

Fermilab Main Injector Beam Position Monitor Upgrade

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Introduction

A project to upgrade the readout electronics of the Fermilab Main Injector (MI) Beam Position Monitors (BPMs) was begun in 2005. This project is one of many improvements to the Fermilab accelerator complex aimed at providing increased luminosity and reliability for the Run 2 collider physics program. The design builds upon many of the technologies and techniques used to upgrade the BPM electronics in the Fermilab Recycler Ring1, the Fermilab Tevatron2, as well as some of the transfer lines.

Operational Requirements

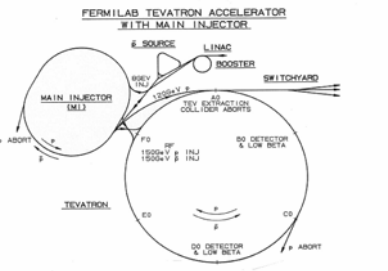


Figure 1-3. Schematic View of the Main Injector Connections to the Booster, Antiproton Source, Tevatron and Switchyard.
 Figure 1 Fermilab Accelerator Complex

The Fermilab Main Injector (MI) is designed to accelerate either protons or antiprotons with an injection energy of 8 GeV and an extraction energy as high as 150 GeV. At any time, however, only one of the two beam species may be present. The time structure of the beam may be one of the following:

- 53 MHz Protons.** From 1 bunch up to a full batch of 84 bunches in successive 53 MHz buckets (19 ns apart). Up to 6 batches, each one of 84 bunches, can be loaded in the MI.
- 53 MHz Anti-protons.** Four consecutive groups of antiprotons, spaced by 396 ns, of typically 5 (up to 9) 53 MHz bunches, are present in MI.
- 2.5 MHz - Protons or anti-protons.** Four 2.5 MHz bunches in successive 2.5 MHz RF buckets (396 ns spacing).

- The supported measurements types are:
- Closed-orbit: narrowband measurement averaging over all bunches for about 40 turns.
 - Turn-by-turn: wideband measurement averaging over all bunches in 1/14 of circumference (1/28 for 2.5 MHz).

MI BPM Read-Out Electronics Hardware

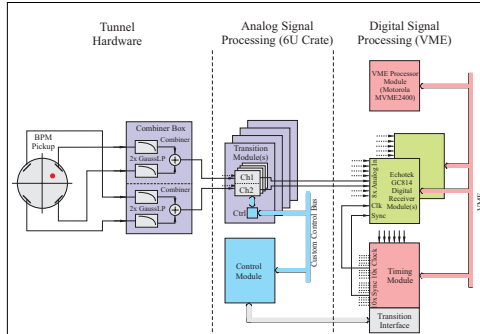


Figure 2: Overview of the Main Injector BPM hardware.

Figure 2 gives an overview of the hardware components of the upgraded Main Injector BPM system. The figure shows 2 signal channels which produce one position channel. All 201 stripline BPM pickups and their tunnel cabling remains unchanged. Upgraded components are the Combiner Boxes, located in the accelerator tunnel and all read-out electronics hardware, concentrated in 7 locations around the ring. The analog electronics – several 8-channel so-called Transition Modules and a Controller Module - are located in a 6U high crate frame, supplied by an external, linear power supply. A core component of the BPM system is the commercial Echotek GC814 digital signal receiver. Several 8-channel modules, together with a processor module (Motorola MVME5500) and an in-house developed Timing & Fan-out Generator (TFG-II) are arranged in a VME crate. All the cabling within a rack and between crates is new.

Analog

Analog signal processing occurs in both the Combiner Boxes and the Transition Modules. The Combiner Boxes accept beam signals from the four stripline electrodes, pass them through a low-pass filter ($f_c \approx 100$ MHz) and combine them to form either a vertical measuring or a horizontal measuring signal pair. The analog Transition Modules interface the signals from the Combiner Boxes to the Echotek digital receiver, adapting signal levels and further filtering frequency content.

Digital

Eight-channel EchoTek ECDR-GC814-FV2 VME64X digital receiver boards are used for beam signal digitization and frequency conversion. Each GC814 channel is comprised of a 14 bit ADC (AD6645), a four-channel digital down DDC (GC-4016), an FPGA accumulator, and 128K x 32 dual-ported RAM. These boards shift the information content of the beam signal from a RF analog form to a stream of digital, baseband I and Q data pairs. The position, P , and intensity, I , are given by:

$$A = \sqrt{I_A + Q_A} \quad B = \sqrt{I_B + Q_B} \quad R = \frac{A - B}{A + B}$$

$$P = a_0 + a_1 R + a_2 R^3 + a_3 R^5 \quad I = A + B$$

where the coefficients a_i were determined bench test measurements.

Performance

The results presented below were obtained using a pre-production system installed for 11 BPM locations. Figure 3 illustrates, for one BPM, the closed-orbit capability at 53 MHz for a simple MI cycle. Figure 4 illustrates the closed-orbit response to a more complex MI cycle; both vertical and horizontal measurements are shown. Figure 5 summarizes the closed-orbit resolutions at 53 MHz obtained for the 11 BPMs, using the method described in Figure 3. Figure 5 illustrates the turn-by-turn capability of the system, using anti-protons injected from the Recycler.

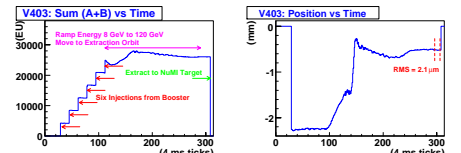


Figure 3: Closed-orbit proton data, 53 MHz band.

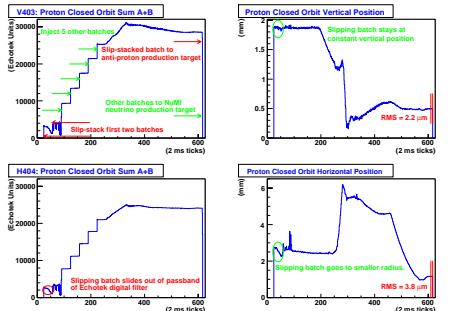


Figure 4: Closed orbit proton data, 53 MHz band. Anti-proton and NuMI neutrino production.

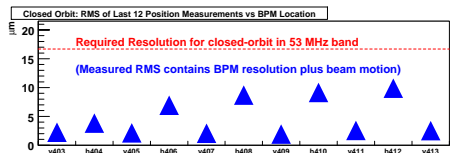


Figure 5: RMS resolution for different BPM locations.

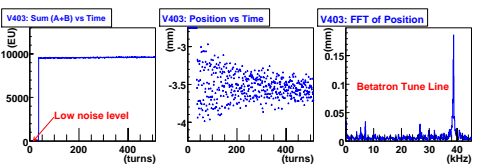


Figure 6: Turn-by-turn 2.5 MHz data for injection of anti-protons from the Recycler.

For further details see the paper contributed to this conference.