A NEW ANALOGUE ACQUISITION FOR THE BPM OF CERN PS

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Abstract

The bunch-by-bunch and turn-by-turn beam trajectory measurement system of the CERN PS accelerator has been in operation for several years. To ensure long-term reliability, the consolidation of the analogue acquisition chain is foreseen during the upcoming LS3 long shutdown including a new architecture with improved performance, which is currently under test in the PS accelerator for final validation. The key element is a custom-designed high impedance head amplifier, replacing the 50Ω amplifier used by the current system, with the advantage of improving, at the same time, bandwidth, dynamic range and noise level. Increased dynamic range opens the possibility of measuring longer acceleration periods without gain switching and better resolution. Increased bandwidth allows the measurement of more beam configuration, in particular with shorter bunch to bunch distance. However, improved performances come at the expense of placing active electronics close to the beamline, in locations with significant radiation exposure, therefore requiring radiation-tolerant electronics. An overview of the PS trajectory system is presented, with the focus on the design of the new analogue acquisition, along with the preliminary bench and beam measurement results.

INTRODUCTION

The CERN PS accelerates either protons from 1.4GeV or ions from 48MeV/u eventually delivered to the downstream accelerators (SPS and AD) and to experimental areas [1]. The bunch intensity range is from $5{\cdot}10^9$ to $\sim 10^{13}$ charges per bunch with a minimum bunch to bunch spacing of 25ns. A versatile RF system allows complex bunch manipulations like merging, compression, splitting and rotation.

For the observation of the beam position 43 electrostatic type pickups, commissioned in the '90s, are installed in the straight sections along the machine. The shape of the four electrodes (Fig. 1) gives a linear, compact (166x80mm aperture, 62mm lenght) and dual-plane position detector [2].

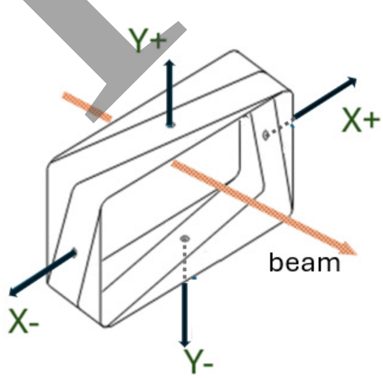

Figure 1: Pickup electrodes.

Each electrode forms a capacitive device with the grounded but not shown surrounding chamber, developing a signal with amplitude proportional to the centre of charge position [2].

Ideally the BPM system should measure the beam position of the individual bunches turn by turn, on every beam configuration and along all the beam cycle from injection to extraction, following the RF beam manipulations. This specification leads to challenging requirements on the acquisition system because of the variety of beam conditions present in the PS. The analogue acquisition's first requirement is a bandwidth wide, flat and extended also at low frequency. This condition is necessary to limit distortion of the time domain response with the consequent possible overlap of signals belonging to different bunches. The second important requirement is a wide dynamic range, ideally allowing the acquisition of the full accelerating cycle without using gain switching that may cause the loss of bunch synchronization.

The system in use can operate without gain switching on regions of the accelerating cycle (i.e. injection, extraction, etc.) but with limited performance if setup to acquire the full cycle. Moreover, bandwidth limitation on both analogue and digital acquisition hinders position measurement when bunch spacing is less than 100ns.

ACQUISITION ARCHITECTURES

The analogue acquisition of an electrostatic pickup can be classified depending on the impedance loading of the electrodes. Depending on this characteristic there are several consequences on both the design of the acquisition and the system performances [3].

Low Impedance (Low-Z) Architecture[1]

In the low impedance case (below ~1kΩ loading impedance), like the PS BPM system in operation (Fig. 2) with 200Ω loading impedance, the main advantage is a relative freedom in the location of the amplifier (e.g. low/free radiation zone), provided that the amplifier input is well matched to the connection line.

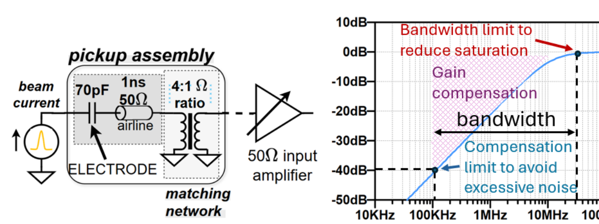

Figure 2: Simplified PS low impedance configuration and frequency response before gain compensation.

[1] 0Ω impedance (i.e. charge amplifier) is a separate case that is more like the high impedance case in terms of positioning constrains and features

The limitation comes from the high pass frequency response of the electrode with the cutoff (8MHz in the PS Low-Z BPM case) defined by the capacitive source impedance and the resistive component of its load. The high pass response requires an active compensation to obtain, at the output of the analogue chain, an overall response flat. At low frequency the extension of the compensation must be limited to avoid excessive output noise despite the use of a low noise amplifier. The high frequency response must also be limited because of the reduced dynamic range intrinsic of the low noise amplifiers. By doing so the risk of saturation is reduced when the bunch length is shortened and its peak amplitude increases.

High Impedance (Hi-Z) Architecture

For the consolidation of the PS BPM system a variant of the high impedance (hundreds of kΩ) architecture has been chosen to improve the system performance. However, because a transmission line with impedance higher than few hundreds ohm is unfeasible, the "basic" Hi-Z configuration requires the amplifier to be placed close to the pickup to avoid resonances due to the long line effects[2] in the pickup to amplifier connection.

In the PS this would imply having active electronics operating in a very severe condition for the semiconductors, with radiation levels in the order of 10kG/year. This level has been reduced by a factor 20 installing the electronics one meter below the pickup using 1.25m long (75Ω, 5ns delay) radiation resistant and low capacitance coaxial cables for the connection (Fig. 3). The frequency dependent impedance loading of the electrode is about 100kΩ at low frequency and 75Ω at high frequency thanks to the AC termination needed to avoid the long line effect that would start from about 10MHz, well into the required system passband.

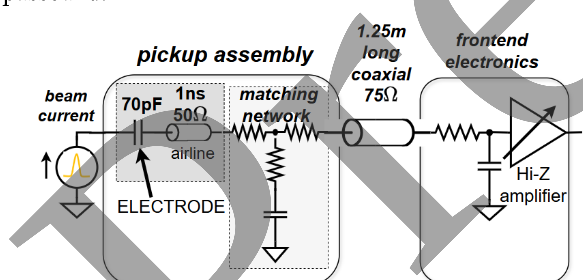

Figure 3: Analogue acquisition frontend blocks diagram.

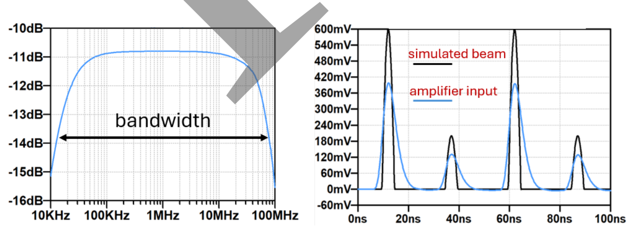

Figure 4: Beam signal to amplifier input frequency and time domain responses.

To keep the frequency response flat and maintain time domain response undistorted (fig. 4), the matching network installed on the pickup must provide the high frequency attenuation required to match the low frequency response. With the chosen cable length, a flat response up to 70MHz is achieved. The 11dB loss is dictated at low frequency by the capacitive divider formed by the coaxial cable capacitance proportional to the cable length (plus matching networks and electronics input capacitances) and the pickup capacitance. The simulated time domain response to raised cosine pulses of different amplitude 5ns long and 25ns spaced is also reported in Fig. 4 to show the compatibility of the system with 25ns bunch space beams.

HI-Z ELECTRONICS

The frontend amplifier installed in the PS tunnel (Fig. 5) has been designed to be radiation hard, low noise, extended input dynamic range, high input impedance and to have a bandwidth large enough to cover the response of the passive input network shown in Fig. 4.

The high input impedance is achieved using a wideband low noise buffer stage based on JFETs configured as "White's" source follower [4]. Ahead of the buffer stage, a capacitive divider can be inserted using reed relays to attenuate signal of high intensity beams. Downstream of the buffer stage the hybrid coupler combines the signals coming from the two opposite electrodes of one plane to produce the sum and delta signals, amplified by a low noise heterojunction bipolar (GaAs HBT) stage in case of low intensity beam. Out of the tunnel, before the digital acquisition calculates beam position using Δ/Σ algorithm [5], a variable gain module is used to fit the signals within the analogue to digital converter (ADC) input range.

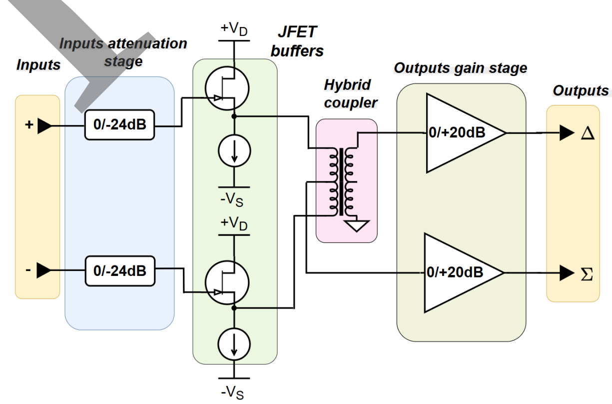

Figure 5: Hi-Z frontend amplifier block diagram.

The exposed active components and the complete frontend electronics have been tested at CHARM, the CERN mixed field radiation facility. JFETs and HBT have been tested unbiased up to 10kGy, with no impact on the final application, while a complete frontend has been irradiated up to 3kGy without significant variation on the electrical measurements. This result should guarantee a lifetime (considering only radiation damage) of at least five years on the most irradiated PS location and one or more decades on the others. The module is designed for a quick

[2] Long line effect rule of thumb: line longer than 1/20 of the signal wavelength

plug-out/plug-in and a stock of spares is foreseen for the replacement in case of failure. Reparation is also an option, when the activation of the module is not excessive.

The bench measurements (Fig. 6) are obtained emulating the final tunnel setup (pickup assembly + 5ns cable + frontend electronics) response to a centred beam. Identical signals are therefore applied on the two inputs (+ & -) and the outputs ratio Δ/Σ is directly proportional to the position offset introduced by the electronics. To keep it low, the input channels have been carefully paired.

The Σ output system bandwidth is from 15kHz to about 60MHz and the JFET input stage can cope with input levels in the order of more than 1V with a gain compression level below 0.1dB.

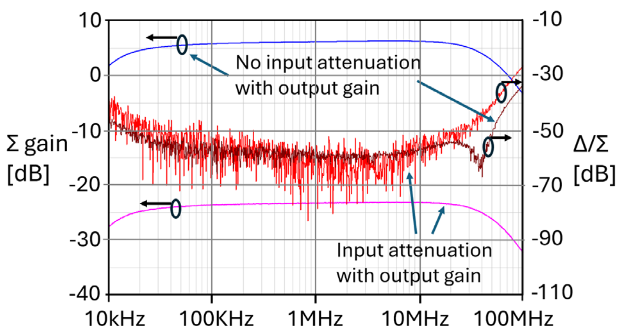

Figure 6: Hi-Z frontend electronics frequency response.

BEAM MEASUREMENTS

The effect of the improved electrical performances is presented comparing a “TOF” high intensity single bunch proton beam acquired by two identical pickups located very close each other (~1m apart) in the PS ring. One pickup is equipped with the operational (Low-Z) analogue architecture, the other with the Hi-Z version. The acquisition is simultaneous and the digital processing is identical.

Low Frequency Noise

On the output analogue signals (Fig. 8) the improved low frequency noise achieved by the Hi-Z BPM is evident comparing the traces on the regions without beam, where they are expected to be flat.

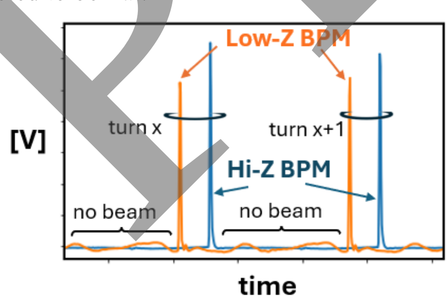

Figure 8: Analogue Σ during two turns.

Dynamic Range

Since the PS beam pickup (Fig. 1) has the combined plus and minus electrodes of each plane providing (almost) 360 degrees radial coverage the sum signal integrated over the bunch length is proportional to the bunch intensity and independent on the beam position. The comparison of the BPM’s turn by turn integrated Σ output with the BCT (current transformer) reading has proved to be useful to detect issues on the BPM acquisition (Fig. 7).

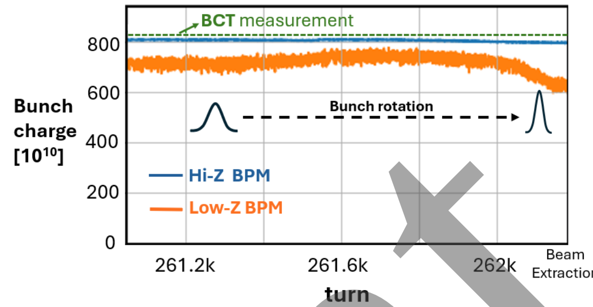

Figure 7: End of cycle turn by turn integrated Σ.

During the last few thousand turns before the single turn fast extraction the improved dynamic range of the Hi-Z BPM is noticeable. The Hi-Z integrated Σ (blue trace) reports a constant bunch charge in agreement with the BCT (hatched), while the Low-Z BPM (orange) is affected by the increasing charge density of the bunch starting at turn 261.3k when bunch rotation is applied.

Position Measurement

Finally, the position measurement (Fig. 9) of the Hi-Z BPM has better resolution and offset. The Low-Z BPM trace is affected by the integrated Σ variation (see Fig. 7) during the bunch rotation. Since position is proportional to Δ/Σ, when the integrated Σ increases the calculated position become smaller and vice versa.

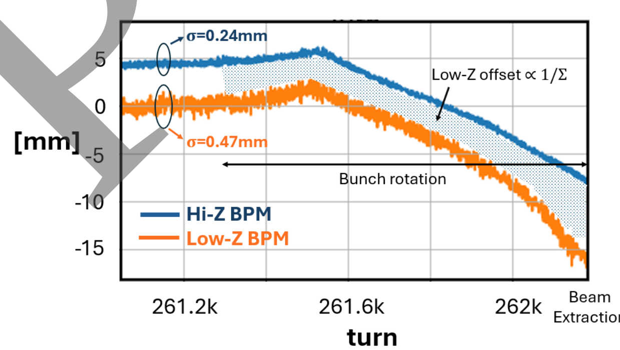

Figure 9: End of cycle turn by turn horizontal position.

CONCLUSION AND OUTLOOK

The proposed high impedance acquisition has demonstrated improvements on the quality of the measurements with the different beam conditions and the custom designed frontend electronics is compatible with the radiation level expected on the foreseen amplifier locations.

Three prototype systems are currently installed in the PS ring to further validate the reliability of the proposed implementation, and the installation is foreseen during the upcoming long shutdown (LS3).

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