LHC Injectors Upgrade

New PS one-turn delay feedbacks and further developments

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CERN

Content

Overview of the new feedback board

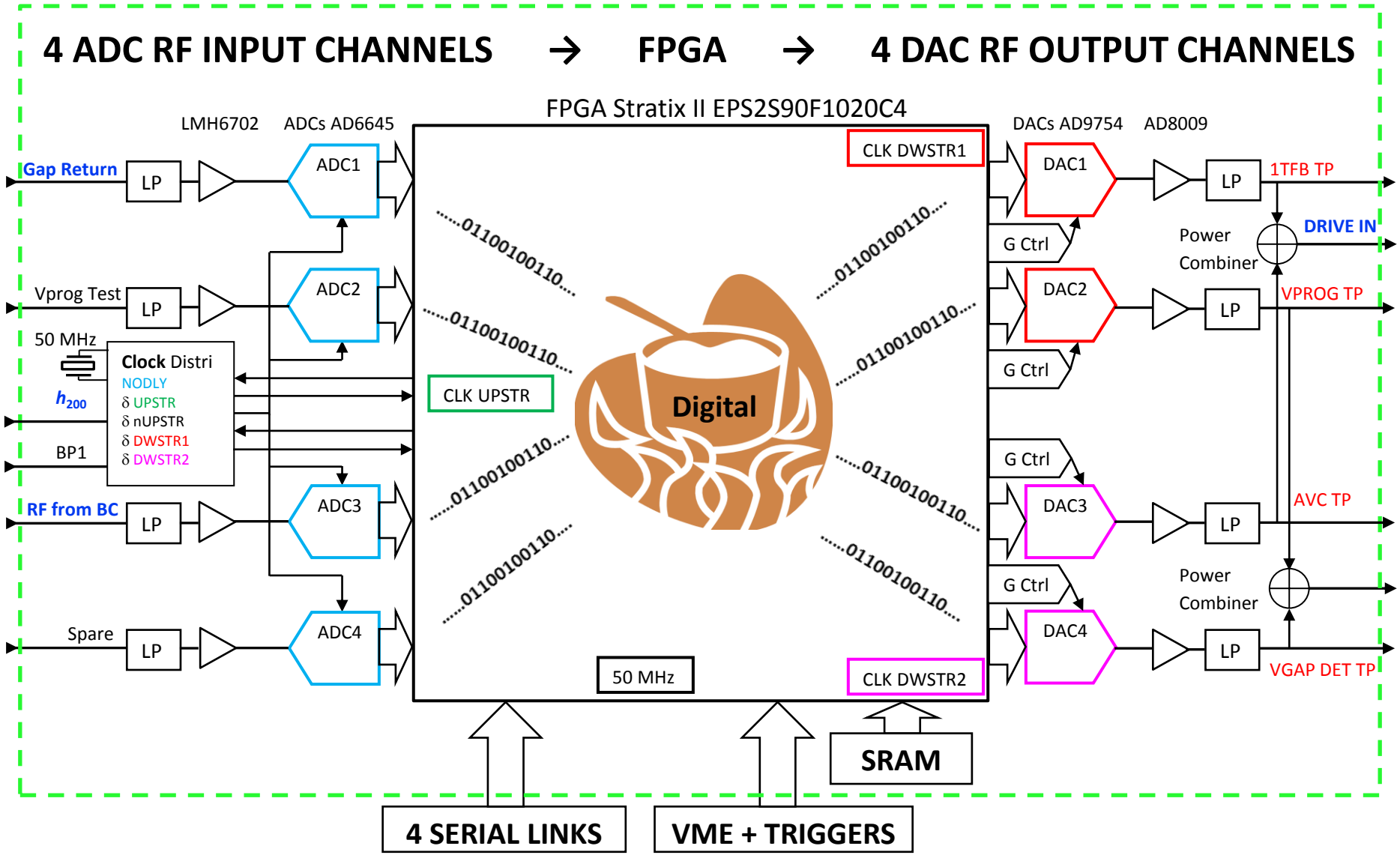
Current implementations:
- PS 10 MHz 1-turn feedback and AVC digital loops
- PS transverse damper

Future developments:
- PS 1-turn feedback cavities 13/20/40/80 MHz
- PS longitudinal coupled-bunch feedback
- PSB/AD/LEIR transverse damper upgrade

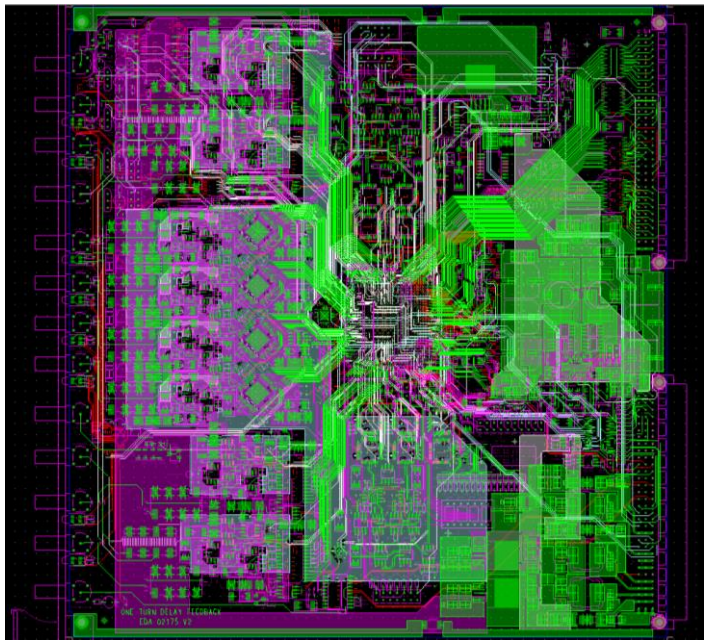
Summary and outlook

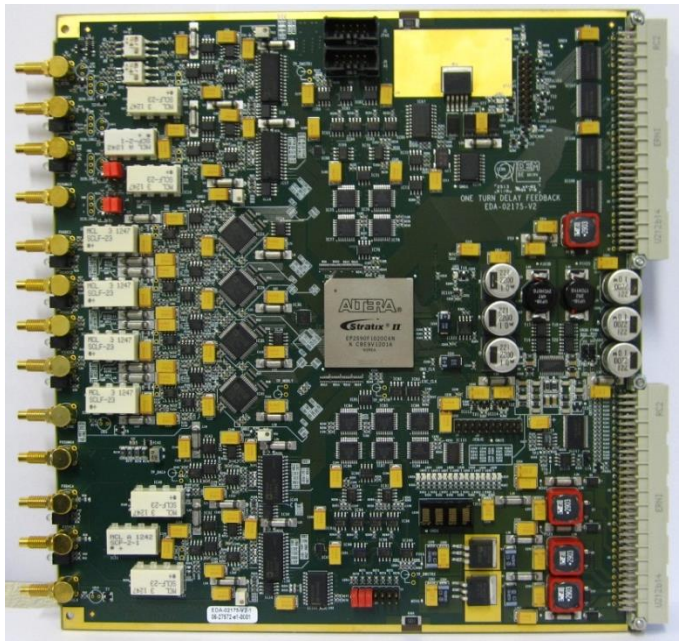
The new hardware

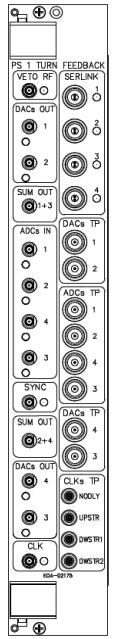
New PS feedback hardware



Electronic board



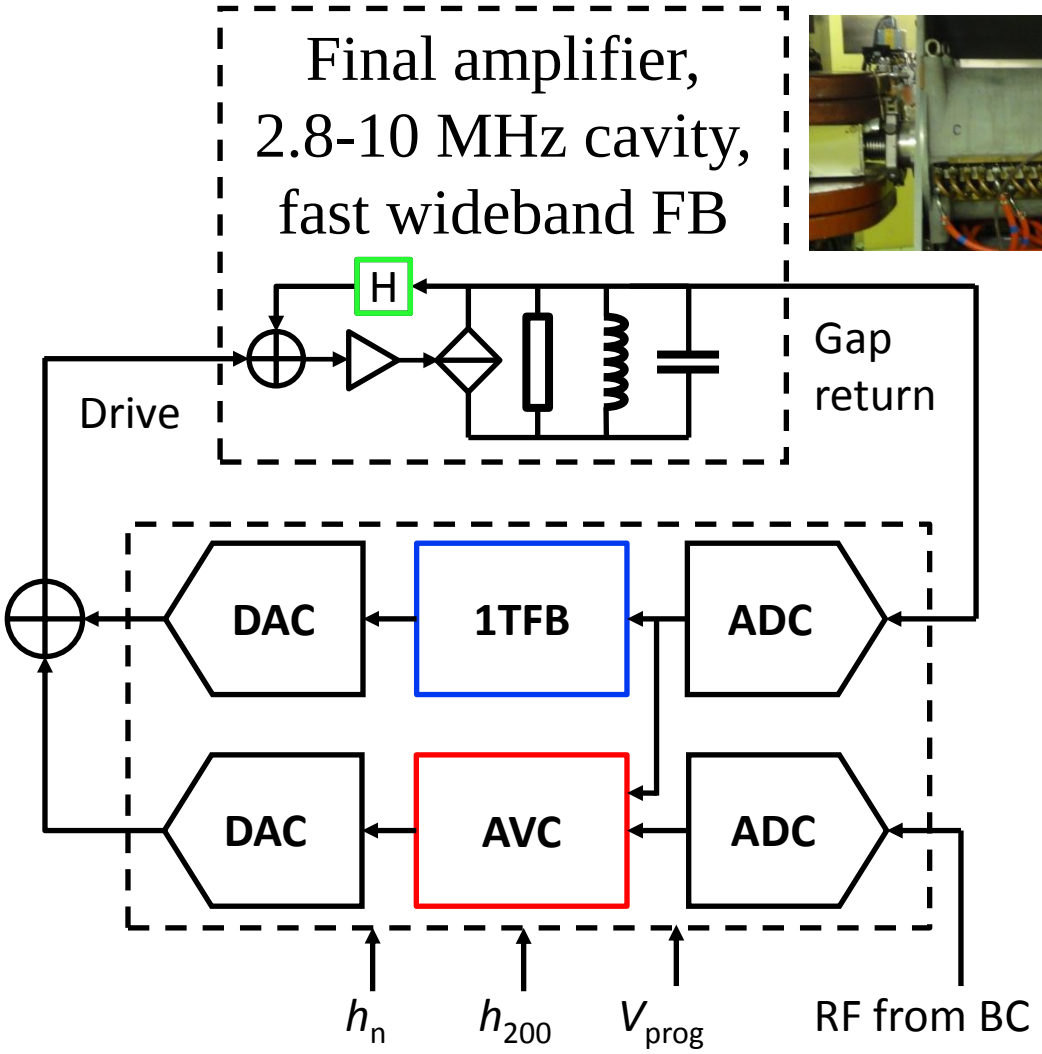


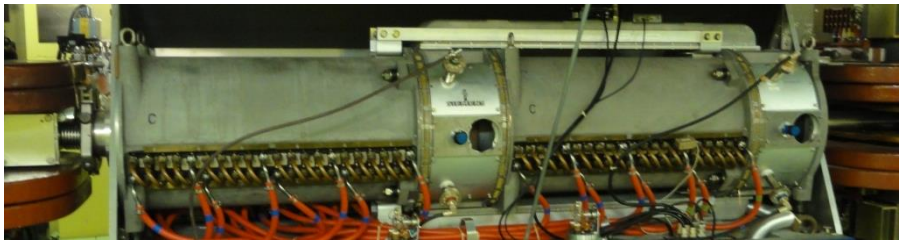


- Generic **VME** board
- **STRATIX II** FPGA and external SRAM
- 4 RF channels **ADC** and **DAC**, **low latency**, **14 bits** and running at 105/125 MSPS
- 2 multiplexed fine delay lines for glitch-free delay changes (DAC and FPGA clocking)
- 4 serial links CVORB or fast 40 Mbit/s

PS 10 MHz loops

PS 10 MHz cavity feedback overview





- Slow voltage control loop (AVC)
  → Gain control at f_{RF}

Reduction of cavity impedance seen by the beam:

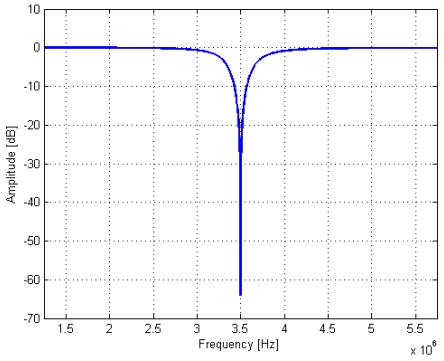
- Fast wide-band feedback around amplifier (internal)
  → Gain **limited** by delay

- 1-turn delay feedback
  → High gain at n × f_{rev}

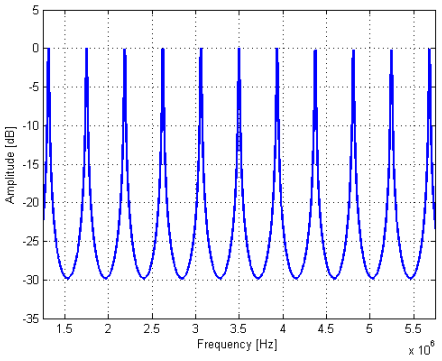
PS 1-turn delay feedback

1-turn delay feedback

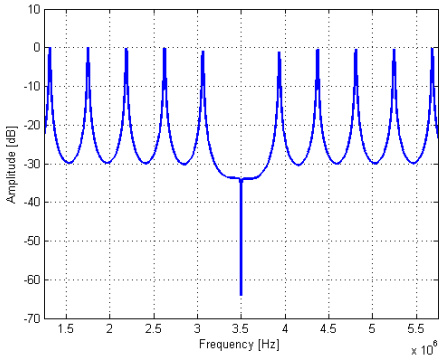
IIR fractional notch h_n/h_s



Periodic comb at f_{rev}

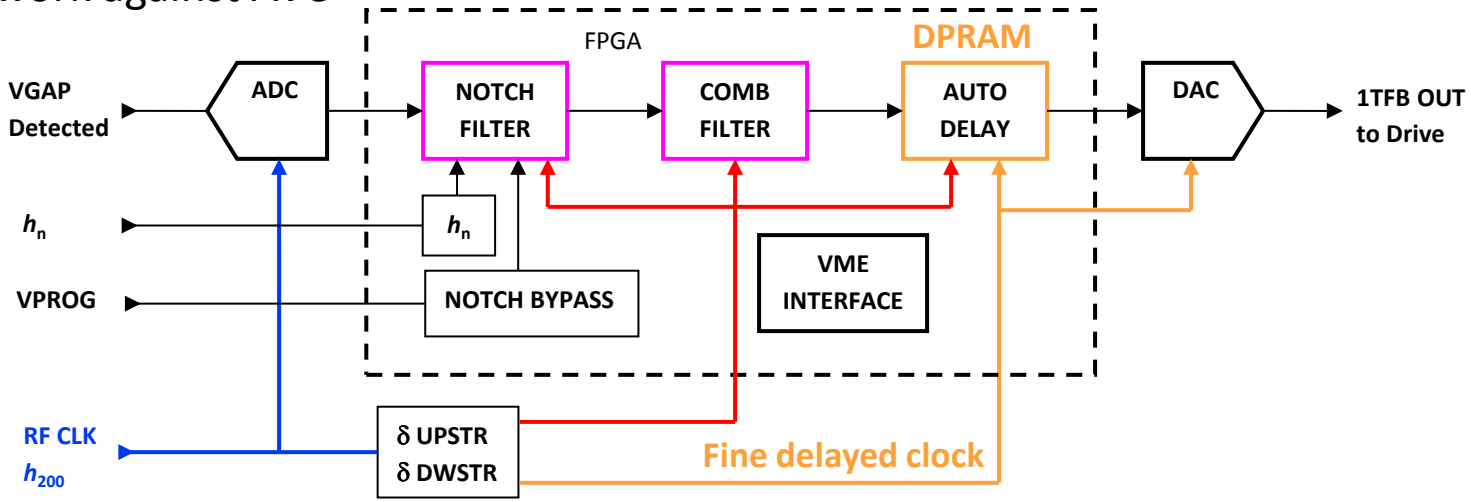


Cascade of notch + comb



Suppress the RF component to not work against AVC

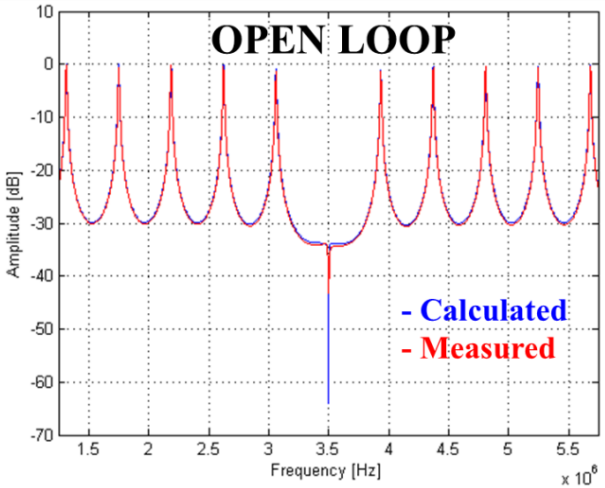
High gain at f_{rev} multiples

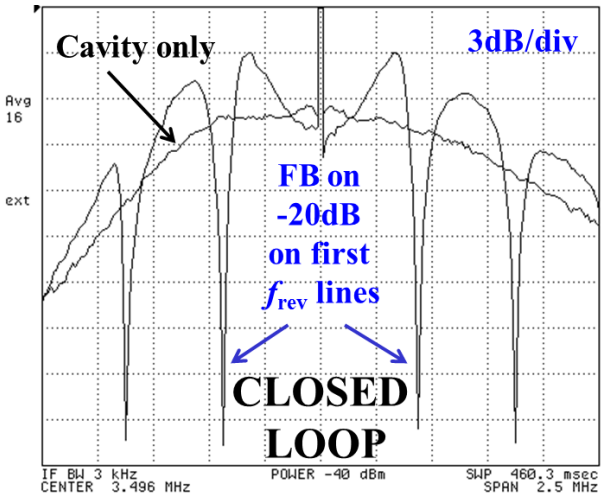


Unique sampling clock h_{200} integer multiple of the revolution frequency

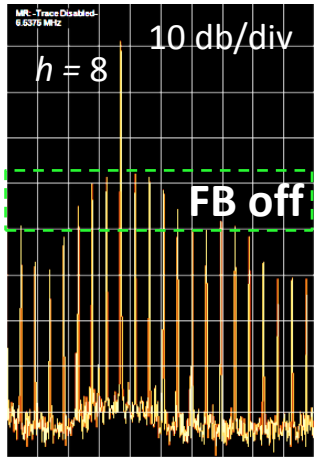
Measurements with beam before LS1

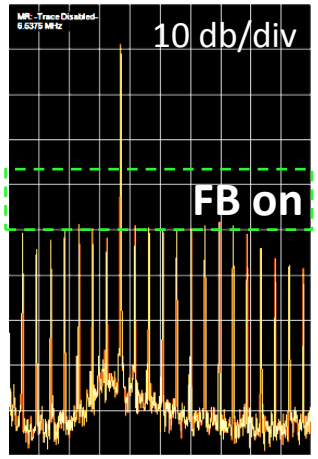
Filters only and closed loop transfer functions



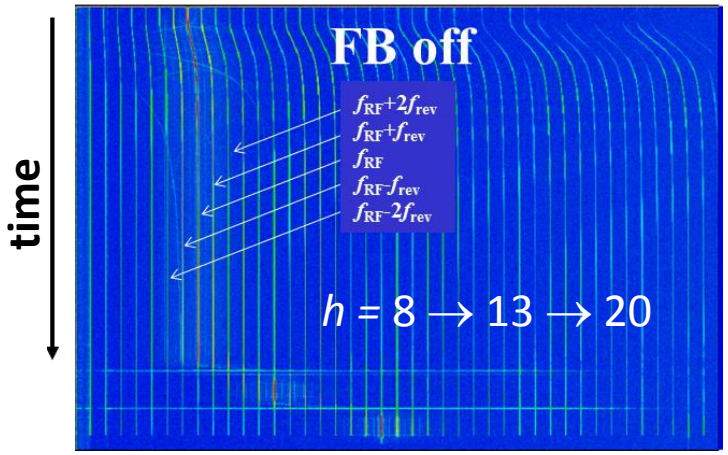


Spectrum at cavity gap voltage of a single high intensity bunch $8 \cdot 10^{12}$ ppb



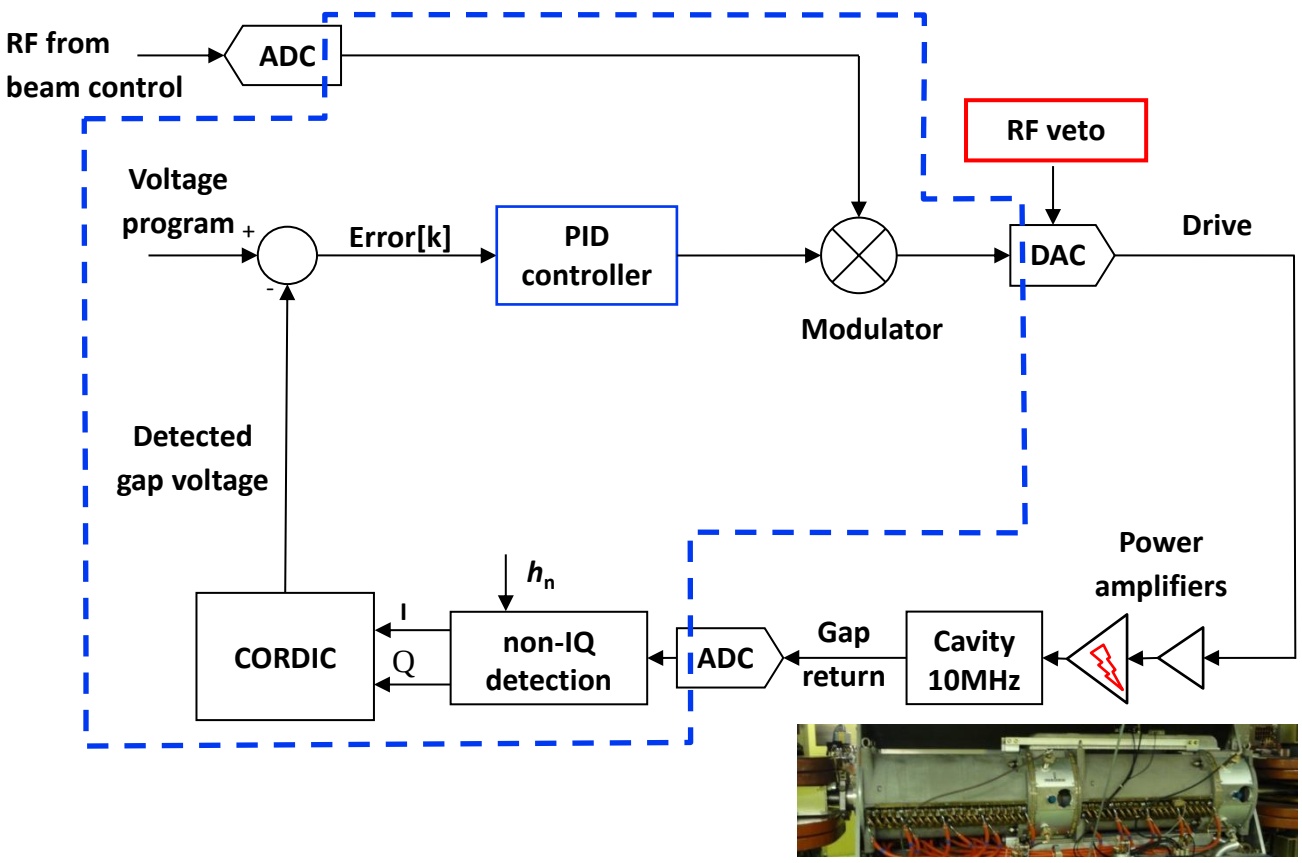


Beam induced spectrum of four bunches during batch compression



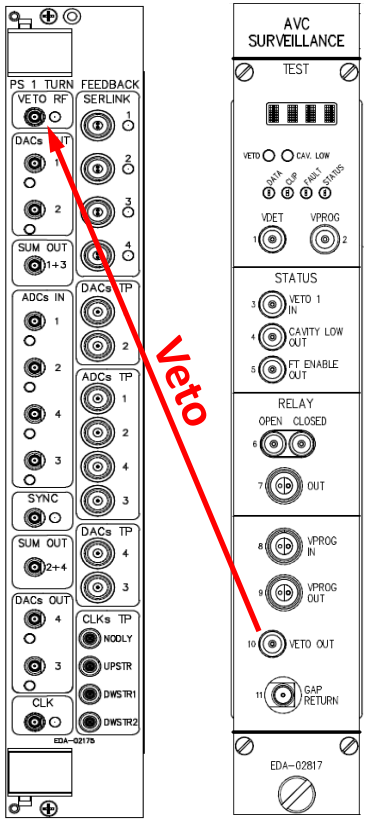
PS digital AVC loop

AVC loop and AVC surveillance



Collaboration

RF-FB RF-IS



H. Damerau, V. Desquiens, M. Haase, D. Perrelet

→ **Amplitude loop only, future phase loop or move to IQ loop**

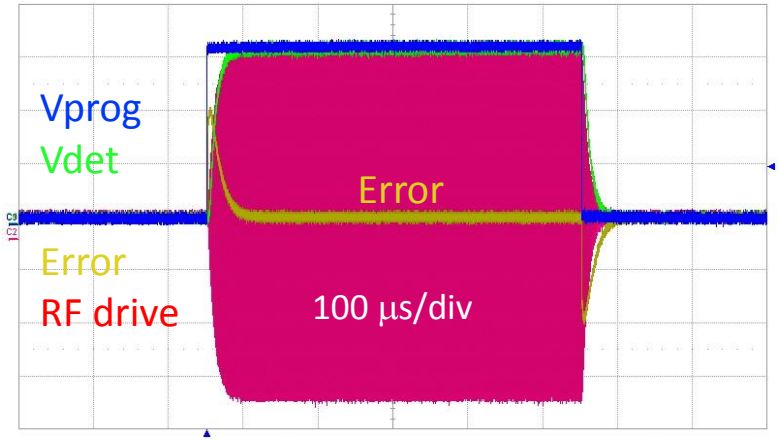
→ **Voltage detection using non-IQ algorithm at given harmonic h_n**

→ **High power hardware safety ensured by separate surveillance module**

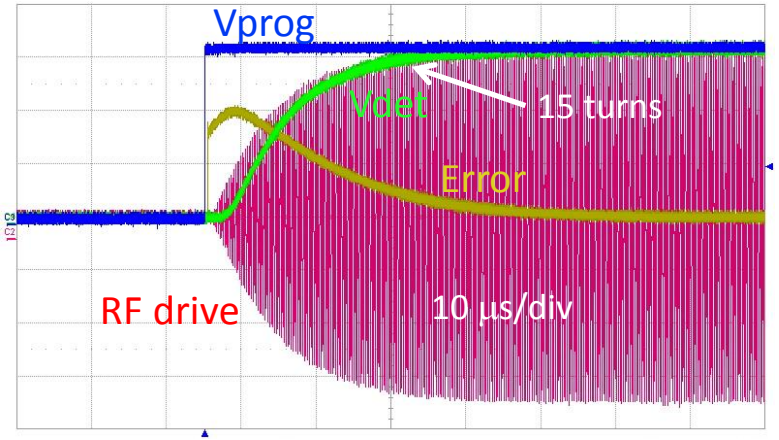
Digital AVC loop measurement

- Step response of the controller around a cable

500 µs test pulse voltage program



Response with fast voltage rise



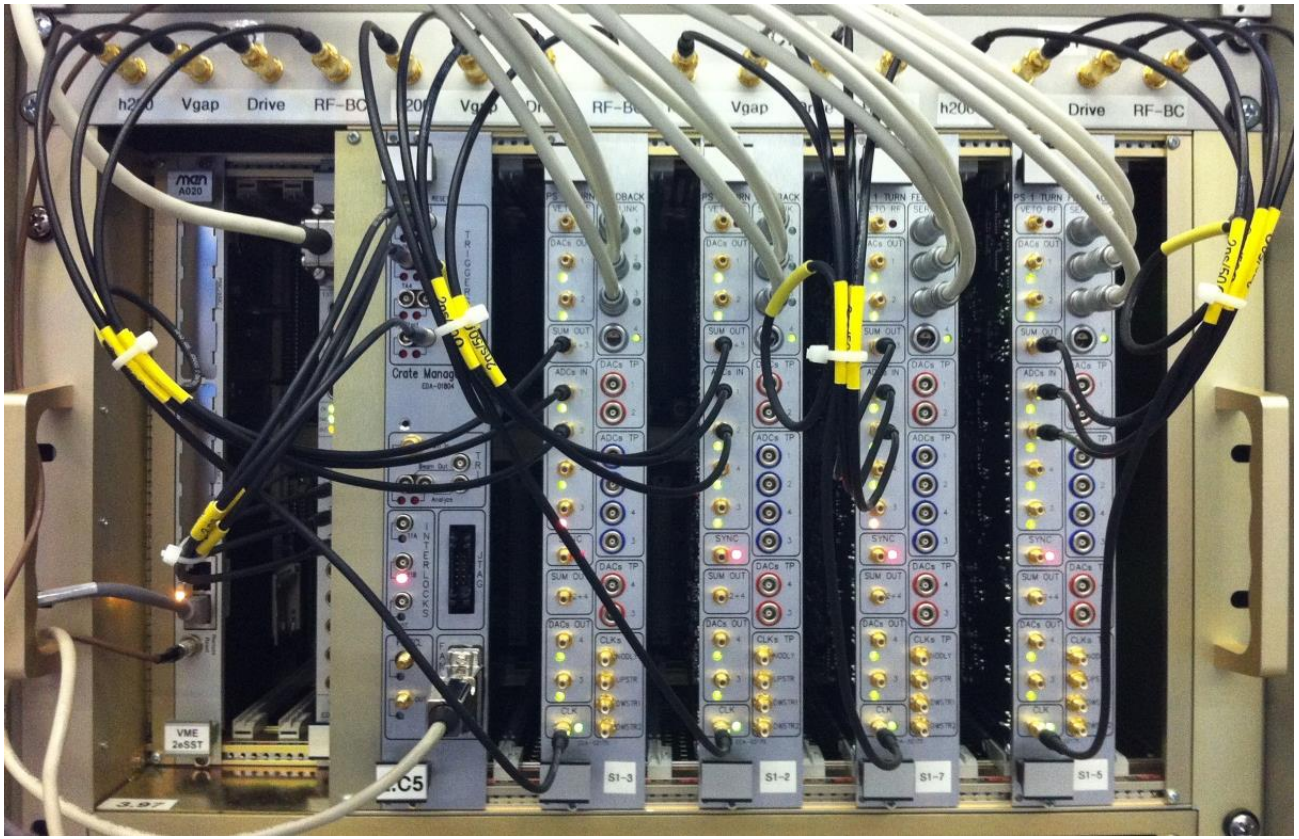
→ Digital PID with adjustable parameters

→ Regulation to full voltage without overshoot in about 15 turns

Installation in the machine

Four new VME crates installed in building 359 (one for each tuning group)

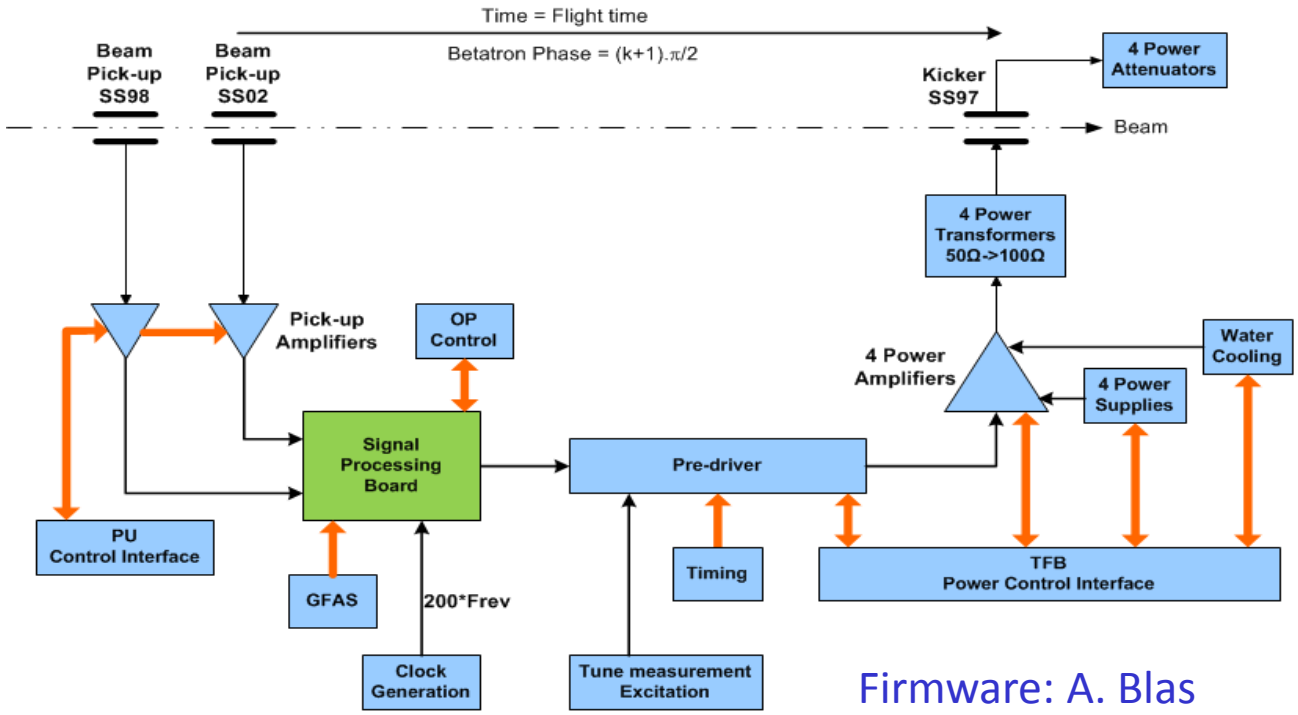
Example for tuning group B (cavities C56, C66, C76 and C81)



→ Full commissioning of the new system during start-up 2014

PS transverse damper

PS transverse feedback



Firmware: A. Blas

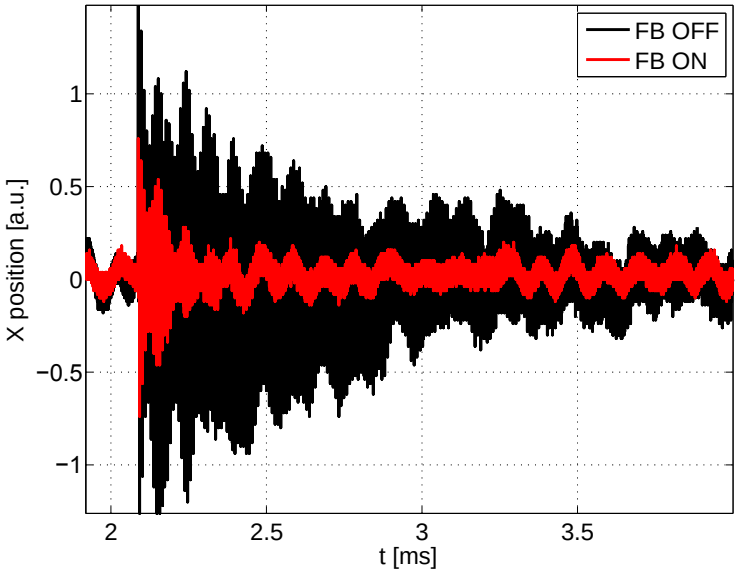
1) PU flight time compensation
2) **Periodic notch** filter for orbit offset suppression
3) **Hilbert filter** for phase compensation at betatron frequencies
4) Automatic delay to complete 1 turn

PS transverse feedback

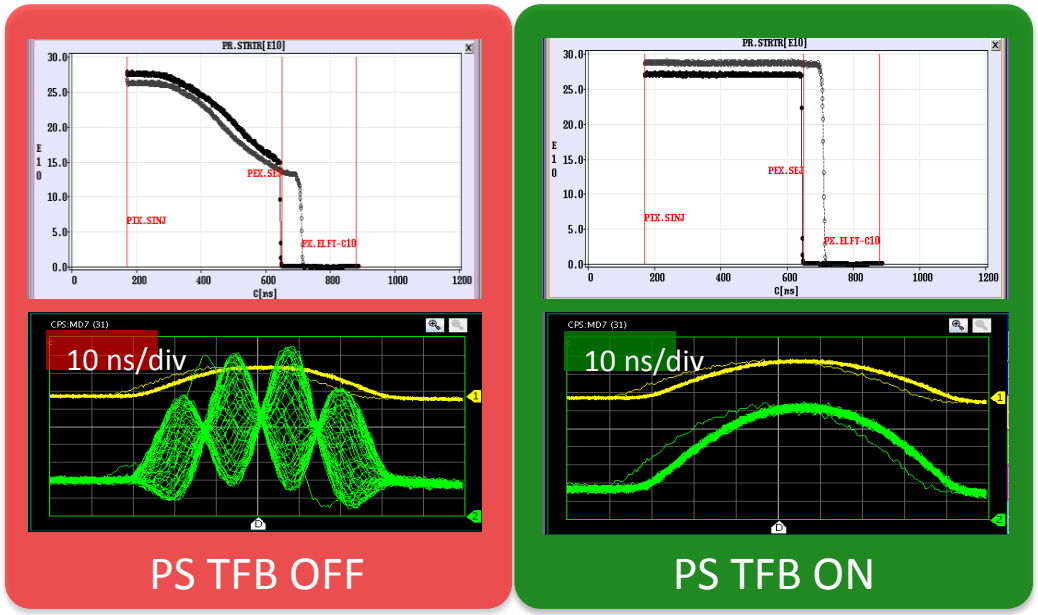
See talk by Raymond Wasef

Damper to cure horizontal and vertical transverse instabilities

Damping of injection errors



Damping of head-tail instability



→ Present PS TFB designed to damp 44 µm/turn at 1.4 GeV (BW 23 MHz).

A.Blas, S.Gilardoni, G.Sterbini

New applications

PS 1-turn feedbacks cavities 13/20/40/80 MHz

Frequency conversion board

Thomas Truszczyński

1) Analog conversion to IF and IQ digital processing

→ Using **existing** and analog frequency conversion boards

or

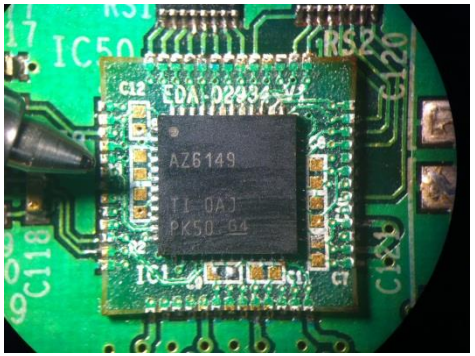
2) Direct sampling

→ Modification of existing board
to achieve higher sampling capabilities

or

→ Build a complete similar **new and fast board**

Mini-PCB to fast ADC adaptation

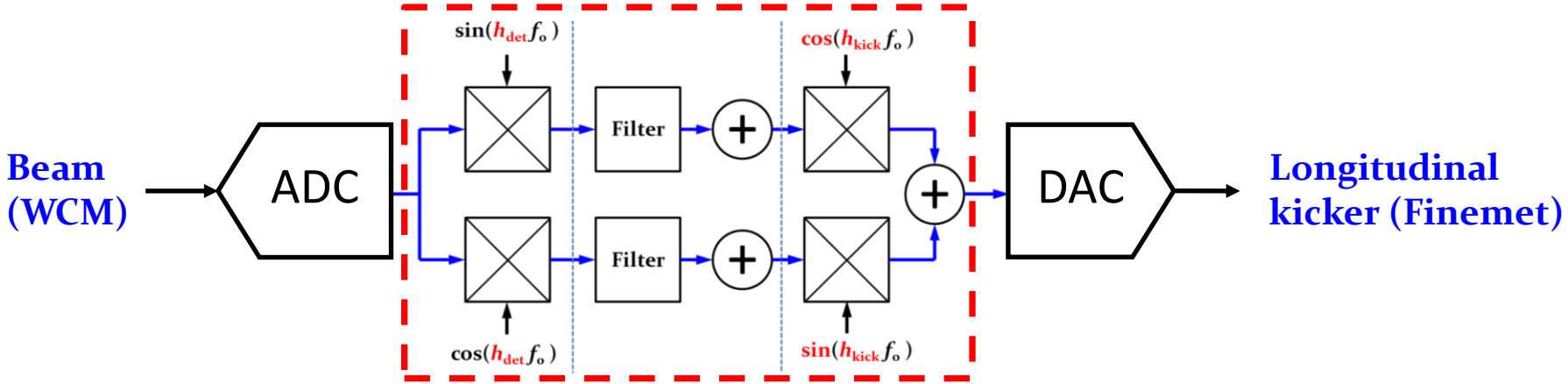


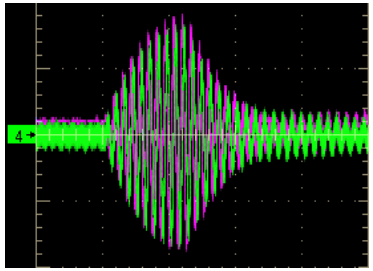
PS longitudinal coupled-bunch feedback

See talk by Letizia Ventura

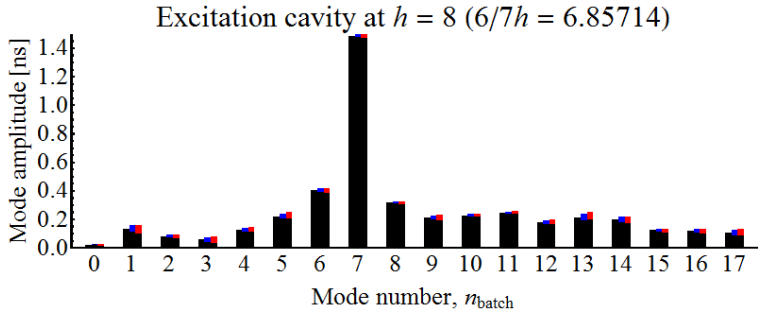
Cross-damping: $h_{det} + h_{kick} = h_{RF} = 21$ → Detect at $h = 13$ and Damp at $h = 8$

→ Make a new digital coupled-bunch feedback for the Finemet cavity





H. Damerau, L. Ventura:



- **Demonstrated with measurements using existing feedback and the spare cavity**

Future developments

Target to other machines:

- **Upgrade of PSB, AD and LEIR** transverse dampers

PS 10 MHz possible improvements:

- **Cavity phase loop** or **IQ loop** (Reliability of RF manipulations)
- **Cavity phase compensation** (More gain for 1-turn feedback)
- **Multi-harmonic RF generation** on-board and use of h_s**=256**

Summary and outlook

- New **generic feedback board** meets requirements

  → **Complex design** but **easy to use** and allows lots of features

- **Two operational loops**: PS 10 MHz **1-turn feedback** and **AVC**

  → Fully digital and remote controlled

  → **Commissioning during setting-up 2014**

- New **operational PS transverse damper**

  → Good results and **required for LIU beams**

- Many **future developments** and projects using this hardware

  → FPGA gives reliability and **flexibility for new ideas**

Thanks for your attention

Many thanks to people from sections RF/FB-CS and RF/FB/IS for collaboration and support :

Alfred Blas, Philippe Baudrenghien, Andy Butterworth, Heiko Damerau, Valentin Desquiens, Simone Gilardoni, Gregoire Hagmann, Matthias Haase, Wolfgang Hofle, Michael Jaussi, Gerd Kotzian, Tom Levens, Gérard Lobeau, John Molendijk, José Noirjean, Anthony Rey, Maarten Schokker, Guido Sterbini and Letizia Ventura.