DESIGN AND DEVELOPMENT OF CONFIGURABLE BPM READOUT SYSTEM FOR ILSF

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Abstract

A configurable electronic system has been developed for button BPMs readout in the storage ring of Iranian Light Source Facility (ILSF). This system calculates the beam position through the output voltage of BPMs. Output signals of BPMs pass through a 500 MHz and 50ohm front-end for noise filtering and also gain control purposes. Then the signal is digitized based on under sampling method by a 130MHz ADC for further analysis in FPGA. Safe dynamic range of 0dBm to -90 dBm can be covered by this electronic system with white noise measured to be around -110dBm. Trigger for this electronic is 2-10Hz as Slow data acquisition for Slow orbit feedback system and 4-10 KHz as Fast data acquisition for fast orbit feedback system. This paper describes the design, analysis, and measurements of the developed electronic system.

INTRODUCTION

The Iranian Light Source Facility (ILSF) is a 3 GeV third generation synchrotron light source facility which is in design stage [1]. In diagnostics group, we have designed different instrument and fabricated some prototypes. Since Beam Position Monitors (BPMs) are the most frequently used non-interceptive diagnostic in particle accelerators [2], we have designed and developed BPM and its readout system. To monitor closed orbit, It is needed to employ 160 BPMs around the storage ring of ILSF. Important criteria in the design of BPMs are to have the intrinsic resolution of less than *1um*, to have as highest and as flattest transfer impedance as possible, to have less higher-order mode (HOMs) resonances, and excellent impedance matching which will result in well-separated bunch by bunch signals with high signal-to-noise ratio [3]. Fig. 1 shows BPM design and vacuum chamber schematic at ILSF.

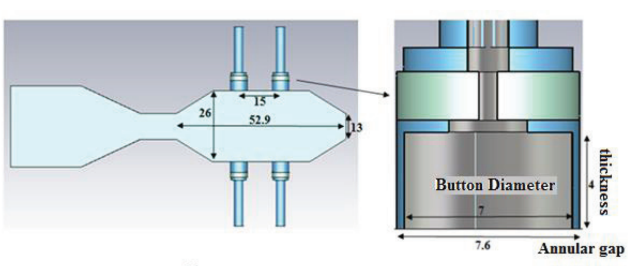

Figure 1: (a) Location of BPMs around vacuum chamber (b) Button BPM structure. All units are in mm.

To simplify BPM parameters calculation, a code was developed in C# [4]. After optimization of BPM design, we have designed and developed a new BPM readout system to improve important parameters of high precision, high speed and high digital processing capability. The developed BPM readout system consists of three parts: the analog front-end, the mixed-signal and the digital circuit. In the analog front-end circuit, each RF input signal is filtered and amplified individually by using two successive accurate IF-band passband filters, and two voltage gain controllers (VGAs) which has been implemented based on combination of attenuators and accurate narrowband amplifiers. Then the four filtered and amplified signals are fed to the mixed-signal section of the circuit to be digitized with high sampling rate and with low noise. Therefore, we used four accurate high speed ADCs and under-sampled the signal using accurate clock signals generated using LVDS clock distributors. Then the digital output and synchronization signals are fed through the FMC connector connected to the main signal processing module (digital circuit). In FPGA (ML605) buffers implemented to transfer raw data to PC by Ethernet for further calculation and analyses in MATLAB [5].
After laboratory tests of this system, final tests were done using the real beam in ALBA. The tests showed precision and resolution of 1 micro meter.

BPM FOR THE ILSF STORAGE RING

As mentioned high sensitivity, high transfer impedance and less parasitic and coupling impedance are the desired features of BPM Design in ILSF. To achieve these features, a code was developed to calculate parameters of BPM such as sensitivity, intrinsic resolution and power dissipation vs bandwidth and current.
It is known that less annular gap causes less parasitic impedance, HOM resonances at higher frequency, and more capacitance. In general more capacitance is equal to less parasitic losses, then increasing it by increasing thickness of button and decreasing annular gap can be helpful. Larger button diameter causes more sensitivity but also increase risk of thermal noise through beam dissipation power on longer button and somehow mechanical deviation at button [6]. Fig. 2,3 shows calculated parameters of designed BPM by using developed code. Fig. 2 shows that BPM sensors supposed to have linear response for almost 10 mm displacement. Fig. 3 also shows induced power on buttons for different

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beam current. In 100mA beam current, induced power is around -22.8 dBm equal to 46 mV Peak-to-peak.

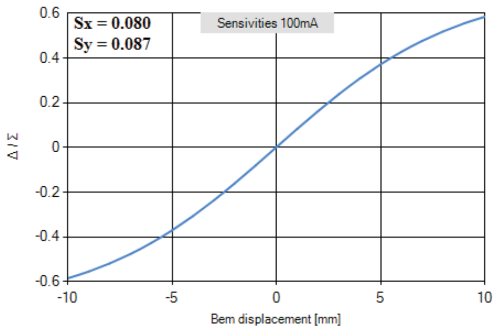

Figure 2: BPM sensitivity vs Beam Displacement.

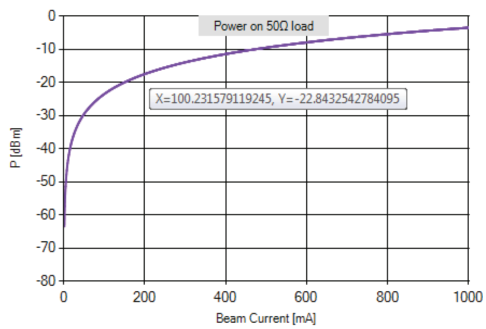

Figure 3: Induced power on buttons vs beam current.

An intensive particle beam moving in a vacuum chamber induces quite strong electromagnetic field named wake field affecting the beam itself. From here the most significant results of collective effects are various instabilities of beam motion, which can lead to beam losses or beam quality deterioration. To calculate Wakefield and induced voltage of BPMs, CST code was used [7]. In this method beam shape was considered Gaussian with standard deviation of 2.9mm. Fig.4 shows calculated induced voltage when beam placed at the centre of vacuum chamber.

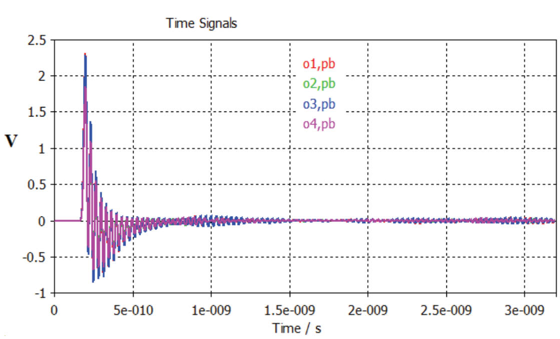

Figure 4: Induced voltage of BPM for single pass beam at centre of vacuum chamber.

Wakefield impedance (coupling impedance) at Fig. 5 shows that resonances are far enough from working frequency range then it confirms assurance of BPM design.

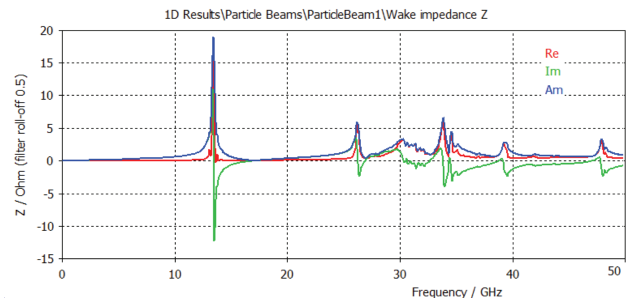

Figure 5: Real and Imaginary parts of longitudinal coupling impedance for a BPM.

Wake potential also calculated by CST as shown at Fig. 6 loss factor for a bunch was also calculated by CST and formula $P_{diss} = \frac{K_l I_{beam}^2}{f_{RF}}$. The power dissipated in the component for a beam is 2.2 Watt which is within the normal value.

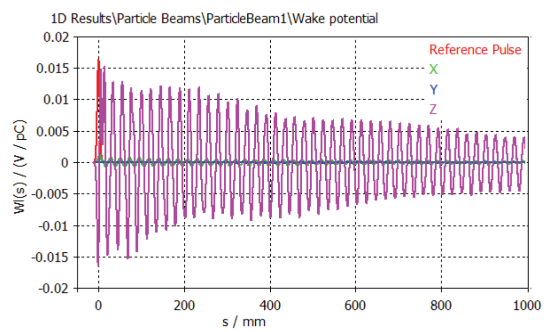

Figure 6: Wake potential as function of distance from bunch for a BPM.

BPM READOUT SYSTEM

After we have done the design of button BPM successfully, we have decided to develop Electronic readout system for beam position monitoring purposes. Based on design, it consists of 3 different parts, the analog front-end, the mixed-signal and the digital circuit (Fig. 7).

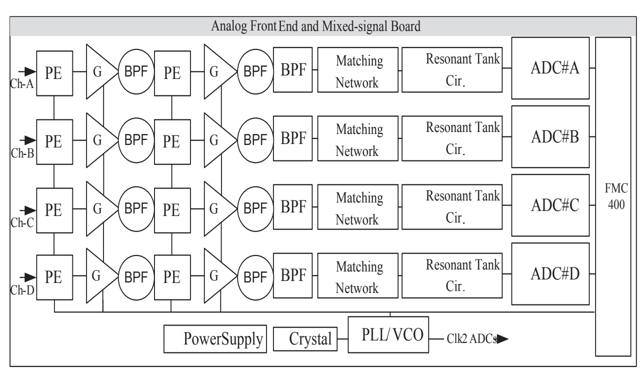

Figure 7: The schematic of electronic components in the board of Analog front end and the mixed signal sampling board.

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The Analog Front-end Circuit

This circuit is composed of VGAs and band-pass filters, which are implemented individually for four IF input channels. In each channel, the VGA module has been designed using two digital controllable attenuators (DAT-31R5-SP+) and two fixed IF low-noise amplifiers (TAMP-72LN+). Each attenuator could be used to attenuate the input signal in the range of 0 to 31.5dB in 0.5dB steps, by setting 6 digital bits in an online or offline way. In the RF front-end, the IF signals are being amplified/attenuated and filtered in the single path configuration, individually. To have a good band-pass filter, we utilized the SAW filters. We used SAW filter, TA0979A, which is a 8^{th} Butterworth band-pass filter with the central frequency of 500MHz and a bandwidth of 6MHz. In addition, it‘s low insertion loss of 2.5 dB is an advantage for the overall SNR of signals

The Mixed-signal Circuit

This is the most important part of the instrument since there are both analog and digital signals in the circuit. Therefore, we took care of the mixed-signal issues in both circuit and PCB design to minimize the crosstalk, signal and power noise, as well as to increase the SNR and dynamic ranges of the system. To have a better quality of pre-processed IF signals, first we used to parallel a RF-transformer and a Balun transformer to convert the single ended signal to differential signal in order to make the SNR of the signal better by decreasing the EMI noises. Then, the signals have individually have passed the anti-aliasing low pass filter and resonant tank circuit and then have fed to the differential high-precision single-channel ADCs. The ADC of LTC2208 was used which has a trade-off between accuracy and sampling rate. It digitizes the signals to 16-bits digital data with the sampling rate of up-to 130MHz and high-precision SNR of 75dB@100MHz. The output data and synchronized signal of each ADC has been buffered and the voltage is changed to 2.5V to be compatible to digital circuit powers. The input clock of each ADCs has been sourced using a LVDS clock distributor (AD9510). We used a very accurate crystal oscillator to source the LVDS clock distributors. The advantage of AD9510 clock distributor is to flexibly control the clock outputs, currents and clock rate by using SPI interface. In our study, we have set the clock rate to 122MHz. To have a connection between analog and mixed-signal circuits and digital circuit, all the ADC signals, power and ground signals, digital control signals were passed through a FMC-400PIN connector compatible with ML605 FPGA board module.

Digital Circuit

The digital circuit is composed of digital modules in order to implement various tasks including data read-out and storage, voltage gains adjustment, ADC and Clock PLL configuration, digital signal processing and communication with computer through the Ethernet and USB interfaces. By considering the complexity of the required digital circuit, we used an advanced ML605 board which contains digital electronic components including FPGA Virtex-6, Ethernet physical layer and USB controller, DDR3 memory, high speed flash and so forth. We utilized FPGA to program and control all the required sub-modules. All the FPGA VHDL codes have been compiled in the ISE 14.7 development software released by Xilinx Company [8]. Final shape of developed readout system is shown at Fig. 8.

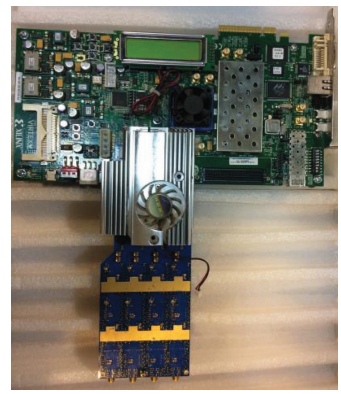

Figure 8: The overall hardware implemented design of BPM system.

Developed GUI Monitor in PC

To monitor beam position and also induced voltage on button BPMs, a code was developed in visual C++ [9] in windows. In this code Mitov GUI [10] has been used to monitor signal push for samples, average of peak-peak voltage and also beam position values. Schematics of this developed GUI are shown at Fig. 9.

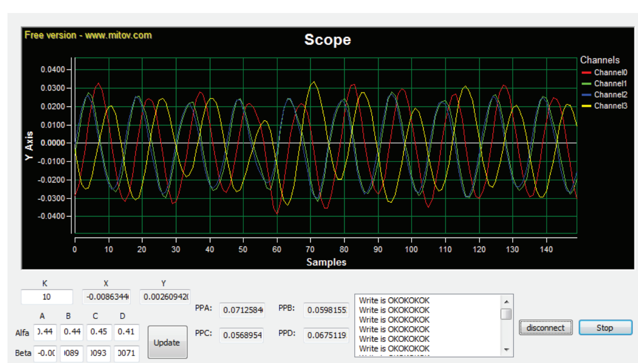

Figure 9: Schematic of developed code for monitoring beam parameters according to the recorded signals from BPM.

Tests in ILSF Lab

In ILSF lab tests were done by signal generator (E8663D Agilent) for 500MHz with different amplitudes as input. Measurements showed that the system works completely linear. Then by calibrating and finding calibration

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coefficients, we could measure the input voltage by the readout voltage.

Tests in ALBA

We had a great chance to test developed readout system in ALBA (Spain) on real beam. To get information about induced signal on buttons, measurement by oscilloscope with 50-ohm termination showed peak to peak voltage around 221mV equal to -9 dBm which is quite in our system's dynamic range. Resolution is around 0.2 um due to wide dynamic range up to -90 dBm and $K(\Delta V)=\Delta x$ formula which K is 10. After calibration of our system by using signal generator for each channel and finding coefficients due to its linear behaviour between BPM output voltage and readout voltage, we started beam position measurements. Beam position calculation was done based on peak-peak voltage measurements and Δ/Σ equation. Fig. 10 shows beam position measurement for an hour in storage ring of ALBA with 3 Hz as system trigger.

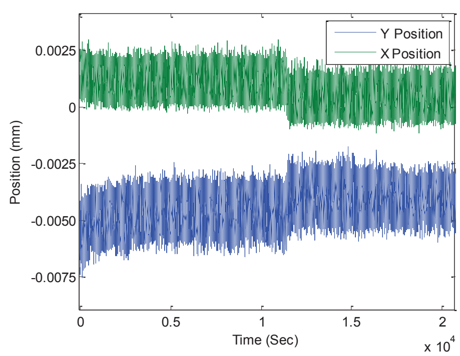

Figure 10: Sample of X-Y position measurement by our designed BPM device.

Results show 0.0016 mm and 0.0015 mm displacement in both horizontal and vertical directions respectively with 0.0014 mm precision (Standard Deviation). The readout system also was tested on ALBA booster. In top-up mode at ALBA accelerator facility, a two-third storage ring filling pattern is used, in which 320 out of 448 buckets of the SR are filled with electrons. For filling these buckets, the LINAC is operated in multi-bunch mode, and it delivers 10 shots with repetition rate of 3Hz including the trains of 32 bunches per shot at each 20 minutes [11]. Fig. 11 shows the measurement of injection pattern by our developed readout system based on the induced voltage on BPMs at ALBA booster.

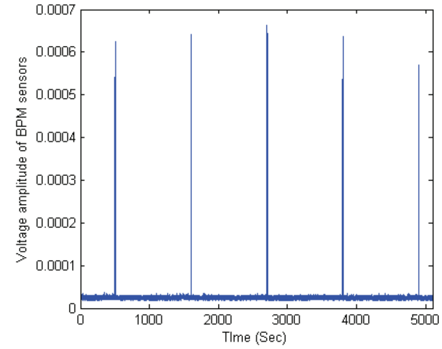

Figure 11: Peak-peak voltage of readout system through measurements at booster.

However the precision of around 1 micro meter for the beam position measurements by this electronic system achieved but higher precision is required. To find out optimized mathematical method to decrease the standard deviation, and consequently increase the precision, we analyzed the recorded raw data offline by different methods. One solution is using PCA (Principal Component Analyses) to reduce the noise through finding the frequency range of max data quantity [12]. By filtering position Data x,y, we got that max data quantity can be found less than 2.9 Hz. Then using PCA technique for these data decreased the precision down to 0.25 micro meters. One of disadvantage of this method is its long processing time, because of that it is applicable for slow rate data acquisition. Fig. 12 shows noise reduction results based on PCA technique in measurement of beam position at ALBA storage ring.

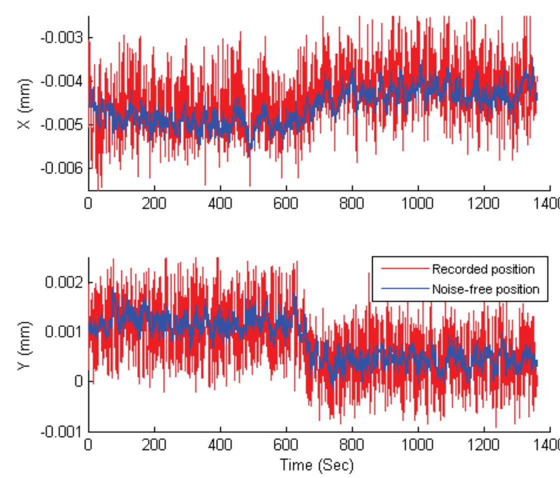

Figure 12: The recorded positions and processed low-noise positions based on PCA.

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