White-rabbit Based Revolution Frequency Program for the Longitudinal Beam Control of the CERN PS

D. Perrelet, Y. Brischetto, H. Damerau, D. Oberson[1], M. Sundal[2], A. Villanueva CERN, Geneva, Switzerland

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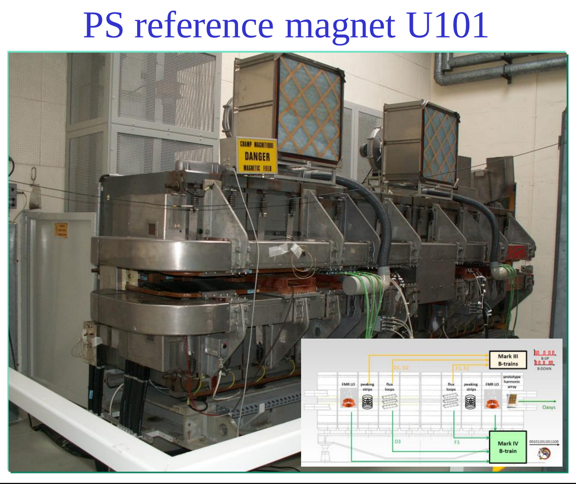
Abstract

The measured bending field of the CERN Proton Synchrotron (PS) is received in real-time by the longitudinal beam control system and converted into the revolution frequency used as set-point for beam phase and radial loops. With the renovation of the bending field measurement system the transmission technique is changed from a differential sequence of pulses, the so-called B-train, to a stream of Ethernet frames based on the White Rabbit protocol. The packets contain field, its derivative and auxiliary information. A new frequency program for the conversion of the bending field into the revolution frequency, depending also on parameters like radius of the accelerator and the particle type, has been developed. Instead of storing large conversion tables from field to frequency for fixed parameters, the frequencies are directly calculated in programmable logic (FPGA). To reduce development time and keep flexibility, the conversion is processed in real-time in the FPGA using Xilinx floating-point primitives mapped by a higher level tool Simulink System Generator. Commissioning with beam of the new frequency program in the PS is progressing.

CERN Proton Synchrotron (CPS) reference magnet U101, new B-field measurement and transmission setup

Mark IV B-train → Transmission of B-field and field derivative B-dot (*dB/dt*) over optical fibers as 32bits signed numbers into Ethernet frames using White Rabbit protocol

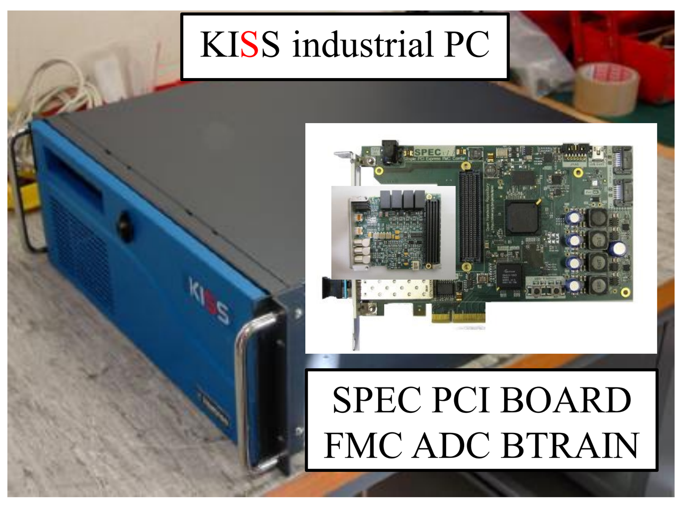
PS reference magnet U101



ADC

ADC

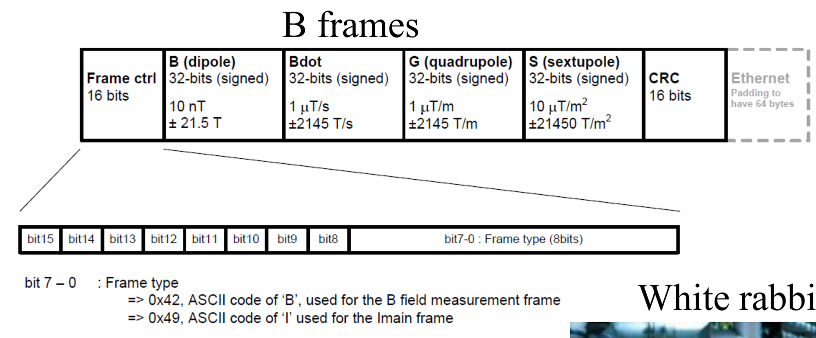
B-field measurement and calibration
FMR for referencing
∫ of flux coil voltage



B-field and B-dot transmission

White Rabbit implementation
Ethernet B frames forging
Streamer fifo TX
WRPC PTP CORE
Ethernet MAC
WR TX → PHY → SFP optical
Firmware, driver and fesa class
DDR memory, publishing data

B frames



White rabbit switch

Optical fiber link 150 meters

New B-field measurement system is referenced at each start of the cycle by a FMR reference marker closer to the injection field, thus reducing the ramp down constraint besides improving the injection accuracy. The resolution is 10 nT and the magnetic field information are distributed at a fixed rate of 250 kHz. The regulation done in *B*, has to cover the range from 600 G to 13000 G with a maximum rate of ~ 30 kG/s.

CERN Proton Synchrotron (CPS) LLRF side B-field reception and conversion to revolution frequency f_{rev} setup

New PS frequency program

CPU MEN A20

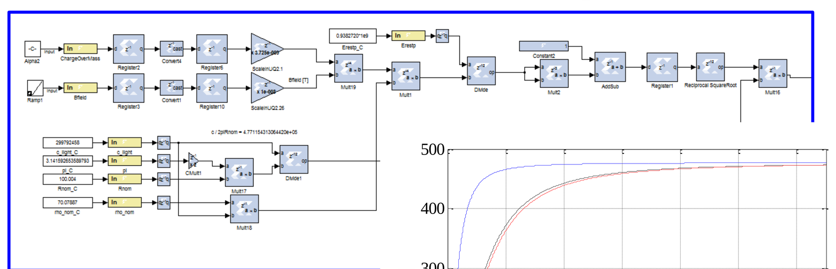
SVEC VME BOARD FMC-DTX/DTRX-4CHA

B-field and Bdot reception

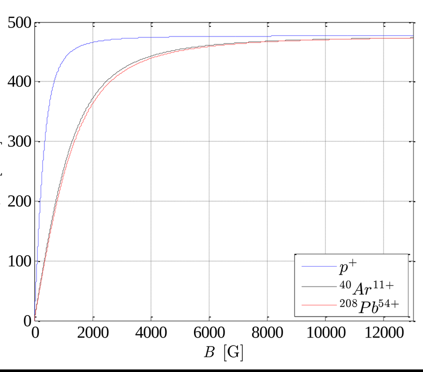
SFP optical→ PHY → WR RX
Ethernet MAC
WRPC PTP CORE
White rabbit implementation
Streamer fifo RX
Ethernet B frames decoding
Link latency measurement
PPM behaviour
Firmware, driver and fesa class
DDR memory for observation

Conversion of B-field to open-loop revolution frequency f_{rev} implemented in floating-point

Theoretical relationship



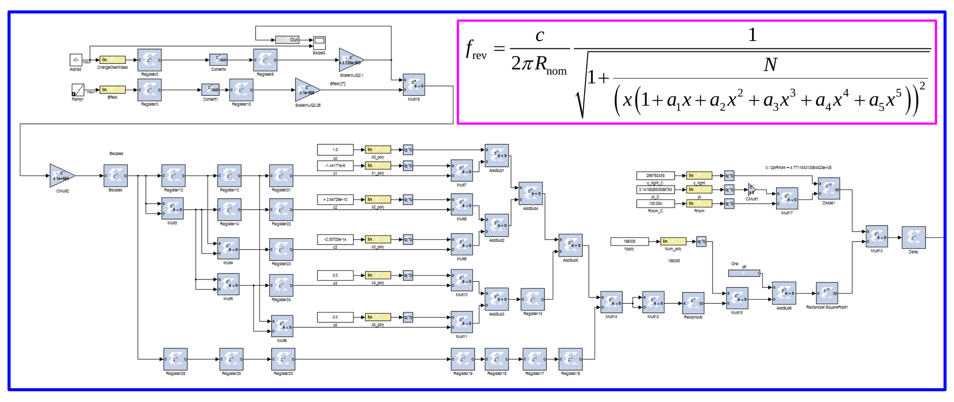
$$f_{rev} = \frac{c}{2\pi R_{nom}} \cdot \frac{1}{\sqrt{1+\left(\frac{E_0}{b\cdot B\cdot c\cdot \rho_{nom}}\right)^2}}$$



Signal processing requires B, b, c, R_{nom}, ρ_{nom} and E_0

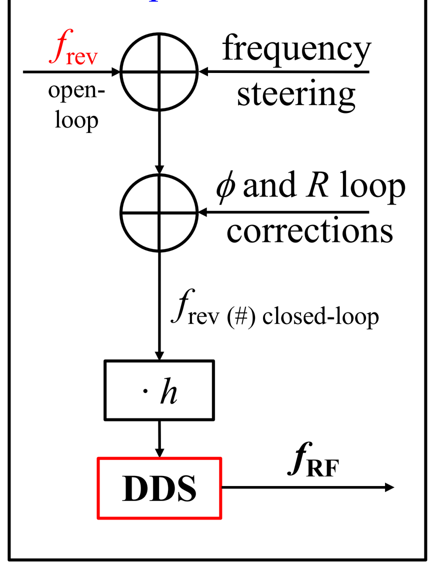
Beam-based fit model

$$f_{rev} = \frac{c}{2\pi R_{nom}} \cdot \frac{1}{\sqrt{1+\frac{N}{\left(x(1+a_1x+a_2x^2+a_3x^3+a_4x^4+a_5x^5)\right)^2}}}$$

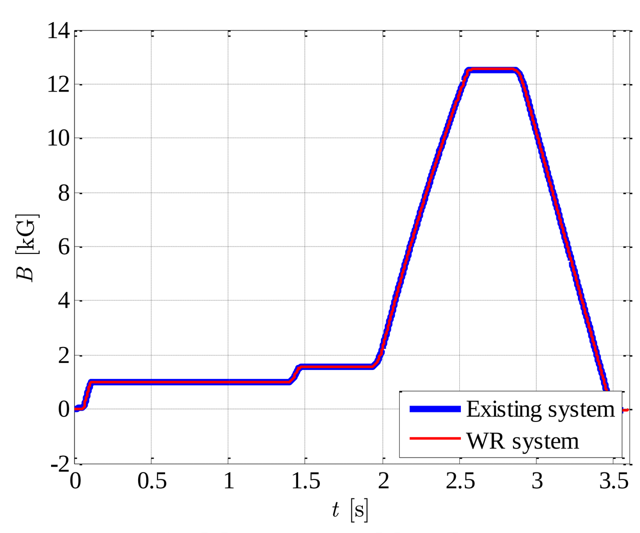


Parameter N and polynomials coefficient $a_1, a_2, .., a_5$ extracted by post-processing

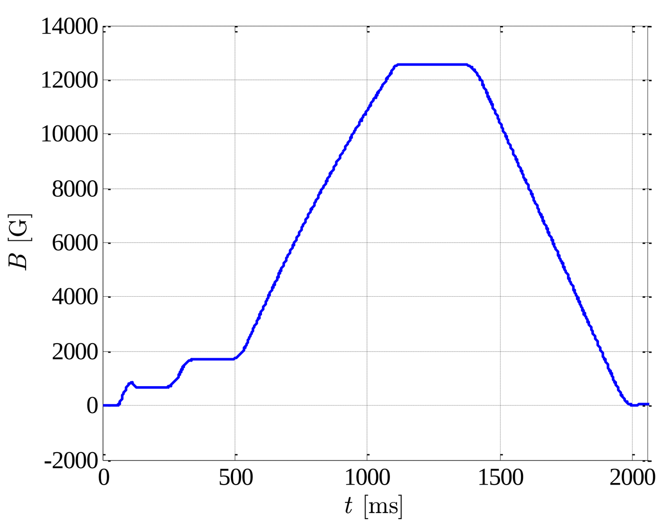
Simplified LLRF



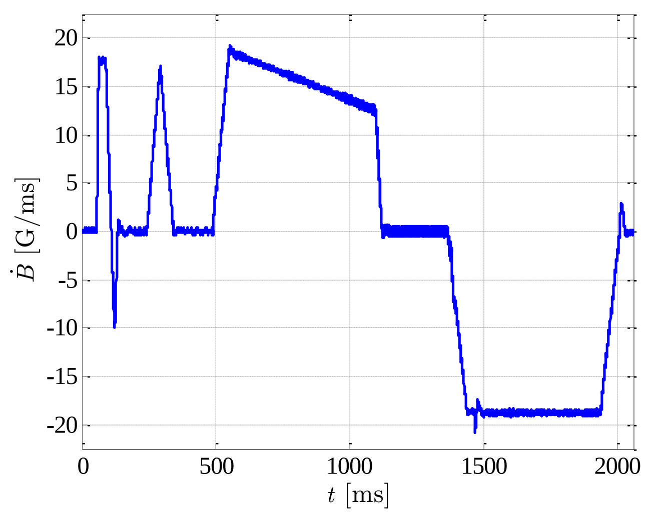
Commissioning and beam measurements



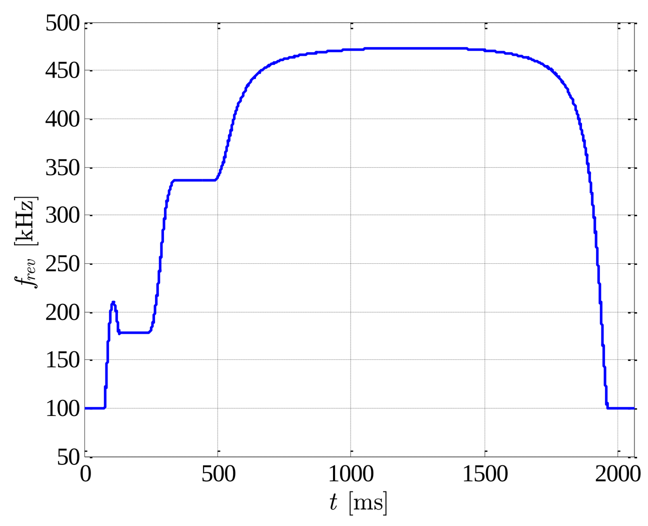
Magnetic field measured by the two systems.



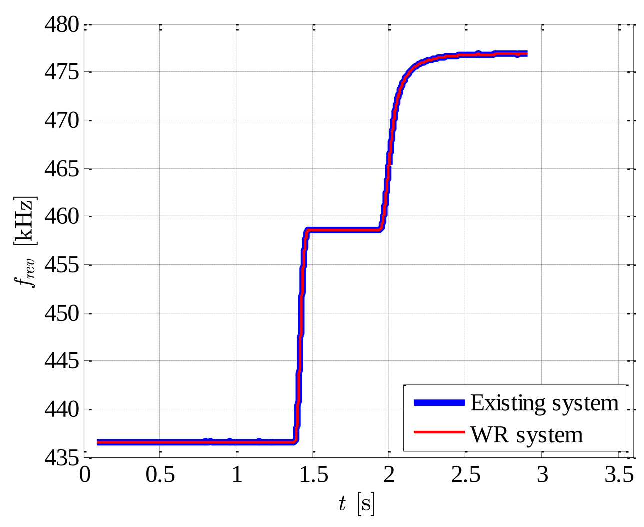
Received magnetic field available in DDR memory of a single bunch ion cycle.



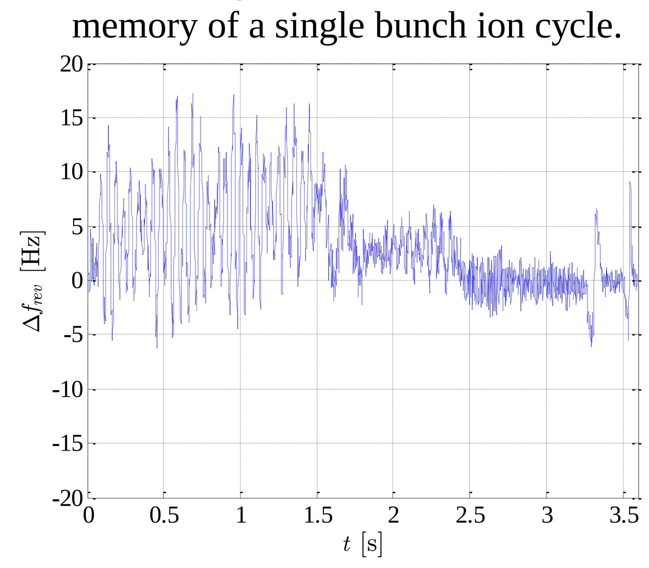
Received magnetic field derivative of ion cycle.



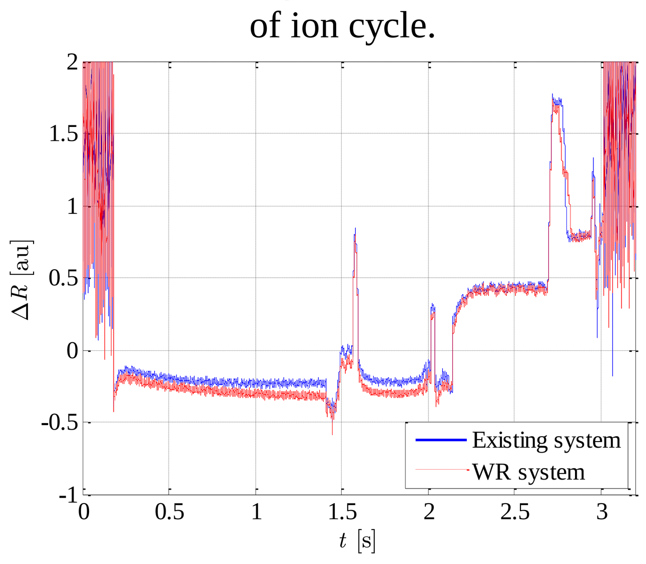
Real-time WR open-loop revolution frequency f_{rev} using $^{40}Ar^{11+}$ scaling factor, b=02773.



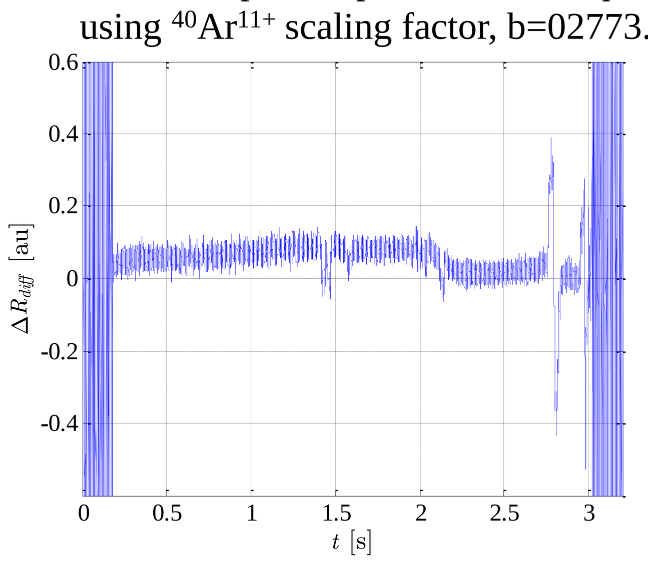
Closed loop revolution frequency of a LHC-type 25ns spaced proton beam for both systems.



Δf_{rev} closed loop between existing and WR-system.



Beam control analogue radial loop error signal ΔR averaged on 4 LHC proton beam cycles.



Difference on averaged ΔR for existing and WR-system. Blow-up, transition crossing and ejection synchronization are visible.

- **New system fulfills requirements and shows ability to accelerate proton beam**
- **Validations and commissioning need to be done with ions to complete its integration in the CERN complex infrastructure.**
- **Future improvements like latency-link surveillance with alarms, more advanced observations in memory being added.**

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([1] HEIA, [2] IST)

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