New CERN PS 10 MHz Cavity One-turn Delay Feedback Hardware and Beam Tests

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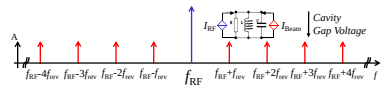
Abstract

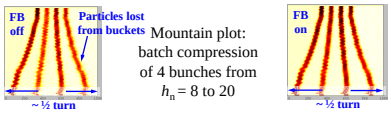
To reduce beam loading in the accelerating cavities of the CERN PS, a one-turn delay feedback (FB) provides significant impedance reduction at revolution frequency harmonics in addition to the direct wide-band FB. This new FB developed within the LHC Injector Upgrade project is based on the LHC one-turn delay FB electronics. The new hardware is able to cope with the sweeping revolution frequency in the PS, as well as with changing harmonic numbers. A unique clock at a fixed harmonic of the revolution frequency, ranging from 35 MHz to 96 MHz, is used. The signal processing features an IIR notch filter, programmable to any harmonic number, combined with a comb filter and a glitch-free variable delay. This delay consists of a FIFO memory with fine delay chains to complete the full revolution period. Moreover, a digital voltage control loop is being added to the firmware, with non-IQ sampling technique to detect amplitude and phase of the cavity voltage. Tests with beam are presented with the full commissioning on all 11 cavities foreseen for the start-up in 2014.

The CERN PS 10MHz Accelerating Cavities with its AVC, Direct Feedback and One-turn Delay Feedback Loops

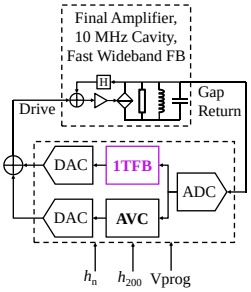
- The longitudinal spectrum in a cavity with a circulating beam contains the RF frequency and periodic revolution frequency harmonics.
- These f_{rev} components of the beam multiplied by the impedance of a RF cavity creates an unwanted beam induced voltage.

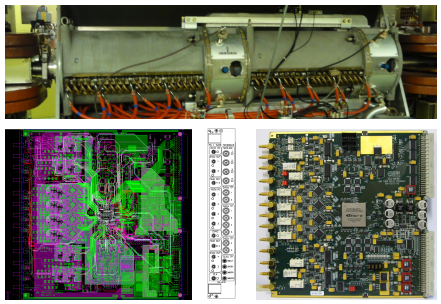


The idea is to **reduce** the **impedance** of the **cavity** seen by the beam at f_{rev} harmonics except for the f_{RF} with a high gain feedback: One-turn feedback



Mountain plot: batch compression of 4 bunches from h_n = 8 to 20





PS main accelerating cavity:
- Ferrite-loaded resonator
- 2.8 – 10 MHz (tuneable)
- Bandwidth with direct feedback covers about
- ±3 f_{rev} harmonics arounf f_{RF}

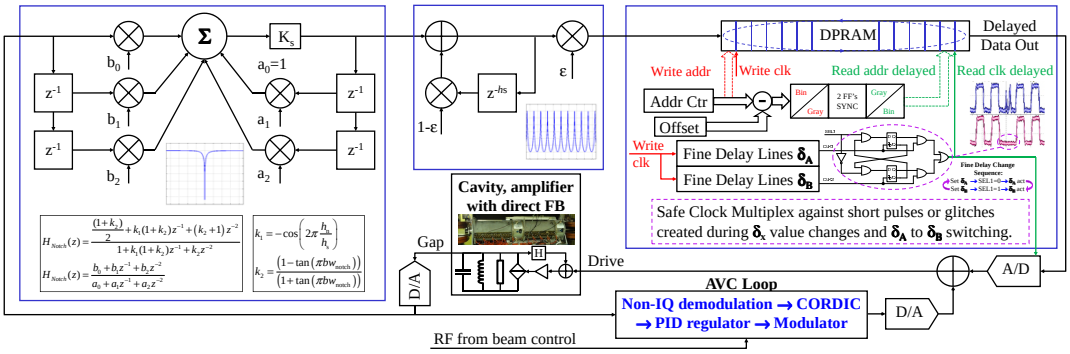
Electronic Board:
- Module EDA-02175-V2
- FPGA Stratix II
- 4x 14 bits ADCs 105MSPS
- 4x 14 bits DACs 125MSPS with digital gain control
- 2x delay line multiplex
- 2 SRAM 72 Mbits
- 4 serial link channels
- VME bus interface

Digital Filters and Automatic Delay Compensation of One-turn Delay Feedback and AVC Loop

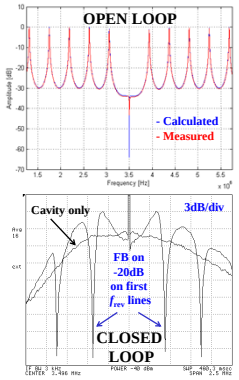
Notch filter (IIR) programmable to any fractional ratio h_n/h_s
→ Suppress the RF component to avoid interference with AVC

Comb filter
→ high gain at f_{rev} harmonics

Automatic delay compensation
→ completes total loop delay to one turn with a FIFO and delay lines



1-turn FB transfer functions for h_n= 8 and f_{rev}= 437 kHz



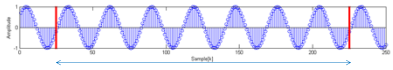
RF Voltage Amplitude and Phase Detection using Non-IQ Sampling Technique

Fourier series of a periodic function:

$$y_n = \frac{a_0}{2} + \sum_{k=1}^{N/2-1}\left(a_k \cos(2\pi k\frac{n}{N}) + b_k \sin(2\pi k\frac{n}{N})\right)$$

Discrete Fourier Coefficients:

$$a_k = \frac{2}{N}\sum_{n=0}^{N-1} y_n \cos(2\pi n\frac{k}{N}) \qquad b_k = \frac{2}{N}\sum_{n=0}^{N-1} y_n \sin(2\pi n\frac{k}{N}) \qquad k > 0$$

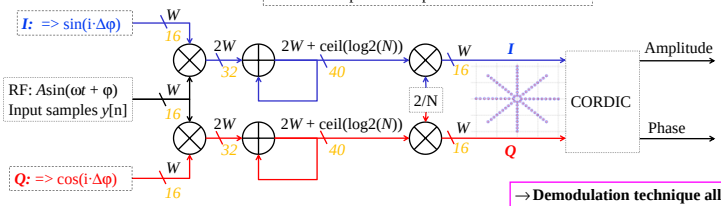


⇒ a_k and b_k at harmonic k correspond to demodulated I and Q:

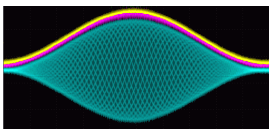
$$I_{h=k} = \frac{2}{N}\sum_{n=0}^{N-1} y_n \sin(n\Delta\varphi) \qquad Q_{h=k} = \frac{2}{N}\sum_{n=0}^{N-1} y_n \cos(n\Delta\varphi)$$

N samples in ***M*** RF periods are required for periodicity: $NT_s = h_n T_{RF}$ → Phase advance between two samples: $\Delta\varphi = 2\pi\frac{h_n}{N}$

i.e. PS, case h_n=7 and h_s=200
=> 200 samples in 7 rf periods = 1 turn machine



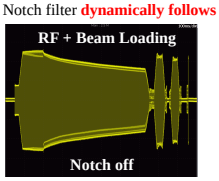
Envelope detection of RF signal h_n=8

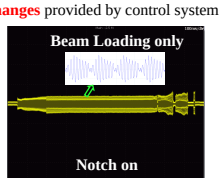


→ **Demodulation technique allows to cleanly detect an RF component which is not necessarily an integer multiple of the sampling frequency**
→ **Latency of one turn acceptable**

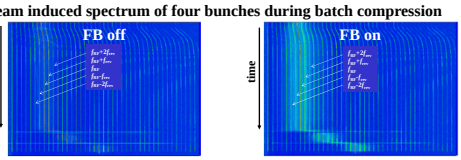
Beam measurements

Effect of Notch filter on cavity return signal, AD Cycle h = 8 → 13 → 20
→ Notch filter **dynamically follows h_n changes** provided by control system

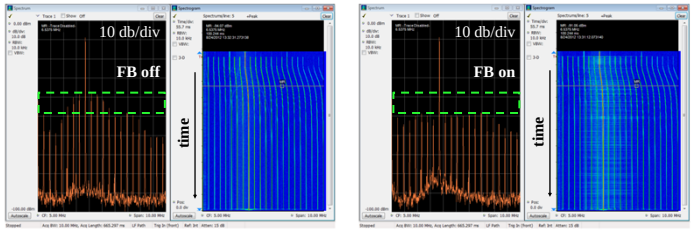




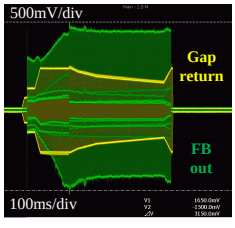
Beam induced spectrum of four bunches during batch compression



Spectrum at cavity gap voltage of a single high intensity bunch (8·10¹² ppb, h_n= 8)



Feedback in and out along cycle



- **Prototype tested, fully validated and series production launched**
- **Complete installation of new system on all 10 MHz cavities during LS1 with Commissioning in 2014**
- **Future improvements (cavity phase compensation, cavity phase loop, I/Q loop)**

References:

[1] D. Boussard, G. Lambert, Reduction of the Apparent Impedance of Wide Band Accelerating Cavities by RF Feedback. PAC'83, Santa Fe, New Mexico, U.S., 1983, p. 2239
[2] F. Blas, R. Garoby, Design and Operational Results of a "One-turn-delay Feedback" for Beam Loading Compensation of the CERN PS Ferrite Cavities. PAC91, San Francisco, CA, 1991, p. 1398
[3] T. Berenc, B. Chase, A Prototype RF Comb Filter Feedback for the Fermilab Main Injector. LLRF2007, Knoxville, Tennessee, U.S., 2007
[4] L. Doolittle, H. Ma, M. Champion, Digital Low-level RF Control Using Non-IQ Sampling. LINAC2006, Knoxville, Tennessee, U.S., 2006, p. 568

Thanks to:

W.Hofle, A.Blas, P.Baudrenghien, J.Molendijk, J.Noirjean, G.Hagmann, T.Levens, G.Kotzian, M.Jaussi, V.Desquiens, M.Haase, G.Lobeau