DEVELOPMENT OF HIGH PRECISION BEAM POSITION MONITOR READOUT SYSTEM WITH NARROW BANDPASS FILTERS FOR THE KEKB INJECTOR LINAC TOWARDS THE SUPERKEKB

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Abstract

The SuperKEKB accelerator complex is now being upgraded to bring the world highest luminosity ($L=8x10^{35}$ /cm^2/s). Hence, the KEKB injector linac is required to produce: electron: 20 mm mrad (7 GeV, 5 nC), positron: 10 mm mrad (4 GeV, 4 nC). To achieve this, the accelerator components have to be aligned within ± 0.1 mm (1 σ). A beam position monitor (BPM) is essential instrumentation for beam-based alignment (BBA), and is required to be one magnitude better position resolution to get better alignment results. Since a current BPM readout system using oscilloscopes has ~50 µm position resolution, we decided to develop high precision BPM readout system with narrow bandpass filters. It handles two bunches with 96 ns interval and has a dynamic range between 0.1 nC (for photon factory) to 10 nC (positron primary). To achieve these criteria, we adopt semiconductor attenuators and optimized two-stage Bessel filters at 300 MHz center frequency to meet both time and frequency domain constraints. To correct position drift due to gain imbalance during operation, calibration pulses are output to the BPM between beam cycles (20 ms). The beam position and charge calculations are performed by onboard FPGA to achieve fast readout cycle.

INTRODUCTION

KEKB Injector Linac is now being upgraded as a part of SuperKEKB accelerator complex [1] to achieve the world brightest luminosity. In order to obtain the $8x10^{35}$ /cm^2/s luminosity, electron and positron beam emittances have to be 20 mm mrad (5 nC) and 10 mm mrad (4 nC), respectively. To realize this, due to the beam optics reason, accelerator structures have to be align within ±0.1 mm accuracy. To perform the BBA stably, BPMs are required to have one magnitude better position resolution than the required alignment accuracy. However, current BPM readout system with oscilloscopes [2-4] has ~50 µm position accuracy, is not met the requirement. To accomplish <10 µm position resolution, we have designed dedicated narrow bandpass filter (BPF) type readout circuitry with 250 MSa/s 16 bit pipeline ADC. Since at the SuperKEKB two bunches with 96 ns interval are accelerated, we have optimized BPF configurations to keep both position accuracy and bunch separation. As the SuperKEKB injector injects electron / positron beams into four different energy rings (SuperKEKB HER/LER, PF and PF-AR) simultaneously, we employed electrical attenuators to keep enough dynamic range. In addition, there may be readout position drifts due to several reasons, we implemented calibration tone generator on the readout circuitry. This gives BPM's electrode calibration tone pulse and induced pulses at the adjacent two electrodes are readout to measure the inter-channel gain balance. We employed FPGA to calculate beam position/charge on board within 1 ms. This paper reports current development status of the BPM readout system.

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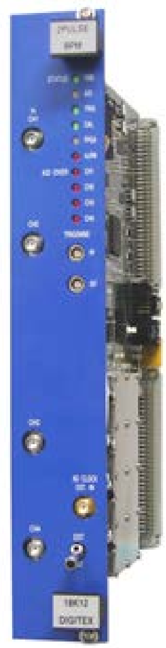

Figure 1: Photograph of BPM Readout System Board.

READOUT SYSTEM OVERVIEW

At the KEKB injector linac, there are 100 BPMs (electrode inner diameter Φ=27 mm, electrode length l=132.5 mm) installed and almost BPMs will be remained. BPMs for positron line will be replaced with large diameter ones (Φ=63 mm, l=132.5 mm) [4].

In this design, we employed narrow bandpass filter (BPF) type readout system [5], which uses only specific frequency component of short beam impulse and forms into long burst signal to measure the beam power precisely. Figure 3 shows our BPM frequency response to the beam with 35-m-long cable losses. We have chosen 300 MHz for the BPF center frequency to meet both BPM frequency response and the Nyquist zone of the ADC (f_s=250 MHz).

BPF bandwidth and its filter characteristics were determined to meet following criteria: (1) passband is

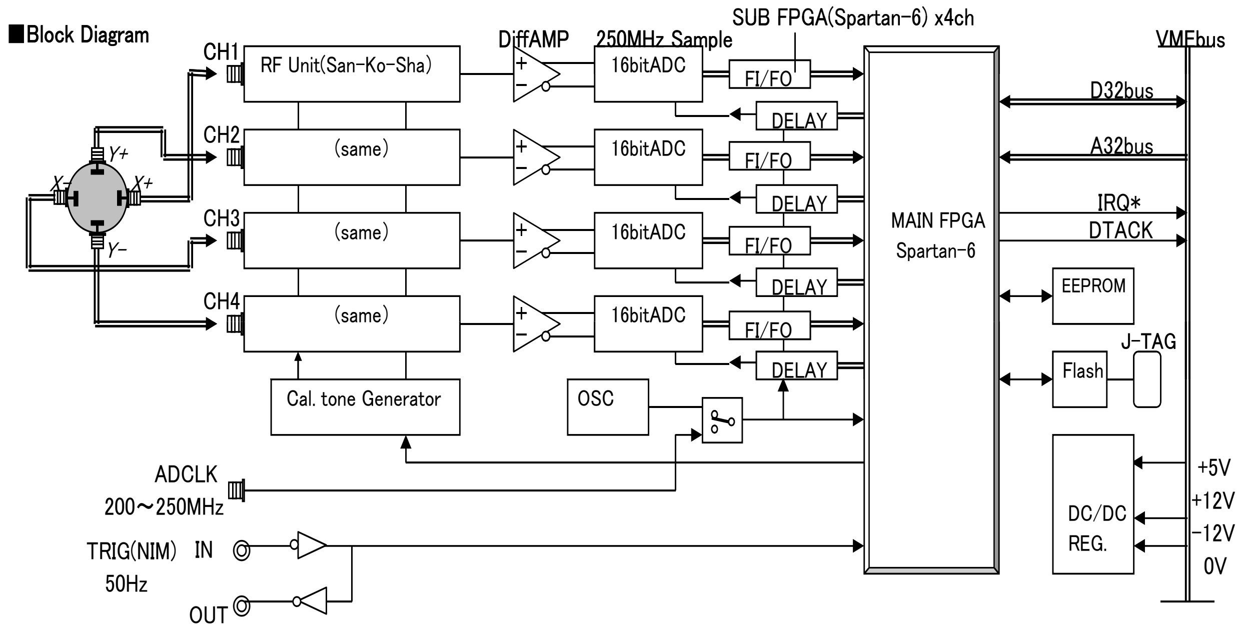

Figure 2: Block diagram of the BPM readout system.

enough within the ADC's third Nyquist zone (250 MHz ~ 375 MHz), (2) burst signal must be settled within 96 ns not to disturb second bunch's signal. Narrower passband helps achieving first criterion, but it gives longer burst signal.

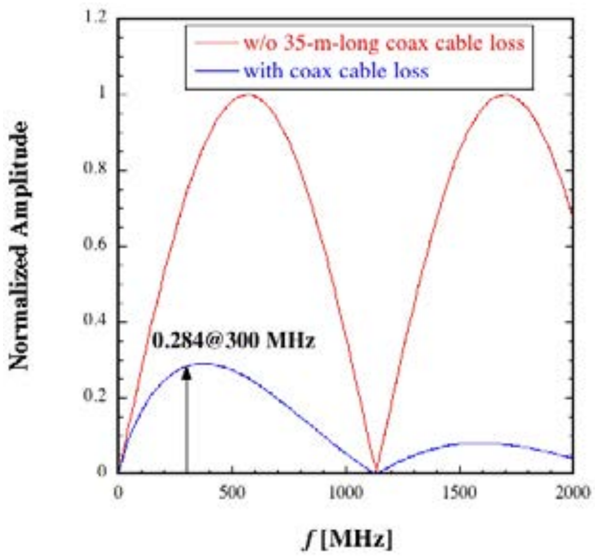

Figure 3: BPF frequency response with 35-m-long cable losses is shown. 300 MHz is at near peak response frequency and at the center of third Nyquist zone.

We employed Bessel filter, which shows good burst settle characteristics and gradual frequency cut-off characteristics. We implemented second-order Bessel filter (f_w=34 MHz) third-order Bessel filter (f_w=28 MHz) in series using helical-coils. It gives ~60 ns burst length and -45 dB isolation at the Nyquist zone edge. (Fig. 4 shows time domain response.)

Block diagram of the BPM readout system is shown in Fig. 2. We employed four 16 bit 250 MSa/s pipeline ADCs (AD9467-250) and each ADC clock can be adjusted in 10 ps step (MC10EP195).

The KEKB injector provides wide range of beam charge to four different accelerator ring simultaneously; for PF ring, it provides 0.1 nC (2.5 GeV) and for the SuperKEKB positron primary, it provides 10 nC (3.5 GeV). Therefore, two 31.5 dB electrical attenuators were implemented to operate in best operating point at each condition.

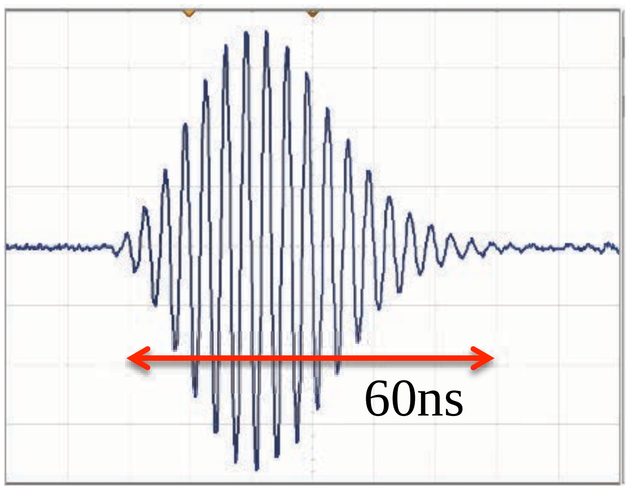

Figure 4: BPF time domain response for beam impulse is shown. Burst signal settles within 60ns.

During operation, measured position drifts may be occurred due to unequally gain drift among opposite channels. To compensate it, calibration tone generator was implemented. This gives calibration tone pulse to a BPM electrode and induced charges at two adjacent electrodes are readout. Their charge ratio gives offset compensation factor.

All operations including beam position and charge calculation are performed by onboard FPGA (Xilinx Spartan-6 [6]) within 1 ms.

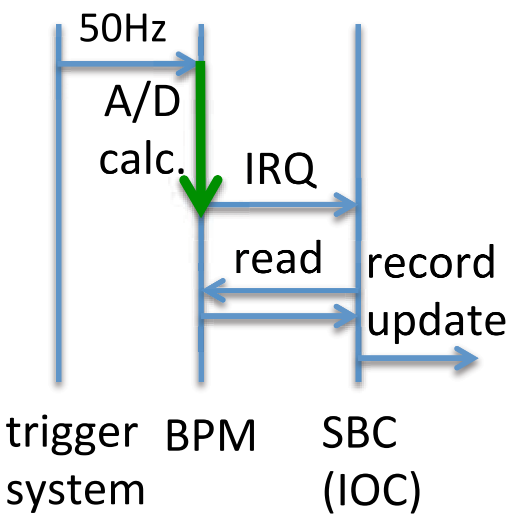

Figure 5: Timing diagram of BPM readout system.

Readout timing diagram is shown in Fig. 5. Before the beam injection, beam type information is provided via an event system (MRF, EVR) and the BPM readout system set proper value for its attenuators. When a trigger signal is given, ADCs start conversion and 1024 cycle (4096 ns) × 4 channels data are fed to the FPGA via each FIFO memories. FPGA performs beam position and charge calculation and then issues an interrupt (IRQ) to notice Single Board Computer (SBC) data ready. When an EPICS IOC process detects the IRQ, it read the data and updates its records.

PERFORMANCE TEST

Pulsar Test

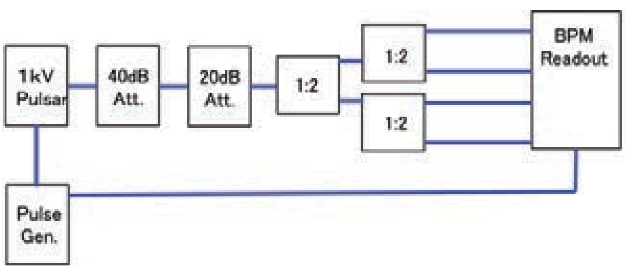

Figure 6: Pulsar Test setup of BPM readout system.

For the first step, we performed pulsar tests with a 1 kV monocycle pulsar (Kentech Instrument, Model SPS/V/L pulse width: 1ns, positive unipolar). Figure 6 shows pulsar test setup. Pulsar output is equally divided to each input in order to emulate ideal beam (no beam jitter) passing through center of the beam pipe.

We took 300 events with this setup and resulted in position resolution: δx=11.9 μm, δy=9.8 μm (preliminary).

Beam Test

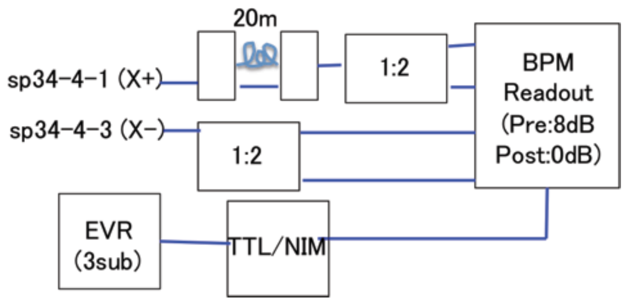

Figure 7: Beam test setup of BPM readout system.

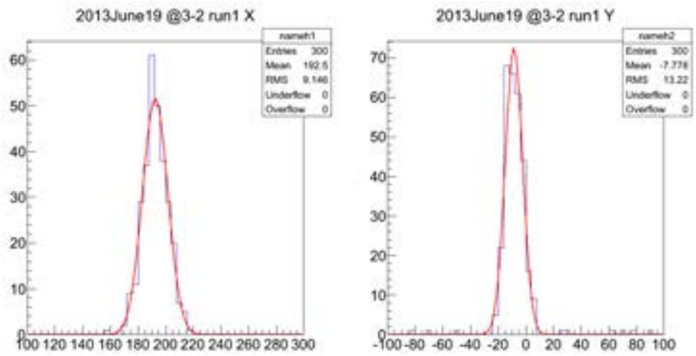

Figure 8: Position histogram example of beam test (0.3 nC). X-axis is position in μm.

We performed beam test to confirm the BPM readout system performance at real condition. Actual beam is also equally divided to two opposite electrode to emulate ideal beam. In addition, 96 ns interval double pulse is emulated with 20 m delay line. (Fig. 7)

We took 300 events with 0.3 nC per bunch and resulted in δx=11.9 μm (1st bunch), δx=14.4 μm (2nd bunch), δy=14.4 μm (preliminary).

We increased beam charge up to 0.45 nC per bunch and took 100 events. It resulted in δx=5.7 μm (1st bunch), δx=8.2 μm (2nd bunch), δy=5.1 μm (preliminary).

SUMMARY AND FUTURE PLAN

This new BPM readout system will be needed in the SuperKEKB injector linac commissioning, therefore we plan to install this new BPM readout system at 2014 summer shutdown time. So far, we have confirmed it achieve less than 10 μm at the beam test.

We will perform 3-BPM tests [4] to check it in real conditions (identical with normal operation). Based on the knowledge obtained in its debugging and tests, we will make updated (final) prototype board. And then we will perform final check and software preparation.

ACKNOWLEDGMENT

Through this BPM readout system development, we thank Dr. Steve Smith, Dr. Andrew Young at SLAC and Dr. Makoto Tobiyama at KEK for their suggestions and advice in design and development.

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