Processing of the Schottky Signals at RHIC

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Abstract

Schottky monitors are used to determine important beam parameters in a non-destructive way. In this paper we present improved processing of the transverse and longitudinal Schottky signals from a hi-Q resonant 2.07 GHz cavity with the main focus on providing the real-time measurement of beam tune, chromaticity and emittance during injection and ramp, when the beam conditions are changing rapidly. The analysis and control is done in Python using recently developed interfaces to Accelerator Device Objects [1]

Detectors

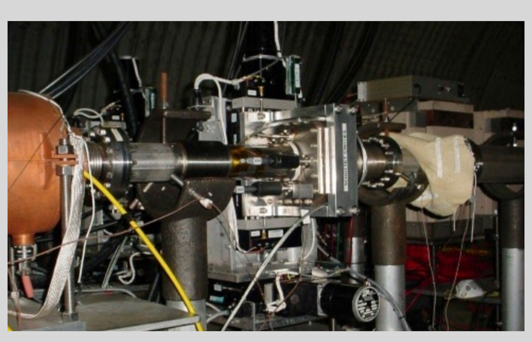


Fig 1. Detector assembly on one of the RHIC beam pipes.

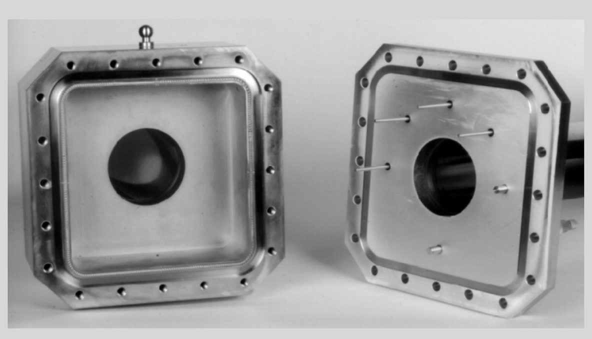


Fig 2. Schottky cavity.

The cavity is mounted on a 2-D moving frame. It uses four probes to detect signals from the different modes in the cavity. Vertical probe 2.067 GHz. Horizontal probe 2.071 GHz. Longitudinal probe 2.742 GHz.

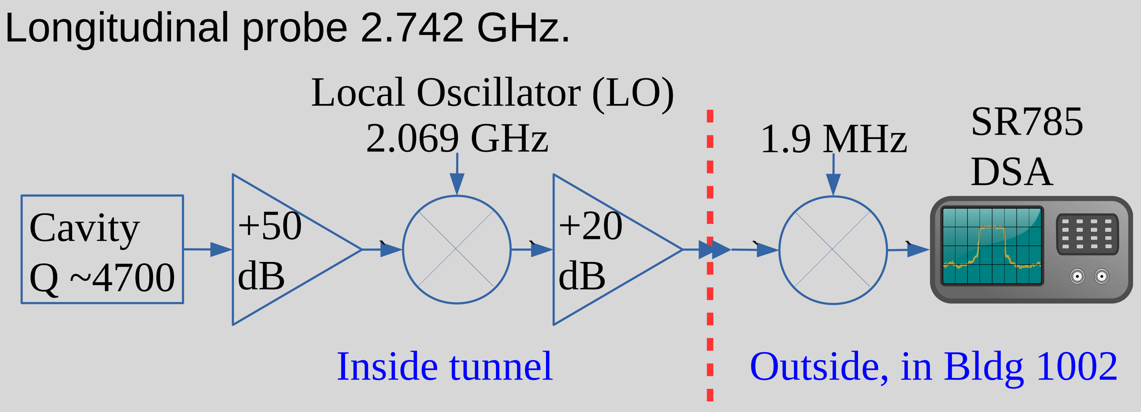
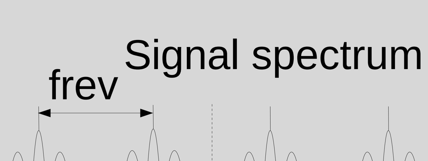
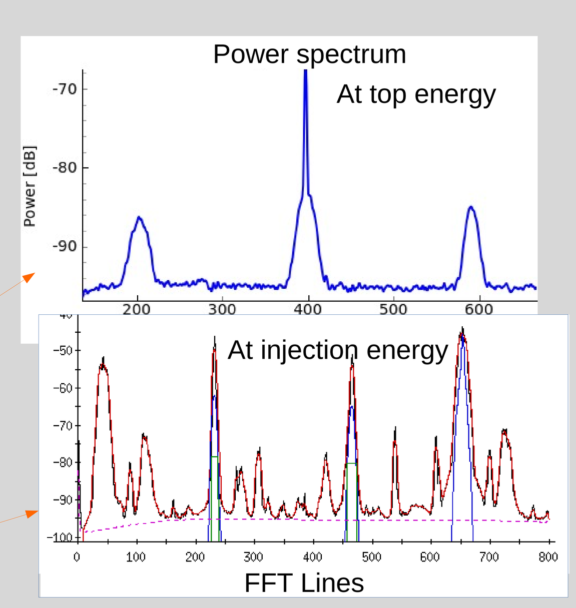


Fig 3. Signal processing diagram.

Measured Power Spectrum

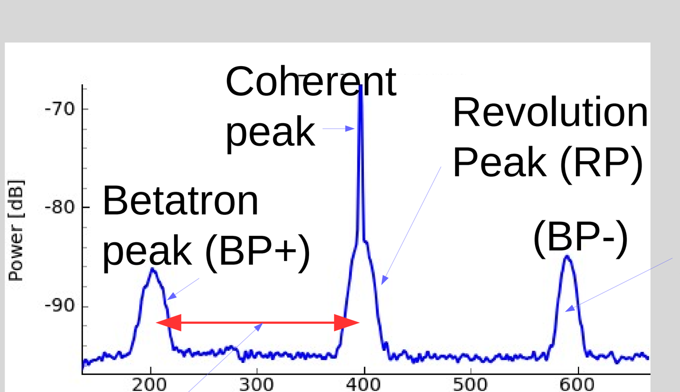


LO = 2.069 GHz
frev = 78 KHz
Harmonic = 26525.5



At top beam energy, the fractional part of the harmonic is adjusted to 0.5. It deviates from that during injection.

Fig 4. Power spectrum is complicated by the existence of image frequencies.



$$Emittance: \sim area(BP_+)$$

$$Fractional\,beam\,tune = \frac{position(BP_+) - position(RP)}{frev}$$

$$Chromaticity: \sim \frac{(width(BP_+) - width(BP_-))}{(width(BP_+) + width(BP_-))}$$

Fig 5. Extracted beam parameters [2], [3].

Acknowledgements

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Processing of the changing signals

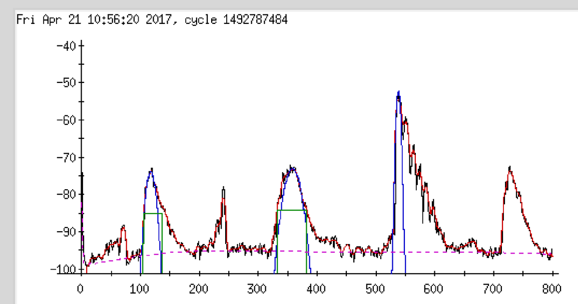

Fig 6. Signal spectrum during ramp-up of the beam energy.

Signals are changing rapidly during the ramp, the RF frequency is changing for ~8 harmonics in 30 seconds.

Two options have been considered

(1) Adjust LO frequency as a function of the RF frequency.

Requires unprecedented stability (~1.e-8) of the control loop

(2) **Post processing of the changing signals, peak recognition based on known RF.**

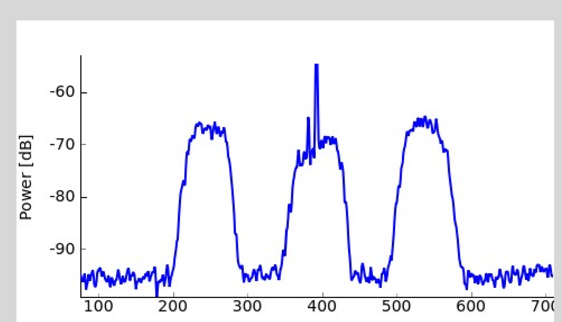

Fig 7. Signal spectrum at top beam energy.

Complications

- Noise is not gaussian,
- Top of the peaks have fine structure due to synchrotron harmonics.
- Peak shape is not always gaussian.

Processing Algorithm

(1) **Convert spectrum data to linear scale**. The data from the spectrum analyzer are in logarithmic scale. The main benefit of using the linear scaled data is that the analysis is less sensitive to the base line fluctuations.
(2) **Filter the noise** using gaussian FIR filter of the N-th order. The order of the filter is selected to be equal to the width of the expected coherent peak but not less than 4. The filter is normalized to conserve the signal energy.
(3) **Peaks recognition**, based on known RF frequency, described below.
(4) **Find the coherent peak** using Gaussian fit in the near vicinity of the found peak.
(5) **Recover the revolution peak**:
- Make the hole in the revolution peak by excluding the coherent peak points.
- Fit the chipped peak with a gaussian.
- Fill the hole in the peak with the fitted points.

(6) **Find parameters of all peaks**.
- Find the left and right edges of the peak at the crossing points of the filtered data at a half-amplitude level. The **peak width** is the difference between the edges.
- The **peak position** is the arithmetic average of edges.
- The **peak area** is the sum of the peak points above the noise floor (pink line above the noise floor on fig. 8).

(7) **Calculate the beam parameters** according to equations on Fig. 5.

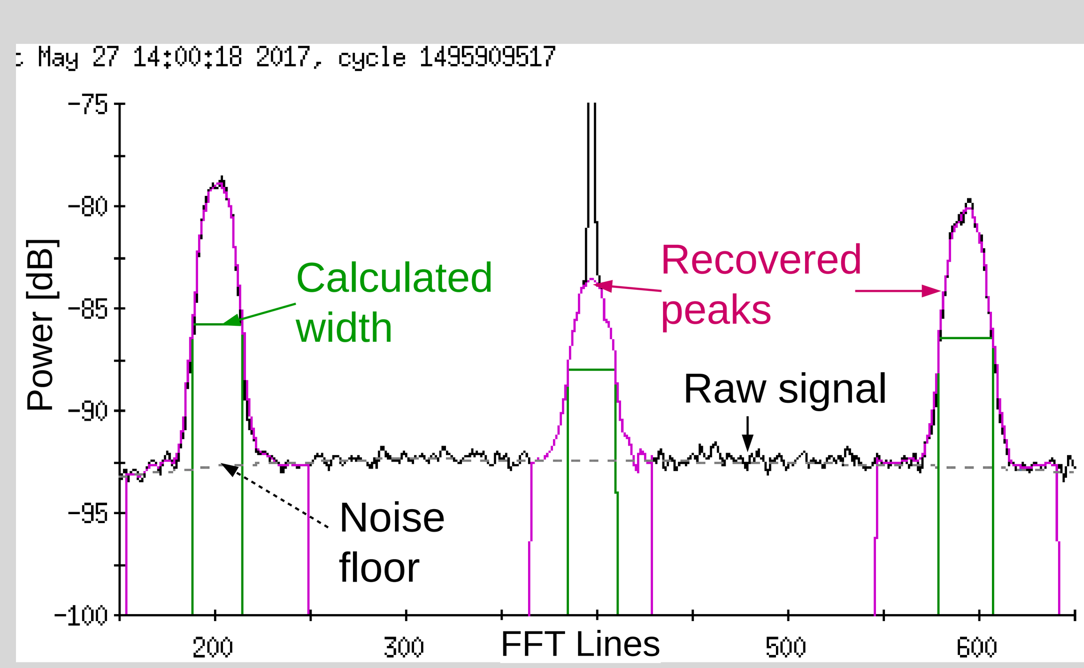

Fig 8. Result of the spectrum analysis.

Adjustable parameters.

There are six adjustable parameters:
(1): Filter Order. Default = 4.
(2,3,4): Guess widths of the coherent peak, revolution peak and betatron peaks.
(5,6): Limits for the expected tunes.

Dynamic Peak Recognition

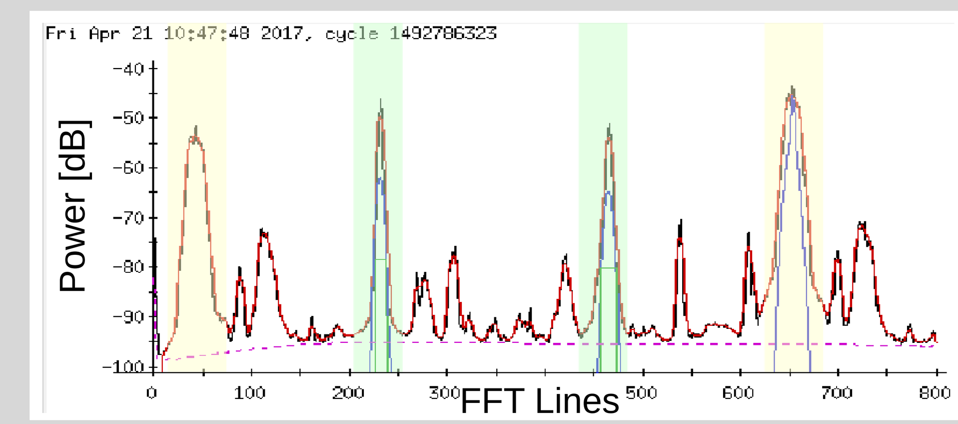

Fig 9. Regions of Interest for coherent+revolution peak (yellow) and betatron peaks (green) at injection energy.

Algorithm:

(1)Calculate ROI (regions of interest) of the coherent peak, based on RF frequency. Two coherent peaks may be present in the spectrum.
(2) Find N=10 of highest local peaks, sort them according to amplitude.
(3) Identify the coherent peak as a highest peak in the coherent ROI.
(4) Iterate over the rest of the peaks and check if they are in the ROI for betatron peaks .

Results and Discussion

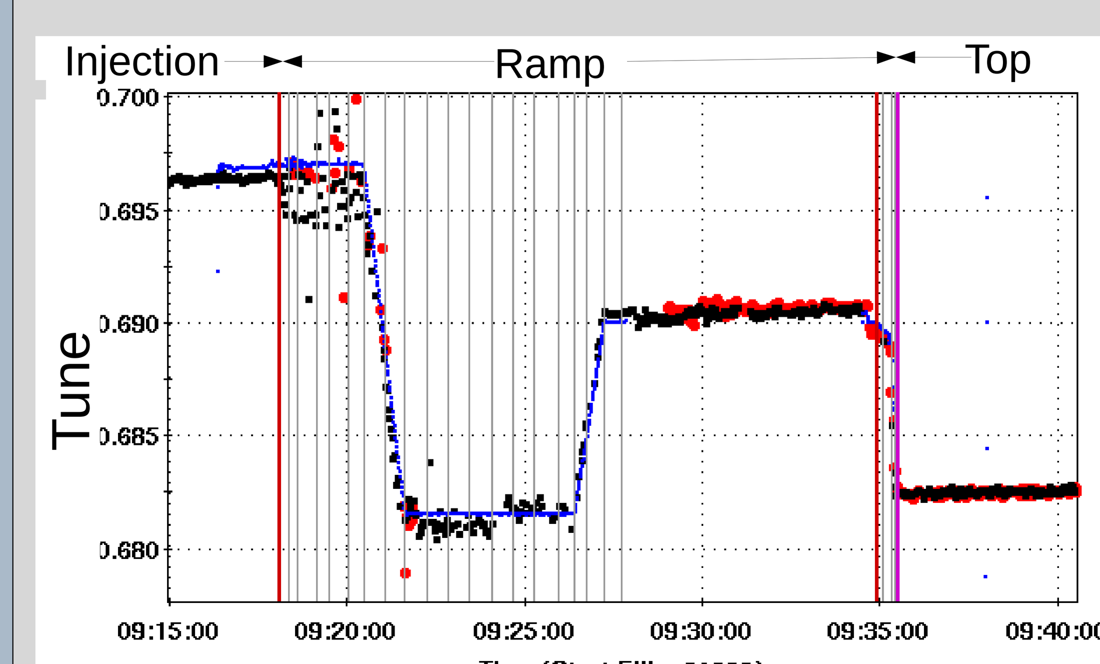

*Fig 10. **Tune** measurement results (black dots) at injection, during ramp-up and at top energy. Shown also are the tune set points (blue line) and the result of an analysis using gaussian least-squared fit (red dots). Precision at top energy is ~0.1%*

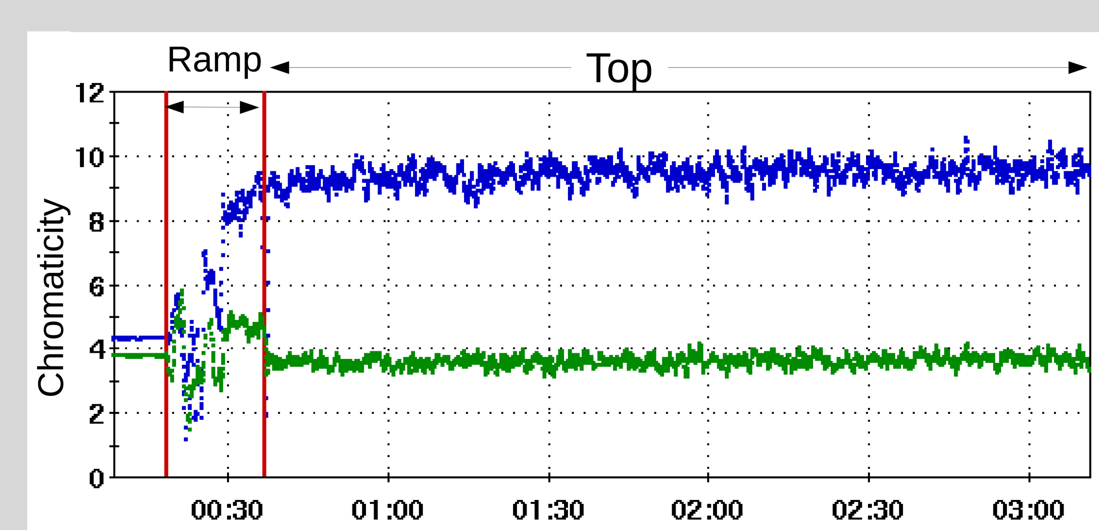

*Fig 11. **Chromaticity** measurement results for horizontal (blue) and vertical (green) schottky probes. The precision at injection energy is 2%, at top energy it is 10% due to the low signal amplitude.*

Conclusion

The fast, robust algorithm for extracting beam parameters from the Schottky signals in dynamic beam conditions is presented. It provides the same precision as a conventional algorithm, based on non-linear least-square fitting, but does not suffer from convergence problems.
- The precision of the **tune** measurement is 0.1% at injection and top energies and 0.4% during ramp .
- The **chromaticity** is measured with precision 2% at injection and 10% at top energy.
- The power of betatron peaks, which is proportional to **emittance,** is measured with 1% precision.
- The implementation using **Python** made it possible to quickly develop new, more efficient algorithms and even gain in processing performance over C++ code (the processing time of a 800-point spectrum is ~20 ms).

References

[1] K.A. Brown , T. D'Ottavio, W. Fu, A. Marusic, J. Morris, S. Nemesure, A. Sukhanov. *ICALEPCS 2017, TUPHA 153*.

[2] D. Boussard, Schottky Noise And Beam Transfer Function Diagnostics, *CERN, Geneva, Switzerland, 1986*.

[3] K.A. Brown, M. Blaskiewitz, C.Degen, A. Della Penna. *Phys. Rev. Accelerators and Beams, v12, 012801, 2009*