A 1.7 GHZ WAVEGUIDE SCHOTTKY DETECTOR SYSTEM

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Abstract

A 1.7 GHz waveguide Schottky detector system has been designed and built for each of the Fermilab Tevatron and Recycler accelerators. The waveguide detector is designed to measure the betatron sideband and longitudinal Schottky signals of the accelerators at a frequency high enough to avoid coherent effects. Two detectors are used for each machine, one for horizontal and one for vertical betatron signals. Each detector is bi-directional providing both proton and antiproton signals. This paper describes the details of the waveguide design and construction as well as the design of the electronic system of the detector. Sensitivity calculations and bandwidth models are included. The electronic system utilizes down conversion to frequencies less than 10 MHz, so that the signals may be analyzed by standard instrumentation, such as a Vector Signal Analyzer. The electronic system includes electronic gates to measure single or multiple bunches of protons or antiprotons with the RF as a source for tracking up and down energy ramps. The electronic system also includes a continuous beam emittance monitor.

INTRODUCTION

With the successful installation and commissioning of the Debuncher and Accumulator Core Stochastic Cooling upgrades, it was decided that the use of slow wave slotted waveguide pickups would be the perfect solution to high frequency Schottky detectors for both the Tevatron and Recycler accelerators. [1,2] A means of non-destructive measurement of beam emittance and tune was necessary for both accelerators. In the case of the Tevatron, the existing low frequency Schottky pickups suffer from the effects of coherent beam signals. Bunched Beam cooling tests in the Tevatron indicated that clean transverse Schottky signals were observed at 4 GHz and above. [3,4] For the Recycler, this Schottky system provides the necessary continuous beam emittance monitor and tune measurement capability. Both systems employ a gating circuit that allows distinguishing protons from antiprotons in the Tevatron and sections of warm and cold antiprotons in the Recycler.

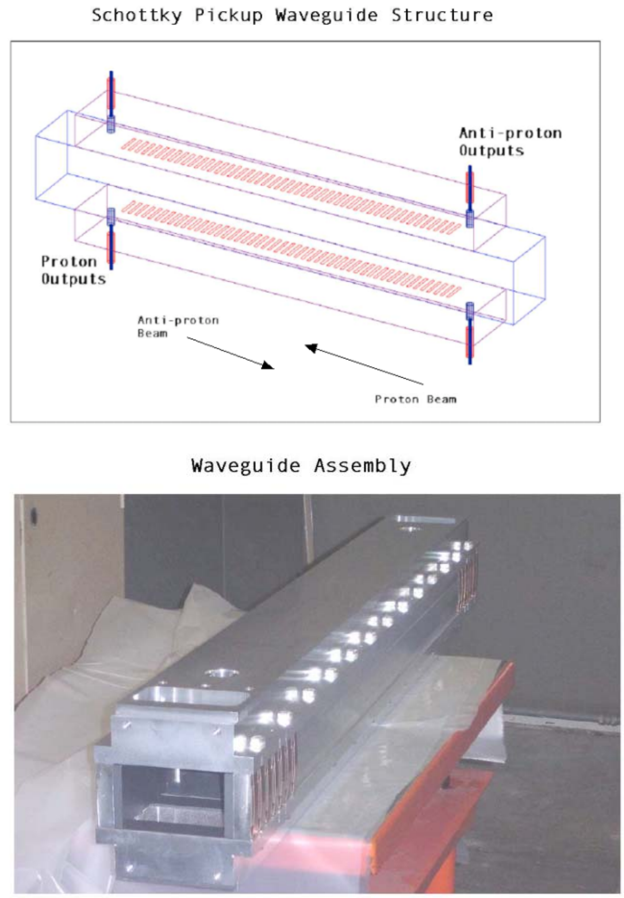

Figure 1. Schottky Pickup design top, fabricated pickup array bottom.

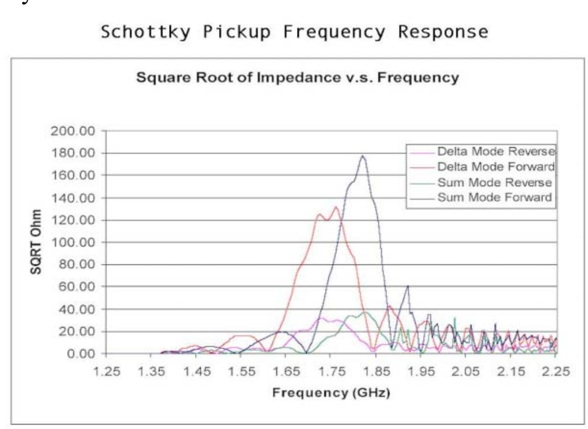

Figure 2. Calculated transfer impedance.

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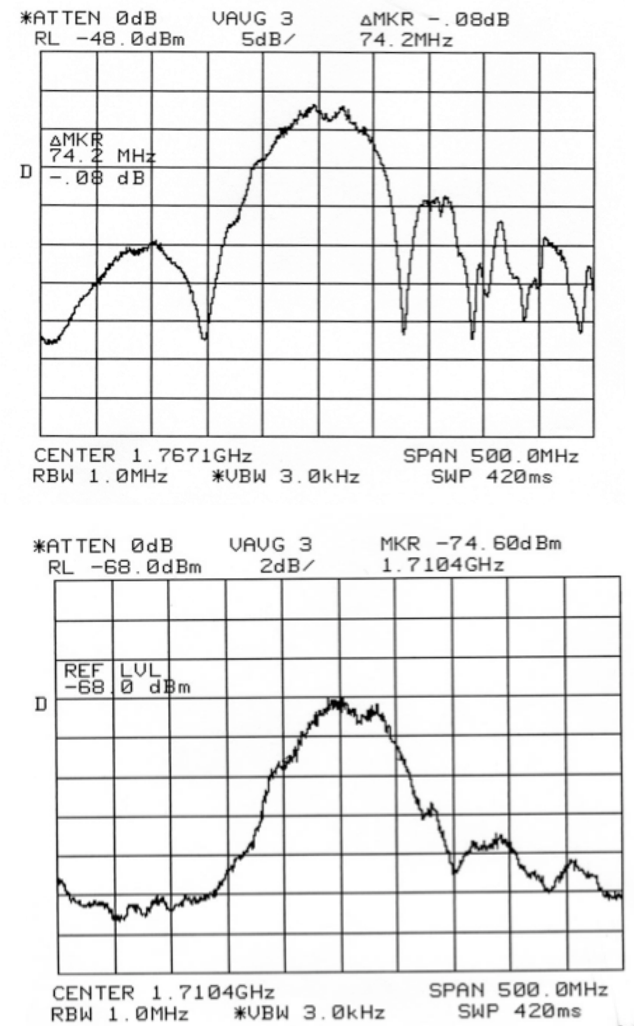

Figure 3. Measured response with 1.4 x 10^{11} protons in the Recycler. Top: sum mode; Bottom: difference mode.

SCHOTTKY PICKUPS

A Schottky pickup consists of a rectangular beam pipe with two waveguides on either side of the beam pipe (Figure 1). The septum wall between waveguide and beam pipe is made of slotted thin aluminum foil for coupling signal into the waveguide. The designed operating frequency is approximately 1.745 GHz (DELTA mode) and 1.813 GHz (SUM mode.) For these frequencies, dimensions of beam pipe are chosen as 4.3" wide and 2.953" high (close to the aperture of the beam pipe in Recycler). Dimensions of waveguide are 4.3" wide and 2.15" high. The design goal of these Schottky pickups is to obtain high impedance with a bandwidth of 100 MHz. To achieve this goal, 216 equally spaced slots are utilized in each foil.

A waveguide to coax launcher couples the signals at each end of the waveguides. All launchers are matched with better than –27 dB reflections. Microwave absorbers (TT2-111R from Trans-Tech Inc.) are placed on the walls of the beam pipe (end area) to prevent microwave signals from propagating into or out of the pickup. Thickness and length of these absorbers are designed to provide adequate absorption (-25 dB) as well as minimum reflection (-23 dB). Figure 2 depicts the calculated transfer impedance. The actual pickup was measured with beam to have a response some 50 MHz below that predicted by the computer model, Figure 3.

RECYCLER

The Recycler beam is maintained in barrier buckets to facilitate the frequent transfer of beams from the Accumulator. As such, it is not a truly coasting beam. It is possible to have a cooled core of beam in the Recycler and freshly injected batches of antiprotons in an adjacent longitudinal portion of the ring. As the particles are cooled, they will be merged before the next transfer. A gating system was developed to allow measurement of the two different beams.

Signal processing includes a preamp followed by down conversion electronics that obtain the local oscillator signal from a phase locked microwave oscillator. The base band signal is shipped from the MI 62 service building (location of the pickups) to the MI 60 service building where a multiplexer and vector signal analyzer (VSA) are located for the Recycler diagnostic system.

The down converted signal is split with one input to the VSA, the other to a second down converter and on line continuous emittance monitor. The DC-89Khz signal is further processed through an active fourth order band pass filter that integrates the betatron sideband signal followed by an RMS to DC converter that generates a voltage proportional to emittance. The emittance monitor is calibrated against the newly installed transverse scrapers. Typical measurement results depicted in Figure 4, installation of pick up in Figure 5.

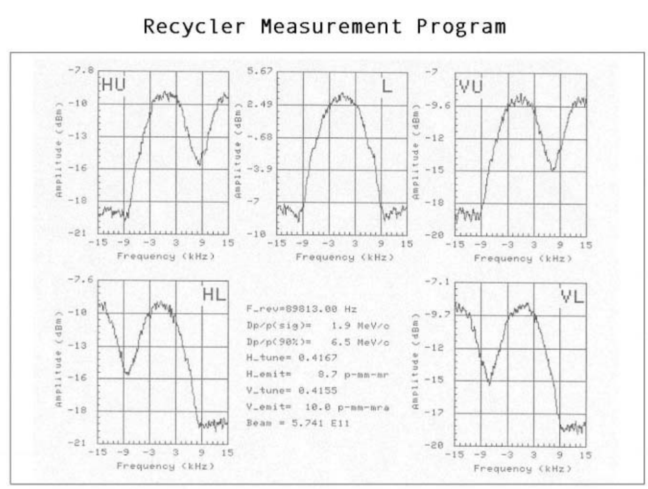

Figure 4. Automated Vector Signal Analyzer measurement of Recycler Schottky signals. Displays tune, momentum spread, revolution frequency, and calculated emittance.

TEVATRON

The Tevatron Schottky signals differ substantially from those observed in the Antiproton Source and Recycler rings. As was observed in the bunched beam cooling experiments, a large coherent signal is evident. (Figure 6) In the absence of front end filtering, this longitudinal line saturated the preamplifier. A different means of signal processing was necessary to keep active components in the linear operation range. A 100 MHz wide at 1.7 GHz cavity band pass filter is installed before the first preamp. This limited the peak signal seen by the first amplifier. The 100 MHz width allows sufficient bandwidth necessary to allow bunch-by-bunch gating. At the E17 location in the Tevatron where the pickups reside, beam separation is one hundred nanoseconds at 980 GeV. The directivity of the pickup was measured at 12 dB. Proton intensities are typically a factor of ten larger than antiproton intensities, hence gating is mandatory to segregate the antiproton from the proton signals.

An additional narrow band pass filter, 5 MHz wide at 1.7 GHz follows the gate reducing the signal level before additional gain and down conversion to base band. Down conversion is synchronous by phase locking to the Tevatron 53 MHz RF to generate the 1.7 GHz local oscillator. This technique allows monitoring the base band signal from injection at 150 GeV through the ramp to 980 GeV. An emittance monitor similar to that described will be added, except that the Tevatron will require a recursive digital FIR filter to remove the revolution components before integrating the betatron side bands.

Horizontal Schottky Pickup - Recycler

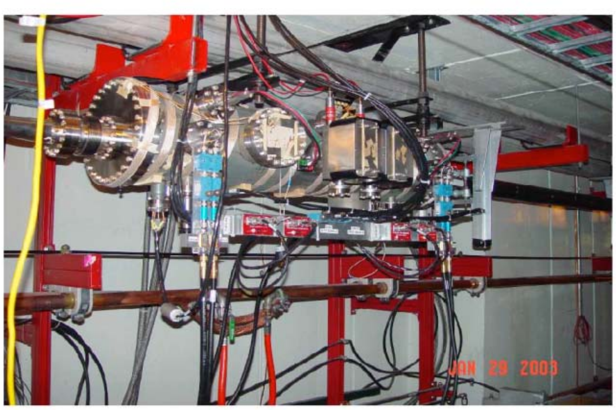

Figure 5. Recycler Horizontal Schottky Pickup Installation.

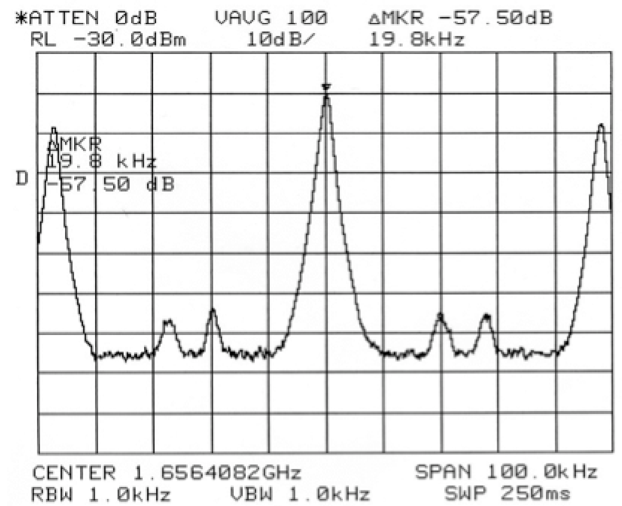

Figure 6. Microwave Spectrum of Tevatron Proton Horizontal Schottky. Large coherent longitudinal signal requires high system dynamic range.

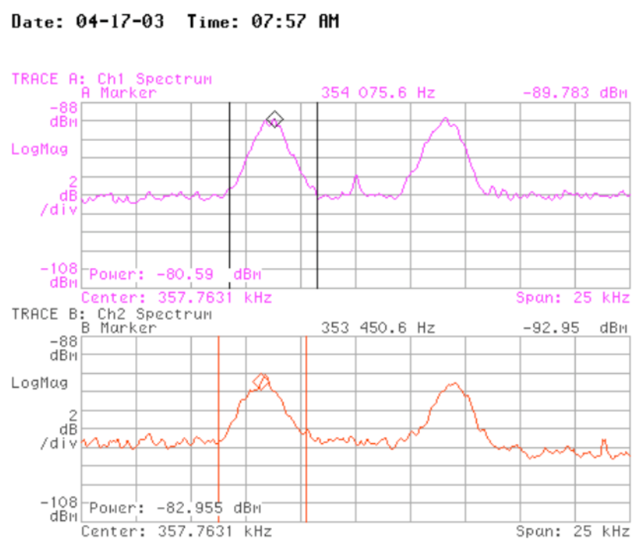

Figure 7. VSA display of Tevatron Antiproton transverse Schottky signals 6.1x 10^{11} Pbars. Top: Horizontal; Bottom: Vertical.

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