 mm have been generated in the vicinity of the BPMs. Figure 6 presents the SPS optics plots that show the beam offset related to the correctors, at the position of the BPMs. The maximum vertical movement is directly observed by the shoe-box pick-up BPV.42108. However, the horizontal measurement on the stripline BPCL.42171 needs to be corrected, since the maximum offset is programmed to be located at the position of the shoe-box BPH.42208, as indicated on bottom plot. Bumps are triggered at 1s after injection and consist of a 200 ms-long plateau with 100 ms rise and fall times.

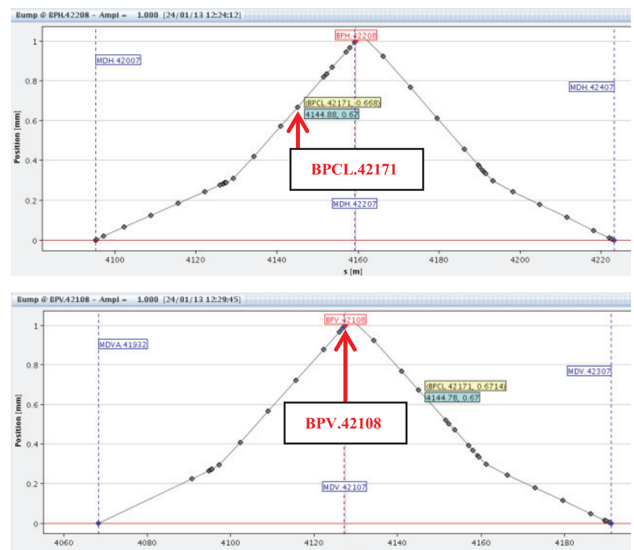

Figure 6: Local beam bumps, either in the horizontal or the vertical plane, are generated using beam corrector elements.

A summary of the bump measurements on single-bunch proton beams is reported in Table 1. The analogue noise on the 40 MHz high-sensitivity channel was estimated at 150 ADC-bins on a turn-by-turn basis in the worst case, which means about 375µm for the vertical measurements. This noise level needs to be reduced in order to improve the performance of this channel.

Table 1: Single-bunch results in High-Sensitivity

TestHCA4/LogBumpProtonSb.csv							
H [Stripline]; V [Shoe-box]							
	-5mm	-2.5mm	-1mm	+1mm	+2.5mm	+5mm	AVG
Sensitivity um/bin H	1.8	1.7	1.8	2.0	1.7	1.8	1.8
Sensitivity um/bin V	2.3	2.5	2.6	2.6	2.4	2.4	2.5

A proton beam of 48 bunches per batch with 25 ns bunch-spacing and 1.4×10^{11} charges/bunch has been used to characterise the 200 MHz and 40 MHz Low-Sensitivity channels. Figure 7 shows acquisition examples from both the stripline and the shoe-box pick-ups for three different beam positions.

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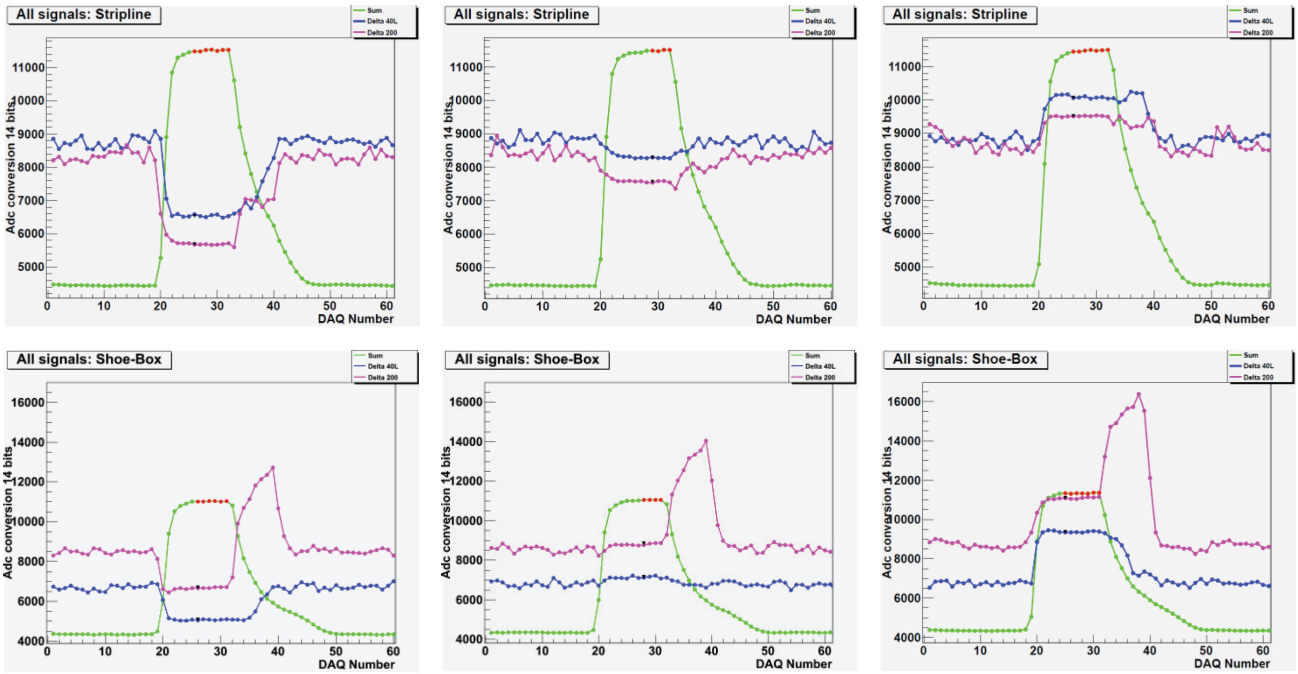

- 5mm 0 mm + 5mm

Figure 7: Data acquisitions, without (0mm) and with ±5mm beam-bumps.

The measurements that were performed on multi-bunch proton beams, using the low-sensitivity channels, are summarised in Table 2. These results confirm that the sensitivity is about 1.7 µm/bin for the stripline and 2.5 µm/bin for the shoe-box, which reflect different BPM apertures. Noise levels, including beam position jitter, limit the estimated resolution to 360 µm in trajectory mode and 80 µm in orbit mode, in the worst conditions.

Table 2: Multi-bunch results in Low-Sensitivity.

TestHCA4/LogBumpProtonMb48_25_selected.csv							
H [Stripline]; V [Shoe-box]							
	-5mm	-2.5mm	-1mm	+1mm	+2.5mm	+5mm	AVG
Sensitivity um/bin H 40L	1.9	1.9	1.5	1.7	2.1	1.8	1.8
Sensitivity um/bin H 200	1.8	1.7	1.4	1.6	1.9	1.7	1.7
Sensitivity um/bin V 40L	2.3	2.4	2.6	2.6	2.2	2.3	2.4
Sensitivity um/bin V 200	2.2	2.3	2.6	2.4	2.1	2.2	2.3

CONCLUSION

A prototype of the new MOPOS electronic system, based on Logarithmic Amplifiers, has been fully tested in the CERN-SPS, allowing the observation of proton and lead-ion beams under various different beam conditions. Using local orbit bumps, the resolution of the system was estimated to 375 µm for turn-by-turn acquisitions and 80 µm in orbit mode, which agrees with the specifications. The system is now being optimized to improve the sensitivity for low charge beams. Our aim is to launch the production of a pre-series to be installed in 2014.

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