Transverse Feedback Systems at SOLEIL

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SOLEIL Transverse Feedback Team

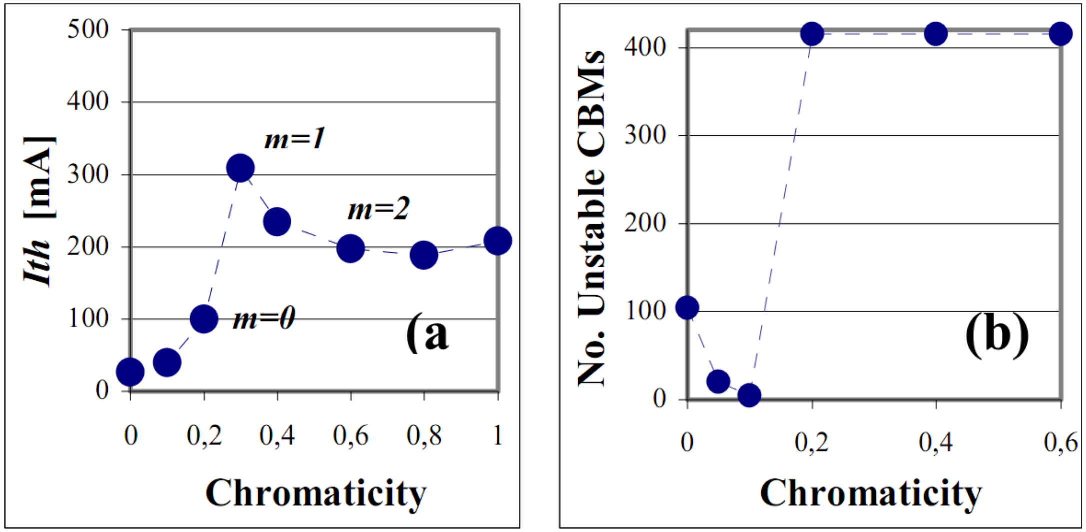
When the 3rd chain was successfully commissioned (22 Nov. 2009)

◊ Background Motivation:

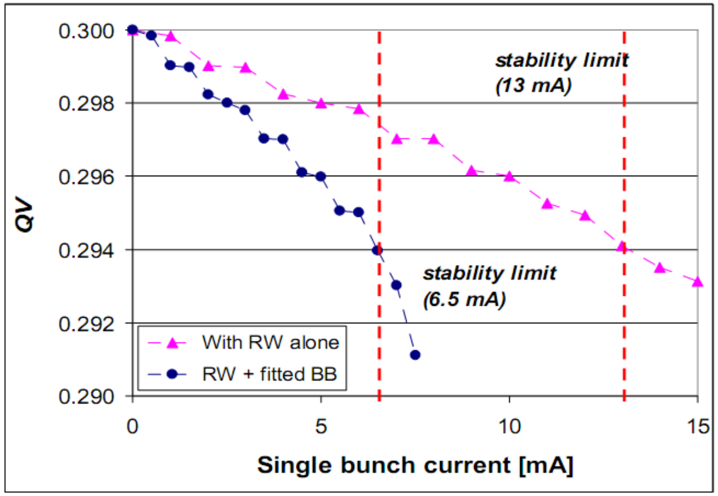
- Very low transverse resistive-wall instability thresholds predicted.

- In particular, positive chromaticity does not guarantee stability due to excitation of higher-order headtail modes.

- Low TMCI and headtail thresholds in single bunch.



Vertical multibunch threshold current (left) and the number of unstable modes (right) predicted



Calculated vertical single bunch detuning

◊ Conditions imposed on the Feedback System to be developed:

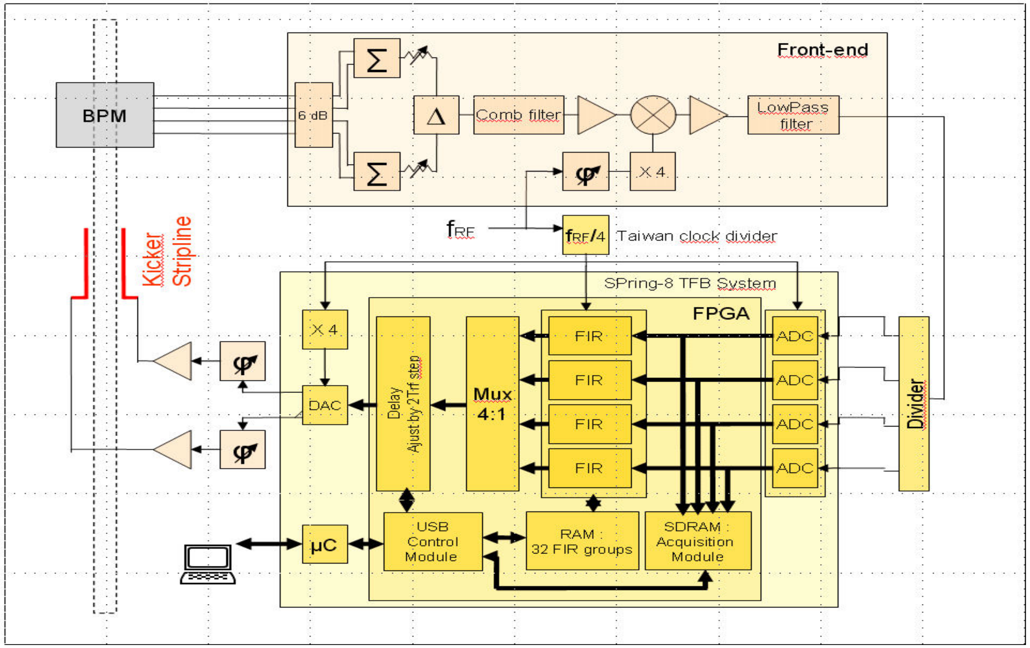
- Bunch by bunch and digital (flexibility) transverse (H & V) feedback.
- Strong enough kicks to combat TMCI (strong headtail)

→ Stripline and amplifier power

- Kicks that do not spoil the low emittance (especially in the vertical plane)

→ High sensitivity detection/High quality filtering/Low noise

◊ Constituents of the feedback chain:

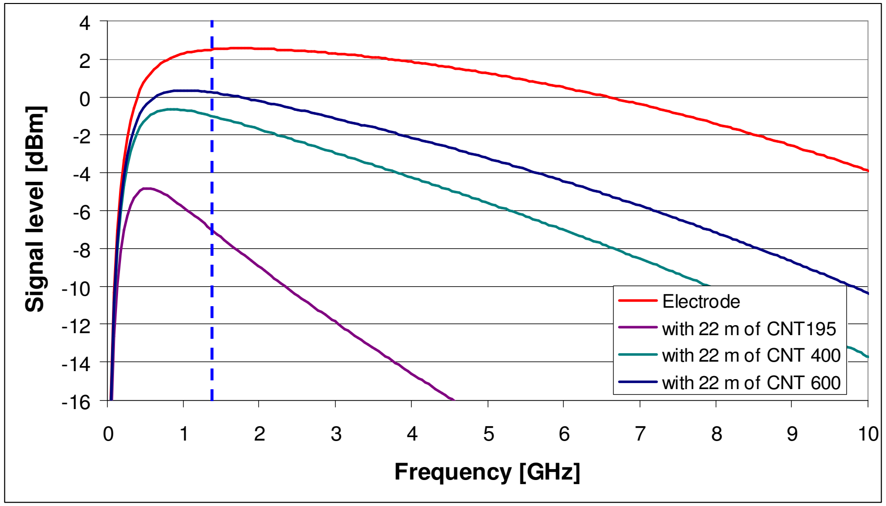


Layout of the SOLEIL feedback chain

- Detector: SOLEIL BPM

The sensitivity at 1.2 mA bunch current was estimated to be

Δ_{peak} ~47 μV/mA/μm → Good enough to be used for TFB



Signal level of a SOLEIL BPM + a 22 m long cable for a 1.2 mA bunch having 20 ps length

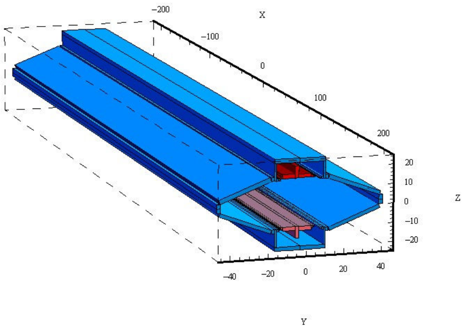
- RF frontend: Home made (ESRF scheme)

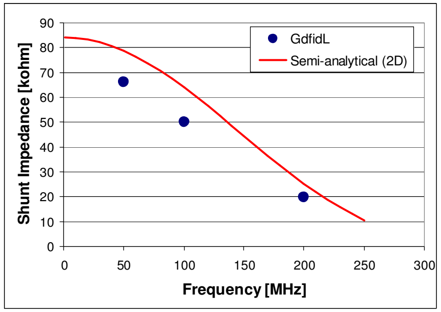
Creates a Δ-signal. Following the frequency dependence of the detection signal level, extracts a band of $f_{rf}/2$ at 4*f_{rf}, then down coverts to the base band (0 - $f_{rf}/2$).

- Digital processor: SPring-8 development (T. Nakamura and K. Kobayashi)
  - Four 12-bit ADCs working at 88 MHz (352.2 MHz/4). Bandwidth: 750 MHz.
  - All FIR filters and multiplexers integrated into one FPGA board (latency < 1 turn)
  - Two 20-tap or one 50-tap FIR filter
  - Five 12-bit DACs (1.2 GS/s)

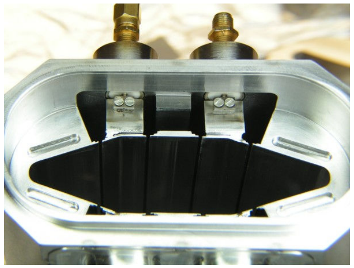
  → SOLEIL TFB team profited much from the technical support of
  T. Nakamura and K. Kobayashi from SPring-8

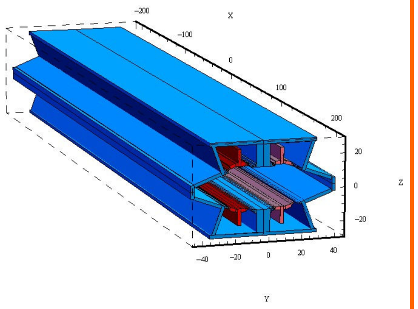
- Kicker: Home made striplines





2-electrode solution





4-electrode solution

(Courtesy C. Mariette)

2- and 4-electrode striplines with high shunt and low coupling impedance were developed and constructed.

◊ Different Modes of Operation and the Digital Filters:

- Purely H, V and the diagonal mode. In the diagonal mode, only the diagonal electrodes of the BPM and the stripline are used. Despite the tune difference of 0.1, the diagonal mode works well at SOLEIL .

- Digital (FIR) filters employed:

Least square fit of the betatron motions, developed by T. Nakamura (EPAC2004):

Fit the measured data x_k (k=0, 1, 2, 3, …) in the form

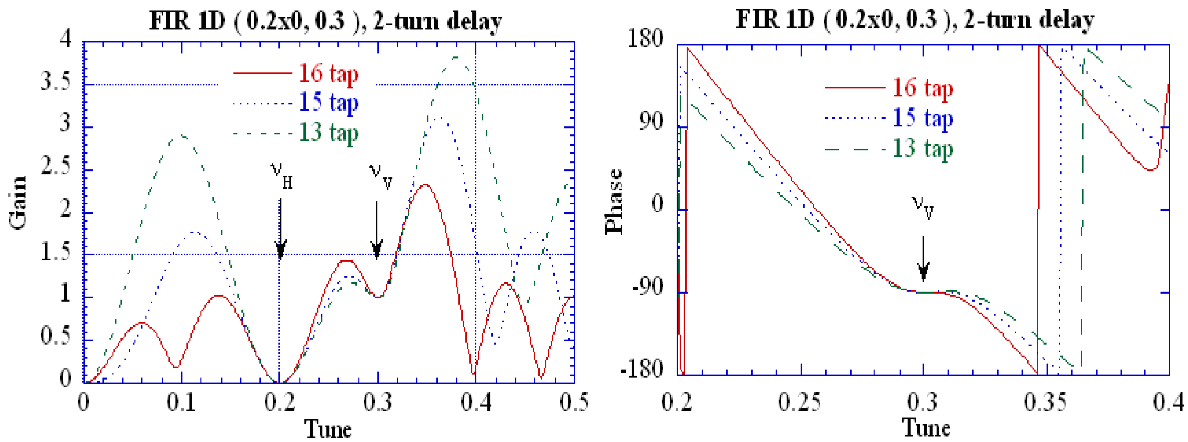
$$x[k] = A \sin[\,(1+\Delta)\phi_k + \psi] + B$$

$$\equiv P_0 \cos\phi_k - P_1\, \phi_k \sin\phi_k + Q_0 \sin\phi_k + Q_1\, \phi_k \cos\phi_k + B + \text{higher-order terms}$$

Determine the coefficients P_0, P_1, Q_0, Q_1, B, … via least square fit of

$$F \equiv \sum_{k=0}^{N-1} \left(x_k - x[k]\right)^2 ,$$

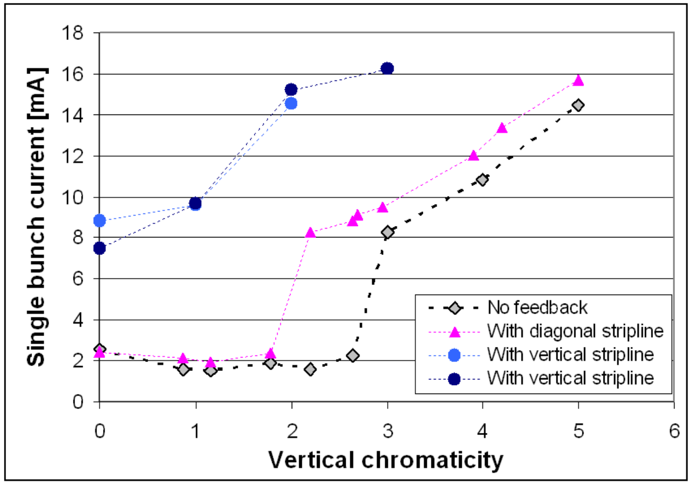
which can be solved by the standard matrix inversion method.



Example: 16-tap and 2-turn delay vertical filter

➔ Three chains, two with 4-electrode striplines and one with 2-electrode vertical stripline have been constructed.

◊ Achieved Feedback Performance:



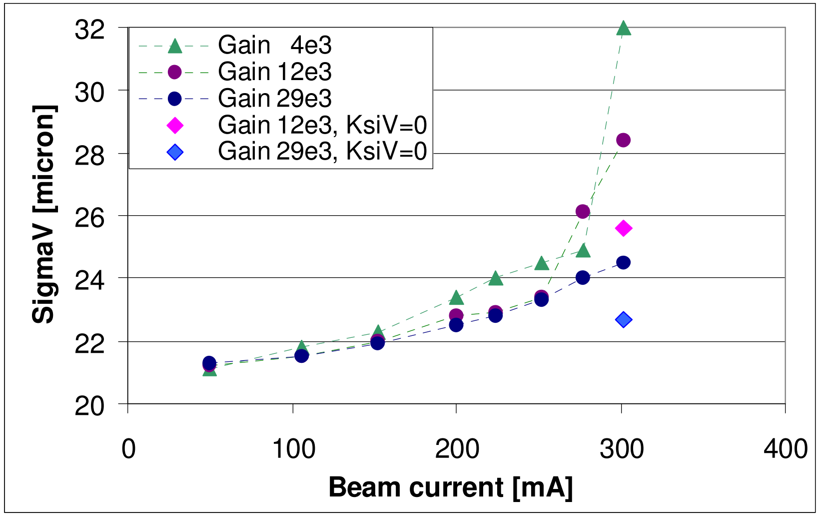
Attained performance against the vertical single bunch instability in comparison with the no feedback case

More than a factor of 3 of increase in the threshold is obtained at zero chromaticity (TMCI)

- In multibunch, a combination of moderate chromaticities (~2) and feedback allows storing a stable beam up to 450 mA (final target: 500 mA) with insertion device gaps closed.

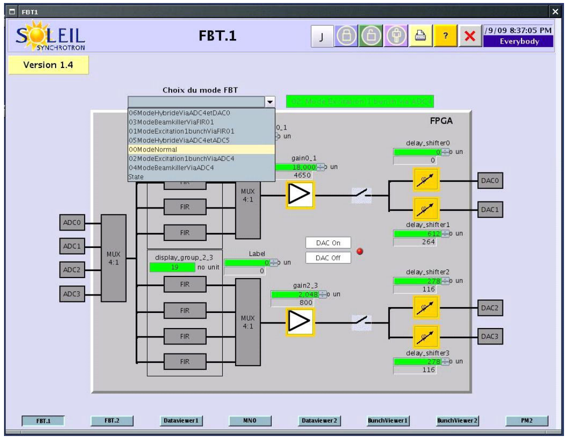
- However, sudden vertical beam losses are often encountered at high currents. Post-mortem data often indicate ion instability (FBII) related symptoms.

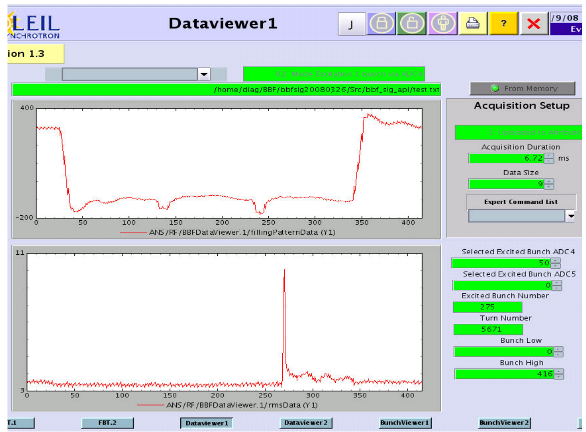
- Evolution of the vertical beam size with current:

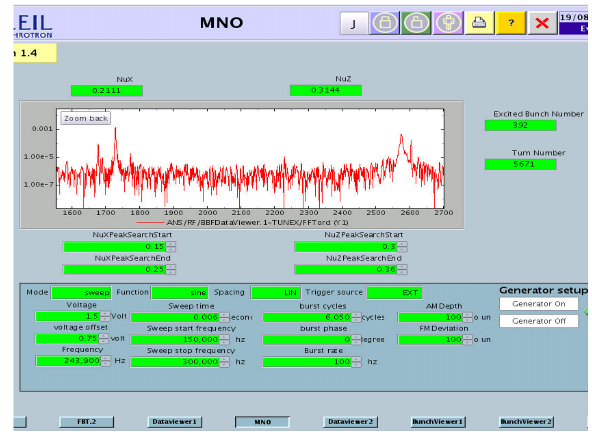


At high current, higher feedback gain and/or smaller chromaticity tend to keep the beam size small.

◊ Extended Applications and Ongoing Development







- Integration into the SOLEIL control system (Tango) (*left image*)

- Selective excitation of a bunch to measure the tunes (*middle & right images*)

- Variation of the feedback gain for selected bunches (e.g. In the hybrid mode)

- Direct frontend sampling at the RF frequency

- Measurement of feedback damping times and fine tuning of the system

◊ Summary:

- As anticipated, TFB turned out to be indispensable at SOLEIL in storing stable high current beam with good lifetime and small horizontal and vertical beam sizes.

- The developed system works successfully in both multibunch and single bunch.
  TFB is combined with a moderate positive chromaticity to achieve the desired current.

- TFB apparently fails in keeping the beam stable against FBII originated beam blow ups, which is currently under investigation.

- Further development is underway:

  - Direct signal sampling at the RF frequency

  - System optimisation via minimisation of the feedback damping