200 MHZ RF SOURCE FOR THE CERN PS

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Abstract

The CERN Proton Synchrotron is equipped with six fixed-frequency cavities at 200 MHz for controlled longitudinal emittance blow-up and bunching. These cavities require a phase-modulated RF signal close to their resonance frequency. Due to the 10% sweep of the revolution frequency during acceleration, the harmonic number of the 200 MHz system changes from 458 to 420 along the cycle. A compact DDS-based RF source has been developed and put into operation. The harmonic number is computed on the fly and the modulated RF signal is directly generated from the digital closed-loop revolution frequency. For the sinusoidal phase modulation a low-frequency DDS has been implemented in the programmable logic controlling the phase of the main RF DDS.

Motivation

The PS is equipped with six fixed-frequency RF cavities at 200 MHz. The cavities are driven by a phase modulated RF signal close to their nominal resonance frequency, f_0 of 199.948 MHz. Originally the modulated drive signal was generated by frequency multiplication of the closed-loop revolution frequency with a complicated phase locked loop system. A divider with a look-up table was required to derive the multiplication factor, i.e. the harmonic number h, for the 200 MHz cavities from a digital representation of the revolution frequency. An external programmable phase shifter was needed for the phase modulation.

The same functionality has been implemented into a **new DDS-based RF source**, **which directly generates the phase-modulated drive signal for the cavities from the digital closed-loop revolution frequency**. Besides a significant reduction of the hardware, the new RF source has a harmonic number range beyond the original PLL-based set-up. This already allowed longitudinal blow-up of lead ion bunches operating the 200 MHz cavities on h = 595, a harmonic number previously impossible due to limitations of the divider.

Algorithm

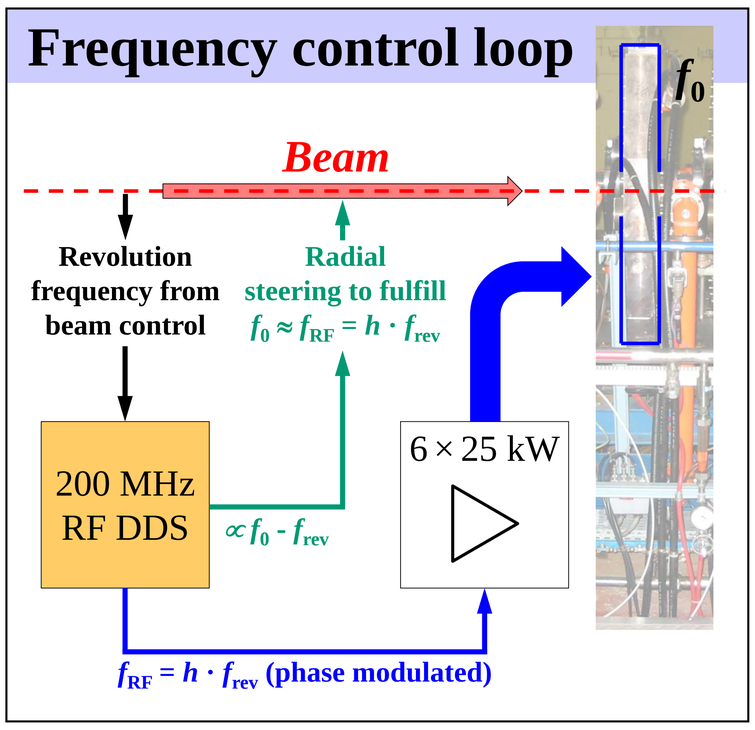
During acceleration of protons, the revolution frequency in the CERN PS increases from 436.6 kHz to 476.8 kHz (10% of velocity increase). For lead ion beams the relative frequency swing can be up to a factor of 2.7. As the bandwidth of the 200 MHz cavities is much lower, the harmonic number must change along the cycle to assure that $f_{RF} = h \cdot f_{rev}$ stays reasonably close to the resonance frequency, f_0 = 199.948 MHz of the cavities, thus:

$$f_{RF} = h \cdot f_{rev} = ||f_0/f_{rev}|| \cdot f_{rev} \text{ with } h = ||f_0/f_{rev}||$$

Especially at injection energy, the revolution frequency is still sensitive to radial position, bending field errors, etc. Therefore, a frequency control loop, using an **analog f_0 - f_{RF} signal, applies a radial steering such that the revolution frequency of the beam remains close to an integer sub-harmonic of the cavities' resonance frequency:**

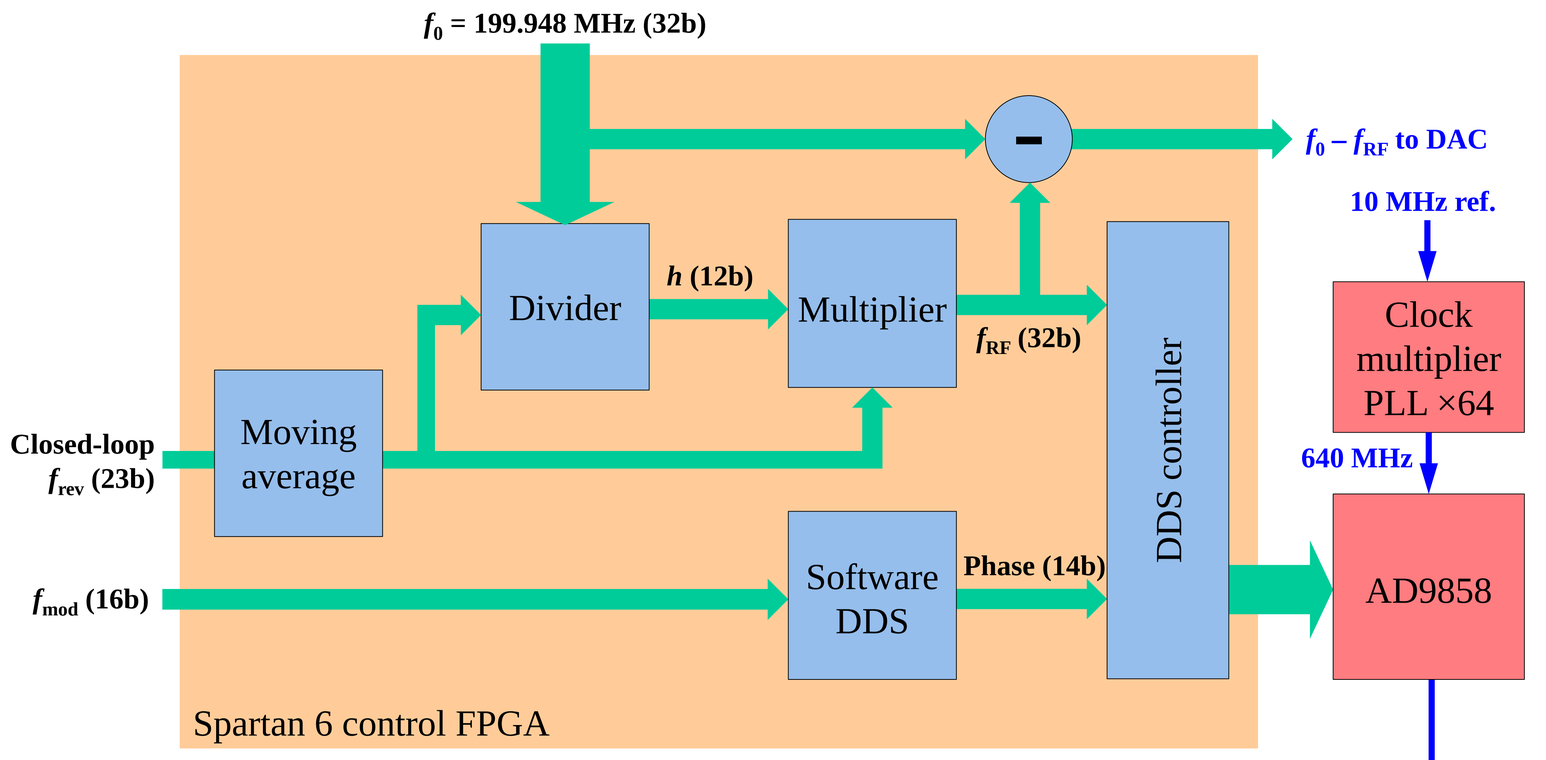
$$f_0 = h \cdot f_{rev} \text{ with integer } h$$

Frequency control loop

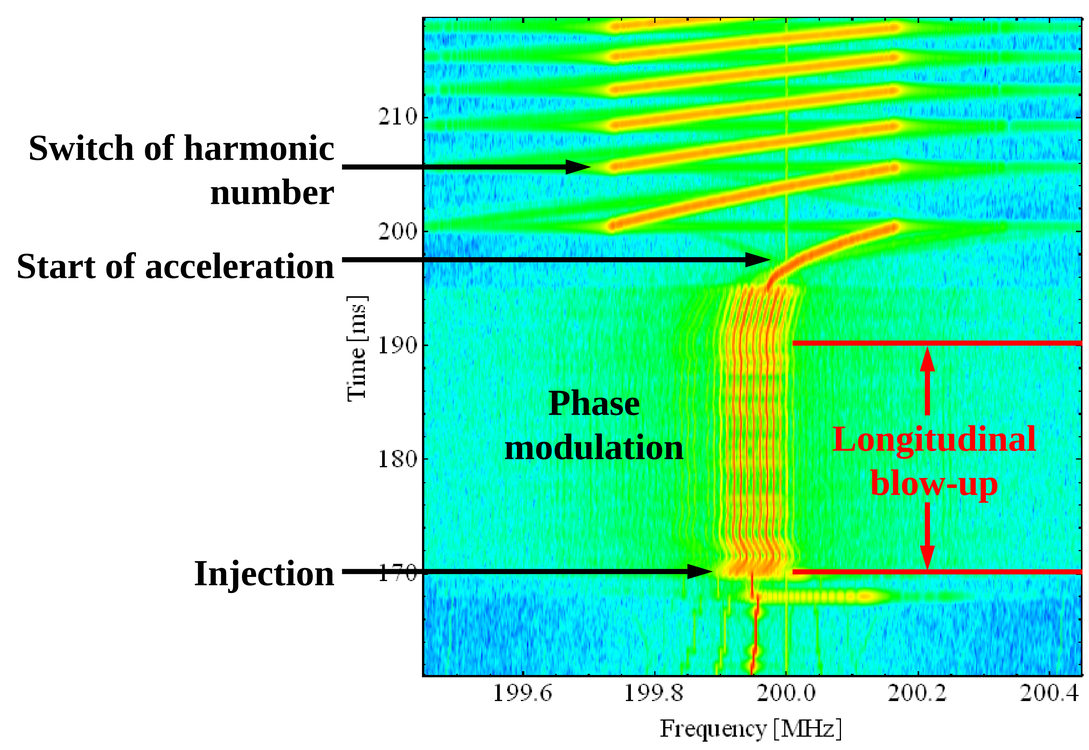


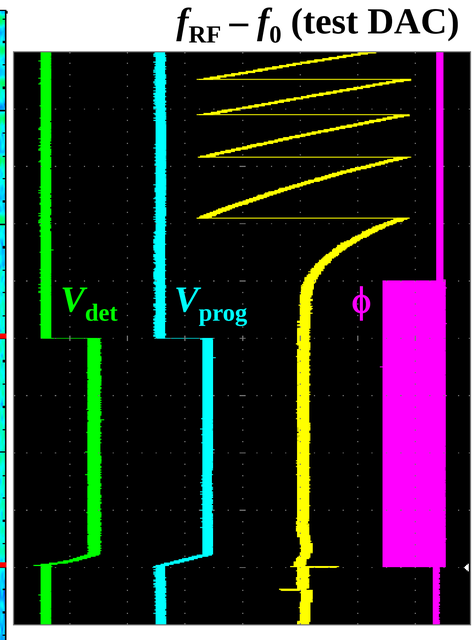
Implementation

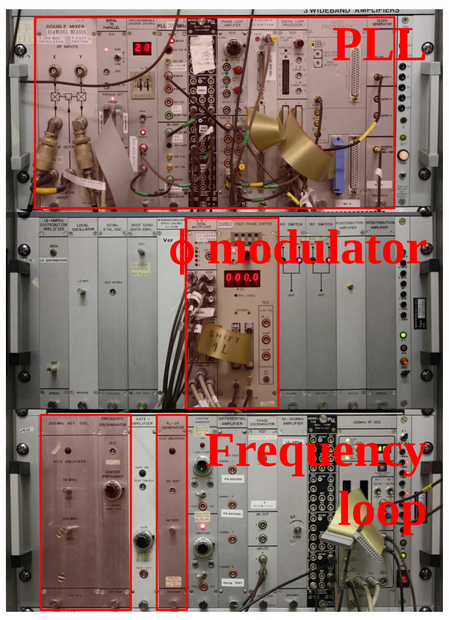
→ **Spartan 6 FPGA, AD9858 DDS, serial data reception and some slow DACs for diagnostic outputs**
→ **Calculation of harmonic number (h = 419...458, p^+; 423...1123, Pb^{54+}) from revolution frequency on the fly**
→ **Internal generation of sinusoidal phase modulation, 12 bit sin table based on Sunderland architecture**



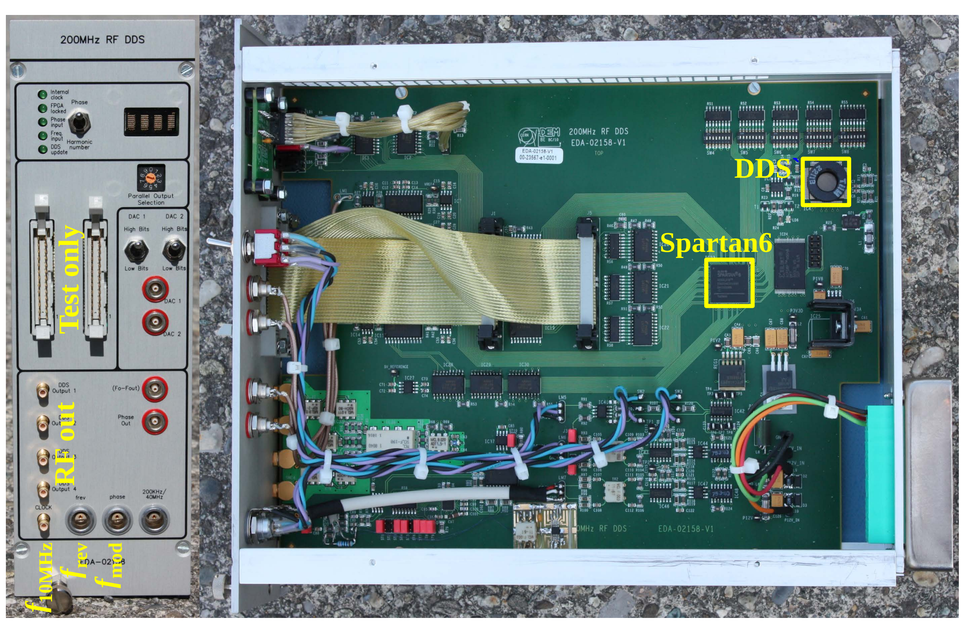
Phase modulated 200 MHz RF







Old hardware



Conclusions

- New **200 MHz RF DDS prototype successfully put into operation**
  - → Few hardware modifications for production of a series of modules
  - → Hard- and firmware running since June 2011 without any problem nor bug fix
- **Improves reliability: no PLL loop gain to adjust, requires only digital closed-loop revolution frequency, $f_0 - f_{RF}$ generated digitally without offset issues**
- **Integrated software DDS to control the phase simplifies generation of modulation**
- **Almost two full NIM chassis replaced by one module with the same functionality**
- **Longitudinal blow-up of ion beam at h = 595, beyond capabilities of the old system**