Microwave Schottky Beam Diagnostics

Tevatron Schottky Signals 1992 Bunched Beam Cooling Attempt

Figure 1: Example of a typical open loop proton vertical power spectrum measured with a spectrum analyzer.
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Tune, momentum spread, chromaticity derived from frequency domain

\[ \nu = \frac{\Delta f_t}{f_{rev}} \]

\[ \frac{\Delta p}{p} = \frac{\Delta f_{low} + \Delta f_{up}}{2 \times \eta \times f_{rev}} \]

\[ \xi = \frac{\Delta f_{up} - \Delta f_{low}}{2 \times f_{rev} \times \frac{\Delta p}{p}} \]

Figure 1: Example of a typical open loop proton vertical power spectrum measured with a spectrum analyzer.
Planar Pickup Arrays

4-8 GHz Planar Loop Pickups for Tevatron Bunched Beam Cooling
Gating is Essential & Allows Single/Multiple Bunch Monitoring

Figure 10. Effect of gating on signal to noise ratio. Left ungated bunched beam cooling signal. Right same signal with gating.
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Slotted Waveguide Pickup
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Schottky Pickup Frequency Response

Square Root of Impedance v.s. Frequency

- Delta Mode Reverse
- Delta Mode Forward
- Sum Mode Reverse
- Sum Mode Forward
Debuncher Cooling
8 Bands 4-8 GHz
1999

Accumulator Core Cooling
3 Bands 4-8 GHz
2002

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Measured Pickup Sensitivity in Recycler 2003

Sum Mode

Difference Mode

Directivity Measured at 12-15 dB
Beam Centering Reduces Common Mode

Not an Option for the Tevatron with Protons & Antiprotons on Helical Orbits

Recycler Horizontal Pickup 1 x 10^{11} Protons
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Location of Tevatron Schottky Pickups
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Recycler Installation

January 2003

Tevatron Installation

May 2012
Original Tevatron Schottky Signal Processing

Single Sideband Demodulation Preserves Chromaticity

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Tevatron Schottky Signal
Large Common Mode Signal Requires High Dynamic Range
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1.7 GHz Tevatron Single Bunch Horizontal Protons
LARP LHC Collaboration

- Propose Schottky system for LHC, Fall 2004
- Schottky accepted as part of LARP, Summer 2005
- Pickup design complete, plans sent to CERN, construction begins, Spring 2006
- Design of analog processing electronics with prototype, Fall 2006
- Installation of pickups and processor hardware at CERN, Spring 2007
- Installation of control interface hardware at CERN, Spring 2008
- Initial commissioning with beam 2009
- Turn over operation to CERN 2010
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Location of LHC Schottky Pickups

Point 4
Figure 2. Impedance of LHC Schottky pickup

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Tight Squeeze
LHC Beam Pipes Separated by 194 millimeters
LHC Schottky Triple Heterodyne Block Diagram
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System Noise Analysis

LARP LHC 4.8 GHz Schottky Monitor System Noise and Dynamic Range Analysis
Pilot bunch case 5x10^9 hybrid CMRR 20 dB
Tests of the 1.7 GHz Schottky at the SPS with 10^9 per bunch yielded 5 volts delta and 51 volts sum at the hybrid output. These results are used to estimate the signal level for the 4.8 GHz Schottky. Hybrid CMRR was 20 dB for the CERN test.

Calculations are done for single revolution lines. The integrated signal power is also calculated so that monitoring of gain saturation is possible at all stages. Total signal power is adjusted with every change in bandwidth due to a filter.

**Bold/RED Values are inputs**

- **Power**
  - Estimated input signal power: 0 dBm
  - Cavity filter 3 DB bandwidth: 20 MHz
  - Xtal filter 3 DB bandwidth: 15 MHz
- **Bandwidths**
  - Pickup input bandwidth: 200 MHz
  - KTB noise floor @ 29K: 174 dBm/Hz
- **Gain**
  - Gain due to gating: 3096.0 linear
  - Gate duty ratio: 2.008-04

**Stage Description**

<table>
<thead>
<tr>
<th>Stage Description</th>
<th>INPUT NF dB</th>
<th>INPUT Gain dB</th>
<th>Gain linear</th>
<th>Gain adjacent 2 stages linear</th>
<th>system liner</th>
<th>system NF</th>
<th>Gain signal dBm</th>
<th>Gain noise dBm</th>
<th>S/N</th>
<th>SNR Transverse (dB)</th>
<th>Total output signal dBm</th>
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</tbody>
</table>

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Pickup tanks installed at Point 4, Spring 2007
Microwave Schottky Beam Diagnostics

Triple Conversion Electronics Installed in Tevatron at E17
June 2007
Figure 6. Measured 100 dB instantaneous dynamic range at baseband in Tevatron signal processing electronics utilizing triple down conversion and crystal filters in 20 db steps. Input signal ranges from +10 dBm to -90 dBm. Center frequency 30 KHz, 2 KHz/div, 10 dB/div.
Importance of Low Phase Noise Local Oscillators

Test in the Tevatron - 400 MHz IF
Different Widths of Sidebands allows Chromaticity Measurement

Test in the Tevatron - Baseband output
Microwave Schottky Beam Diagnostics

400.78897 MHz RF to 10 MHz Reference Divider for LO sync

10.000 MHz Output

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LHC Pickup Plate Hardware
Switches, Variable Attenuator and Phase Shifter allow for Calibration & Common Mode Rejection
Microwave Schottky Beam Diagnostics

Crated up and on its way to CERN April 2007!
Microwave Schottky Beam Diagnostics

Point 4
Alcove
Hardware
May 2007

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Microwave Schottky Beam Diagnostics

Cable plant alcove point 4
LHC Pickup Hardware
Installed May 2007
Fermilab

Microwave Schottky Beam Diagnostics

Touring Final Installation
May 2007

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Microwave Schottky Beam Diagnostics

Tevatron Schottky Comfort Displays

Protons

Antiprotons
Microwave Schottky Beam Diagnostics

Tevatron Tune Plot and Gate Monitor Comfort Displays
Tevatron Antiproton Beam-Beam Tune shift Before and After Correction based on Schottky Measurement
Microwave Schottky Beam Diagnostics

Measured Beam Beam Tevatron Tune Shift

Store 4243

- BB tune spread from Schottky+SBD
- Xi parameter from SL+SBD (arb units)

SBD=sampled bunch display
SL=synchrotron light monitor

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Tevatron Individual Antiproton Bunch Tunes & Chromaticity
Microwave Schottky Beam Diagnostics
LHC Schottky Comparison Protons and Ions

Bunch by bunch spectra (stable beams)

- Protons
- Ions

Beam 1
Revolution frequency in LHC
Schottky bands

Beam 2
Horizontal

Beam IV Site 125 Beam IV Site 46

Beam IV Site 125 Beam IV Site 46

Vertical

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Microwave Schottky Beam Diagnostics
LHC Schottky Protons @ 3.5 TeV
Microwave Schottky Beam Diagnostics

LHC Schottky Chromaticity Injection thru Ramp
Summary

- H & V Pbar Schottky in Recycler 2003-2011
- H & V Proton + Proton Schottky in LHC 2009-Present
- Ability to measure tune, chromaticity, momentum spread
- Gating allows measurement of individual and any combination of bunches
- Emittance can be measured when calibrated
- 100 dB of dynamic range
Thank You!