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BEAM POSITION MONITORING SYSTEM FOR FERMILAB'S MUON CAMPUS*

N. Patel†, P. Prieto, J. Diamond, D. Voy, C. McClure, N. Eddy,
Fermi National Accelerator Laboratory, Batavia, USA

Abstract

A Beam Position Monitor (BPM) system has been designed for Fermilab Muon Campus. The BPM system measures Turn-by-Turn orbits as well as Closed Orbits (average of multiple turns). While in the early commissioning phase of this program, preliminary measurements have been made using these BPMs. This paper discusses the design and implementation of these BPMs.

INTRODUCTION

A BPM system is required for providing transverse position to transport proton bunches through the Muon Campus beam lines shown in Figure 1. Ninety-four split plate style BPMs are placed along the transport lines and 120 split plate BPMs are in the Delivery Ring.

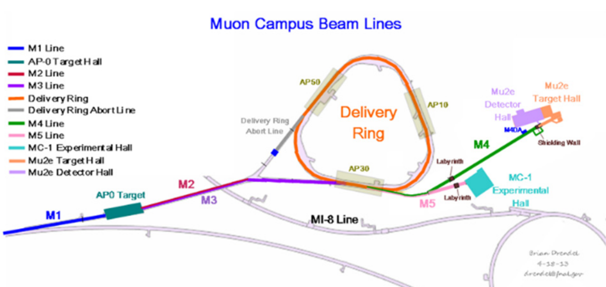

Figure 1: Map of muon campus beam lines.

Table 1: Beam Specifications

Parameter	Requirement	Units
Maximum Intensity	$1x10^{12}$	protos
Revolution Frequency (central orbit)	590018	Hz
Bunch Length (rms)	35	nsec

DESIGN OVERVIEW

The BPM system block diagram is shown in Figure 2. Each BPM has 2 ports corresponding to each of the pickups of the split plate style BPM. All of the 94 transfer-line and 120 Delivery Ring BPMs were already installed for previous experiments. As such, it was found that 4 different types of split plate BPMs were used throughout the transfer line. The majority of them are cylindrical with 4.5" diameter, however a few of the split-plates are rectangular. Figure 3 shows a picture of the most common BPM used. There are 5 service buildings along the transport line which house the electronics. The BPMs have a type-N connector welded on the housing. The coaxial cables connecting these to electronics in the service buildings can vary in length from 100 to 900 feet. The variation of cable type and length used results in a 4dB variation in loss across all the channels.

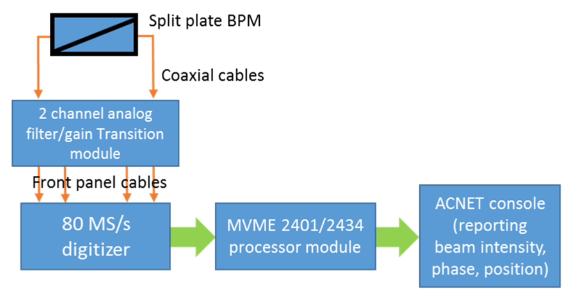

Figure 2: Muon campus BPM system block diagram.

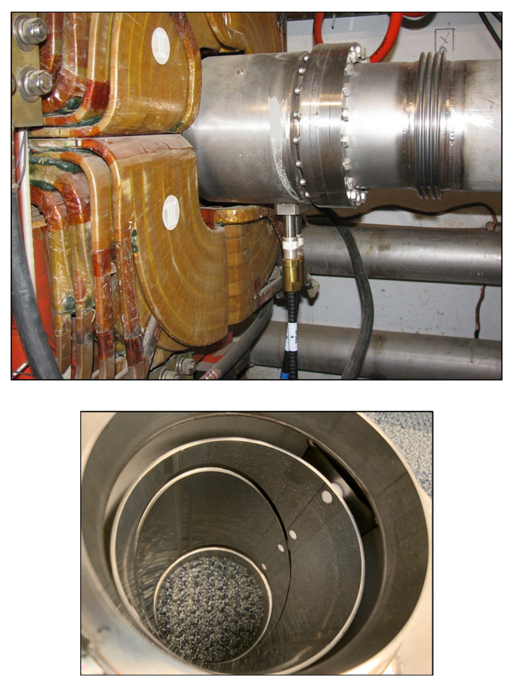

Figure 3: Picture of split-plate BPM implemented.

A stretch wire scanning test was performed to map out the BPM pick up response versus position. In this test, a wire is stretched longitudinally within the beam pipe. The response of the BPM pick-ups was measured as the wire was swept in the transverse direction. Data from this test is shown in Figure 4. The good linearity from this split-plate style BPM can be observed in this plot. The scaling

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factor, a critical parameter obtained from this test, is required to know the relation between relative signal strength and position from the center of the beam pipe.

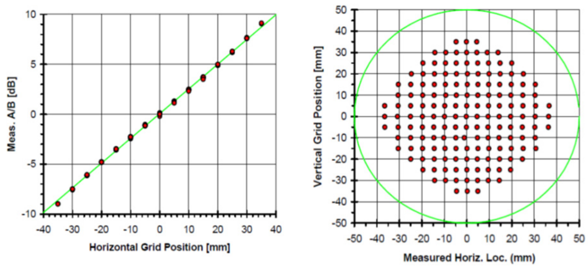

Figure 4: BPM wire-scanning test for a Delivery Ring BPM.

TRANSFER LINE BPM SYSTEM

The plot in Figure 5 shows what the signals from the output of the split-plate BPM look like. The duration of this pulse is approximately 200nsec. For the transfer line BPMs, this signal is digitized and the absolute value of the signal is integrated to get a magnitude for signals A and B. Beam position is calculated by a difference over sum of channel A and B magnitudes and this ratio is multiplied by a scaling factor obtain from the wire scanning test.

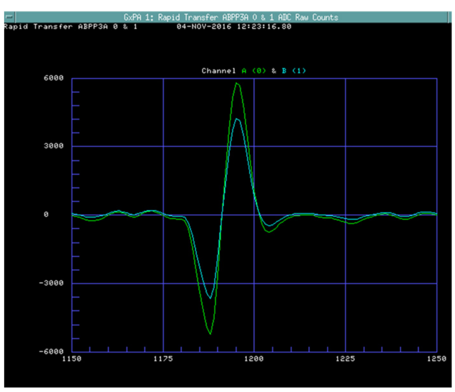

Figure 5: Signal from BPM pick-up.

The analog electronics for the single pass transfer line consists of operational amplifiers and a 2.5 MHz low-pass filter for signal conditioning. The signal of an individual proton bunch is then sampled at 80 MSPS and then integrated. A difference over sum calculation is performed between the two channels and a scaling factor is applied to obtain a final position measurement. A picture of the assembled printed circuit board (PCB) is shown in Figure 6. This circuit board was repurposed and with modifications to the low-pass filter and gain.

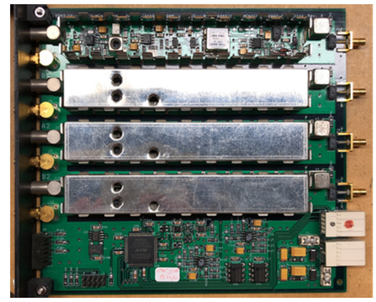

Figure 6: Transfer line analog transition board.

DELIVERY RING BPM SYSTEM

The mu2e Delivery Ring BPM design relies on using a 5 MHz bandpass filter to allow the signal coming from the BPM to produce a ringing effect. The signal is amplified, digitized and processed.

The analog electronics for the Delivery Ring were repurposed from former Recycler BPM system which consists of low-pass filtering and amplification. Modification to these boards involved changing the amplifier gain and converting the tunable low-pass filter to a tunable band-pass filter. A picture of this circuit board is shown below in Figure 7.

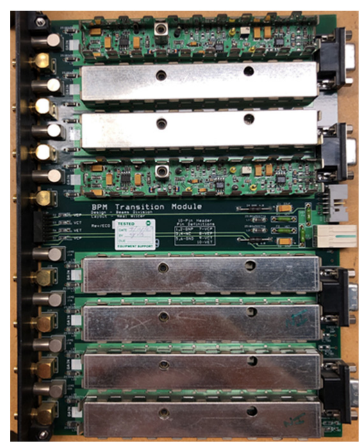

Figure 7: Delivery ring analog transition board.

Figure 8 and Figure 9 show plots of the beam signal with different traces representing different bunches. Due to the high-pass response from the BPM, lower frequencies are attenuated more significantly. So to get a signal with a better signal-to-noise ratio, it is advantageous to have a higher frequency signal (40-100MHz). However, from Figure 8 below, we see that 5MHz is approximately the highest frequency before signal level drops appreciably and bunch to bunch signal level varies noticeably. As a result, a 5MHz analog bandpass filter is used in this design.

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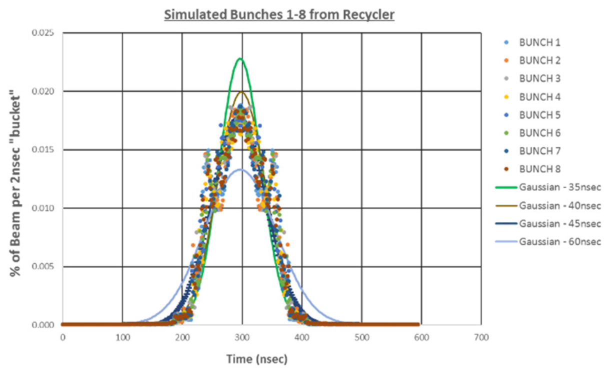

Figure 8: Variation of 8 successive bunches.

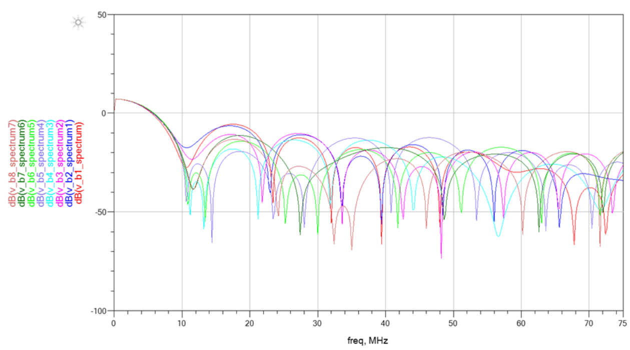

Figure 9: Spectrum of signal from 8 bunches out of BPM pickup.

The 5MHz signal coming from the analog electronics is shown below in Figure 10. This signal gets processed in the digitizer and goes through digital filtering to output a signal magnitude for channels A and B. Position is calculated from these magnitudes in a manner similar to the transfer line BPM system.

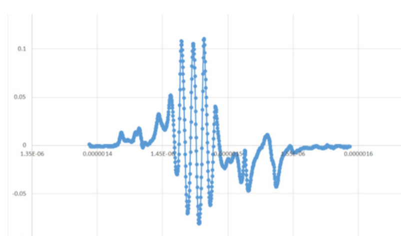

Figure 10: Signal from delivery ring transition board.

IMPLEMENTATION

All electronics for a system fit within one rack as shown in Figure 11. Analog transition boards are in-house custom designs which allow for flexible, low-cost and compact designs. The digitizers were made by Echotek and controlled by Motorola MVME 2401 (Delivery Ring) and Motorola MVME 2434 (transfer line) processor boards. Timing boards were designed and developed in-house. A T-clock event is used to arm the system to prepare to take measurements and a Beam-Sync event is used to trigger the system to begin acquiring data. Each set of channels have user adjustable time delays to account for delays from the cable and electronics.

Figure 11: Layout of electronics rack (Delivery Ring: left, Transfer Line: right).

MEASUREMENTS

As the beam through the transfer line maintains its parameters, position data is taken to quantify measured beam position variation. Standard deviation across transfer line BPMs is shown below in Figure 12. Future work lies in understanding and possibly reducing the variation, as well as reporting variation of BPMs in the Delivery Ring.

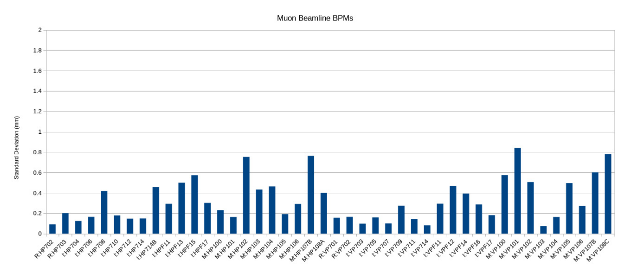

Figure 12: Standard deviation of position in transfer line.

CONCLUSION

Two low cost BPM systems were designed and implemented for Fermilab's Muon Campus. Preliminary measurements allowed users to get beam through the transfer line and Delivery Ring.

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Jim Fitzgerald, Fermi National Accelerator Laboratory, Batavia, IL 60510, USA
George Deinlein, Fermi National Accelerator Laboratory, Batavia, IL 60510, USA