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REAL TIME MOMENTUM SPREAD MEASUREMENT OF THE CERN ANTIPROTON DECELERATOR BEAM

P. Freyermuth*, B. Dupuy, D. Gamba, CERN, Geneva, Switzerland

Abstract

Constant optimisation and diagnostics of the cooling processes in the CERN antiproton decelerator (AD) relies on a de-bunched beam momentum spread real time measurement. This article will describe the renovation of the acquisition chain of the longitudinal Schottky diagnostics in the AD, using standard CERN hardware and software to maximize reliability, ease maintenance, and meet the requirements for standard operational tools. The whole chain, from the pick-up to the operation software applications will be described with emphasis on the implementation of the data processing running on the front-end computer. Limitations will also be discussed and outlook for further development given.

THE AD LONGITUDINAL PICK-UP

The AD longitudinal pick-up (LPU) consists of two specially designed ultra-low noise ferrite-loaded beam current transformers and amplifiers [1]. They are optimized respectively for high (0.25 – 30 MHz) and low (0.02 – 3 MHz) frequency ranges.

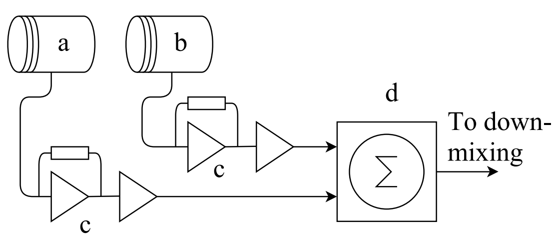

Figure 1: LPU transformers (a & b), amplifiers (c) and summing unit (d).

The output signals of the two transformers are filtered and added together by a summing unit to obtain a flat frequency response over the 0.02-30 MHz bandwidth (Fig. 1). This system is used since the AD went operational in 2001.

SIGNAL DOWN-MIXING

The longitudinal Schottky spectrum of a de-bunched beam consists of bands of frequencies (Schottky bands), located around harmonics (n) of the average revolution frequency. The momentum spread distribution can be derived from these Schottky bands. The power spectral density of these bands decreases with n, but the width of these bands increases by a factor n (Eq. 1) [2].

$$\Delta f = n\, f_0\, \eta\, \frac{\Delta p}{p} \quad , \tag{1}$$

where Δf is the width of the Schottky band, n is the harmonic number, f_0 is average revolution frequency, η is the slip factor given by the synchrotron parameters and $\Delta p/p$ is the momentum spread.

The band selection, therefore, of the harmonic, is a balance between signal-to-noise ratio, frequency resolution, and LPU and acquisition bandwidth.

To accommodate the different revolution frequencies of the AD cooling plateaus, the signal from the LPU is mixed with a signal generated from a harmonic of the revolution frequency minus 50 kHz (Table 1).

Table 1: Down Mixing Frequencies

Plateau momentum [MeV/c]	Revolution frequency [kHz]	Harmonic	Mixing frequency [kHz]
3574	1589.411	2	3128.822
2000	1487.722	2	2925.445
300	500.465	8	3953.721
100	174.155	8	1343.240

The mixing unit includes filters for image frequency rejection. The result is a transposition of the signal to a fixed centre frequency of 50 kHz, enabling fixed parameters for different cooling plateau energies and modest analogue-to-digital converter (ADC) hardware specifications.

An additional 32 dB amplifier is also placed before the mixer (Fig. 2), pulling the signal strength into the range of the ADC sensitivity.

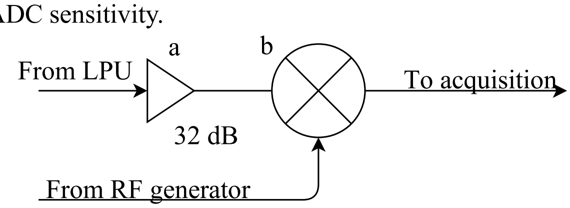

Figure 2: Simplified schematic of the signal down-mixing with a low-noise amplifier (a) and the mixing and filtering unit (b).

* pierre.freyermuth@cern.ch

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SIGNAL ACQUISITION

The signal acquisition was previously performed by a now obsolete National Instrument ADC module. It has been replaced by a CERN Open Analogue Signal Information System (OASIS) [3].

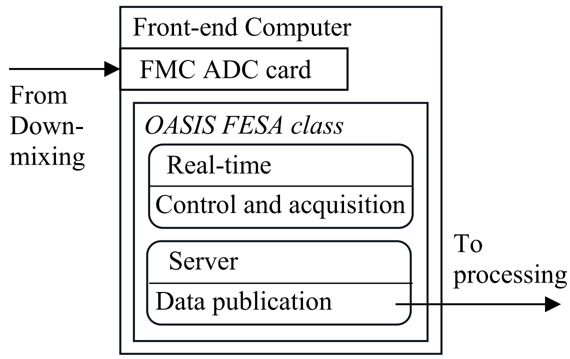

Figure 3: Overview of the acquisition system.

It consists of a 4 channel 100 million samples per second (Msps) 14-bit ADC card embedded on a FPGA Mezzanine Card format (FMC). The ADC card is operated in a Front-End Computer (FEC) by the OASIS system. OASIS is using the CERN Front-End Software Application (FESA) framework [4], enabling clients to subscribe remotely to the digitalized signal data (Fig. 3).

A typical acquisition setting is a sampling rate of 3 Msps during a 100 ms segment, for a total of 3E5 samples per segment. The acquisition segment is repeated and published continuously at 5 Hz. The voltage range is set to the maximum sensitivity at +/- 50 mV.

PROCESSING

The computation of the Schottky spectrum is performed by compiled C++ code running on the same FEC as the acquisition, using the FESA Framework (Fig. 4).

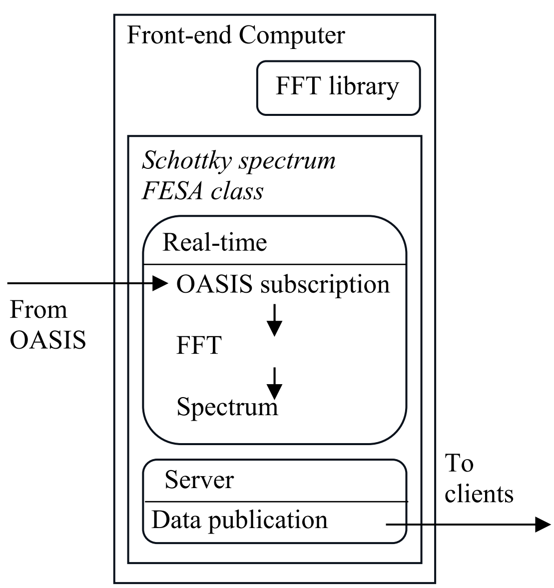

Figure 4: Overview of the signal data processing.

The real time layer of the FESA class is subscribed to the OASIS device and receives the raw data. The optimised library FFTW [5] is used for the fast Fourier transform (FFT) of each acquired segments.

The power spectrum is computed, and only a frequency range centred around 50 kHz is stored. The typical frequency range corresponding to the AD momentum spread capabilities is 48 – 52 kHz. It allows a data reduction down to 500 points per spectrum, easing the data transfer and storage.

The server layer of the FESA class takes care of the publishing of computed data to the subscribed clients.

The FEC is fitted with an Intel Core i5 CPU and can run two instances of the FESA class, producing and publishing Schottky spectra at 5 Hz per device.

Additionally, another FESA class generates snapshots of a Schottky spectrum, only updated at key moments along the AD deceleration cycle (Fig. 5).

AD OPERATION

The main goal of the renovation of the acquisition and processing chain was to be able to get a visual representation of the momentum envelop along all the AD cooling plateaus. (Fig. 5).

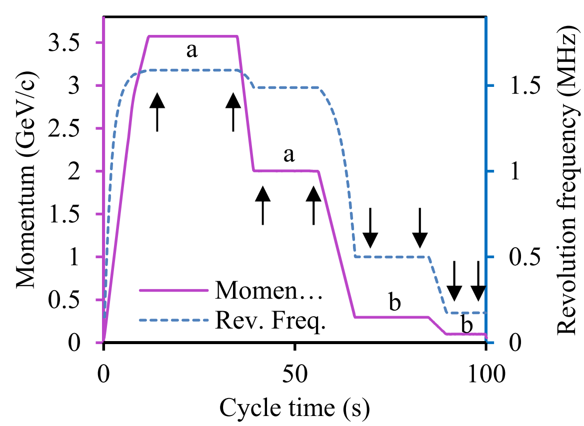

Figure 5: The two stochastic (a) and the two electron (b) cooling plateaus of the AD deceleration cycle, and the key moments indicated by black arrows.

Such real time publication of the longitudinal Schottky spectrum enables live animation in multiple applications used daily in operation. Live data availability is particularly relevant for a slow cycling machine, giving the operators the opportunity to apply corrections before the start of the next cycle, reducing setting-up and diagnostic time.

The Operation Application

A java application has been developed for the operators, available on control rooms computers (Fig. 6). Schottky spectra are displayed in a three-dimensions chart. The time axis is kept horizontal to be synchronised with other two dimensions time charts. The power spectrum value is colour coded, and the vertical axis represents the frequency.

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The AD magnetic field and circulating intensity chart is synchronized with the time horizontal axis and displayed at the bottom. The actual spectrum is displayed on the right and synchronized with the vertical frequency axis. All the charts are animated with the real time publishing of the data at a rate of 5 Hz.

This application is daily used by the operators for diagnostic and fine tuning. The resulting picture is easily memorised by operators, and any drift or shape changes can be spotted efficiently in one look. It is also a useful asset for time consuming setup and adjustment, such as the tuning of the stochastic cooling, where the representation of the evolution of the beam momentum envelop along the cooling process is instrumental.

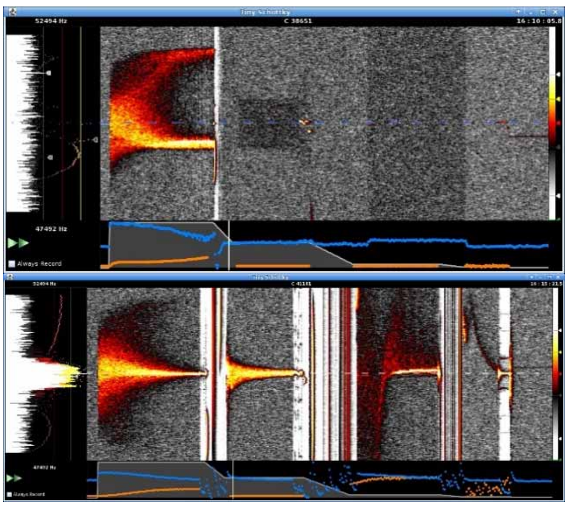

Figure 6: Real time longitudinal Schottky spectrum showing a de-tuned stochastic cooling system during AD start-up (top) and a nominal AD operation cycle (bottom).

Long Term Logging

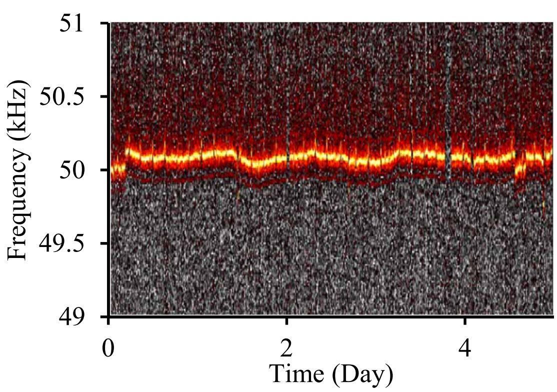

Figure 7: Example of historical data of the longitudinal Schottky spectrum at the end of the 300 MeV/C cooling plateau, over 5 days.

Schottky spectra at the start and the end of each of the four cooling plateaus (Fig. 5) are recorded for every AD cycle using NXCALS, the CERN logging infrastructure [6]. It allows machine stability analysis over several days and observation of any drifts of the cooling systems (Fig. 7).

Averaging

The full cycle length Schottky spectrum recording of each AD cycles are also saved as an image. By averaging images of several cycles during a stable operation period, one can enhance the details of the envelop of the longitudinal cooling processes performance (Fig. 8).

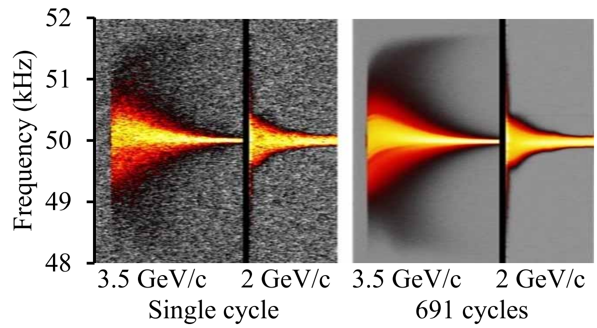

Figure 8: A single Schottky recording of the stochastic cooling plateaus (left) and the average of 691 recordings (right).

The Anti-Proton Production Status Screen

Displayed on large screens in control rooms and published worldwide via a CERN webpage [7], the status screen (also called "fix-display") of the AD now integrates the real time animated Schottky spectrum. This addition enables better, and faster diagnostics of the AD cooling processes for a prompt action from the operation team.

LIMITATIONS

Due to hardware limitations, the generated signal derived from the revolution frequency, used for the down mixing process, works only for stable energy plateaus. In addition, the dynamic of the signal for bunched beam is too high for the acquisition chain. This prevents the system to give any valid measurements during ramps.

The LPU rather weak signal during the 300 MeV/c and 100 MeV/c low energy plateaus is also a known limitation of the system. Consequently, less details of the momentum envelop during the electron cooling processes are visible.

CONCLUSION AND OUTLOOK

The AD longitudinal Schottky measurement for operation has been renovated and successfully deployed with standard CERN hardware and software. It is used for day-to-day operation, and it is a key asset for setup and diagnostics.

Further improvements are under studies, like the computation of the actual momentum spread in percent instead of the signal frequency.

A feasibility study to deploy a similar system for the ELENA machine, where the beam energy is even lower, is ongoing.

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REFERENCES

[1] C. Gonzalez and F. Pedersen, "An ultra-low noise ac beam transformer for deceleration and diagnostics of low intensity beams.", *Particle Accelerator Conference, New York, USA,* 29 March - 2 April, 1999, pp. 474-476. doi: 10.1109/PAC.1999.795736

[2] D. Boussard, "Schottky noise and beam transfer function diagnostics 1995 ed.", in *CAS - CERN Accelerator School: 5th Advanced Accelerator Physics Course*, pp.749-782. doi: 10.5170/CERN-1995-006.749

[3] What is OASIS?, https://be-dep-css.web.cern.ch/oasis

[4] What is FESA?, https://be-dep-css.web.cern.ch/fesa

[5] FFTW, https://www.fftw.org

[6] J.P. Wozniak and C. Roderick, "NXCALS - Architecture and Challenges of the Next CERN Accelerator Logging Service", in *Proc. ICALEPCS'19*, New York, NY, USA, Oct. 2019, pp. 1465-1469. doi:10.18429/JACoW-ICALEPCS2019-WEPHA163

[7] AD-ELENA, https://op-webtools.web.cern.ch/Vistar/vistars.php?usr=ADE

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