Bunch-by-Bunch Processing on MicroTCA at Diamond

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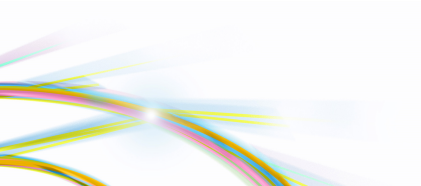
Diamond Light Source

Monday 30th November 2020



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MBF for Diamond 2

The new Multi-Bunch Feedback processor was implemented fairly recently and will be adopted for Diamond 2 without any further planned changes.

The Diamond 2 booster is likely to require transverse stabilisation, this will require an extra copy of the MBF system and brings some extra challenges.

Note that this talk is largely derived from a talk given to DEELS 2018.

Applications

Applications of MBF (Multi-Bunch Feedback) system

- Beam stabilisation
- Tune measurement
- Diagnostics and Machine Physics experiments
- Postmortem Analysis
- Vertical (and Horizontal) Emittance Control

History of MBF at DLS

The immediate precursor to Multi-Bunch Feedback at Diamond Light Source is:

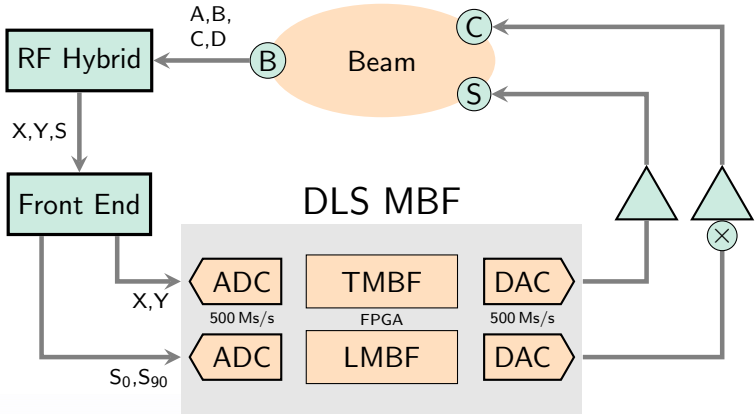
- ESRF, Eric Plouviez et al., reported 2006, implemented on the Libera platform, written using Xilinx System Generator.

At Diamond the following evolution occurred:

- Converted from System Generator to System Verilog by Isa Uzun, and tune sweep and individual bunch control added, reported 2008.
- Substantial rework by myself and Isa, reported 2013, introduction of sequencer and bunch bank control.
- Converted to VHDL to avoid licensing problems, adopted by ALBA 2014.
- Rewritten and ported to MicroTCA COTS hardware, 2016 to present.

The MBF system would not exist in its current form without substantial design and requirements input from Guenther Rehm.

System Setup for Bunch-by-Bunch Control

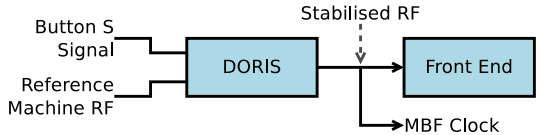


(B) EBPM pickup; (C) Longitudinal cavity; (S) Transverse striplines.

RF Phase Stabilisation

Compensating for long term machine RF phase motion

The phase of the electron beam tends to move unpredictably relative to the RF generator reference — this is mostly driven by RF group adjustments, mostly during machine development days.
This is compensated for by inserting an RF phase stabilisation unit:



Delayed Orbit Reference Improvement Scheme

MBF on MicroTCA

The old Libera platform was based on 15 to 20 year old hardware, and our FPGA was full. Using MicroTCA lets us use modern Commercial Off The Shelf hardware for data acquisition, signal processing, control.

FPGA carrier Vadatech AMC525 provides a Virtex-690 FPGA (with 3,600 DSP units), 2GB of fast RAM, 8 lane PCIe3 interconnect, support for 2 FMC cards

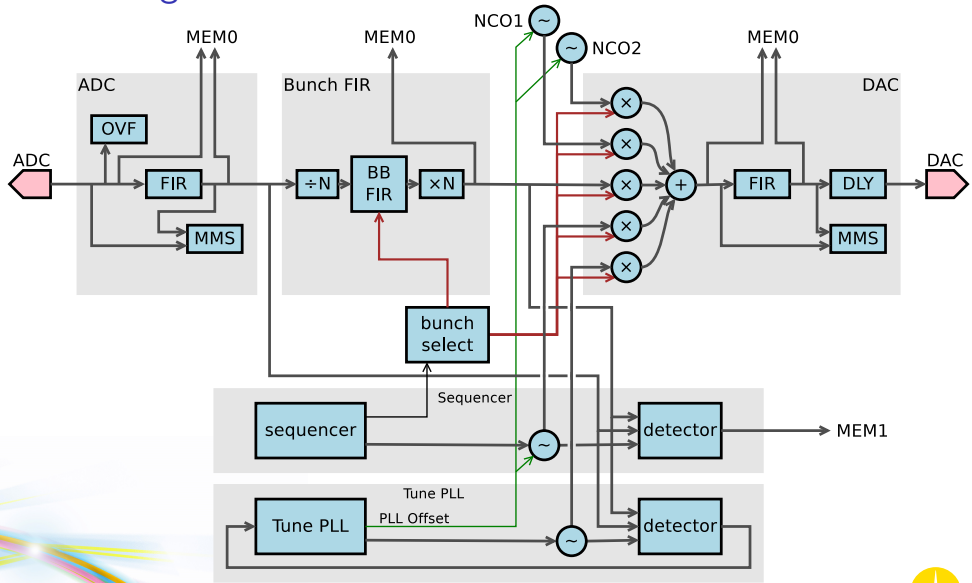
ADC/DAC FMC Dual 14-bit 500 M Hz ADC and 16-bit DAC.

This platform gives us plenty of room and allows for high performance, in particular the 8×PCIe3 readout of captured memory is valuable.

Capabilities of DLS MBF

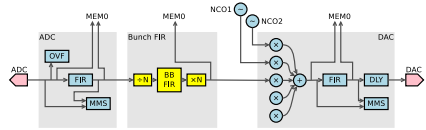
- Bunch by bunch feedback with 16-tap FIR per bunch
- Up to four different FIRs selectable for different bunches
- ADC compensation and DAC pre-emphasis with FIR
- Dynamic view of bunch motion: min, max, mean, variance
- Programmable sequencer with swept NCO excitation and synchronous detector
- Capture and fast readout of up to 1 second (2 GB) of dual channel bunch by bunch data
- Longitudinal feedback supported via bunch by bunch downsampling on FIR and 90° channel phasing for IQ output
- Tune tracking of selected bunches
- NCO frequency compensation from tune tracking
- Precise control over system contribution to each bunch

Signal Processing Chain



Bunch FIR

Bunch By Bunch Feedback

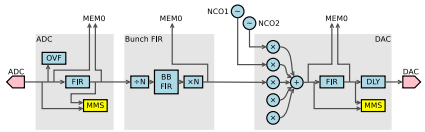


This is the heart of the system: all the rest is noise and diagnostics, really!

- 16-tap bunch-by-bunch filter to control phase of feedback
- Global feedback level set through the control system
- Feedback level separately controllable per bunch
- Optional bunch-by-bunch decimation: required for longitudinal operation, effectively extends length of filter by N.

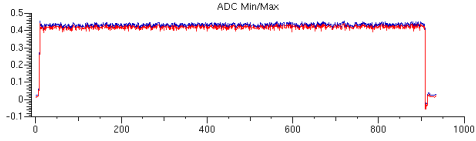
Min/Max/Sum (MMS)

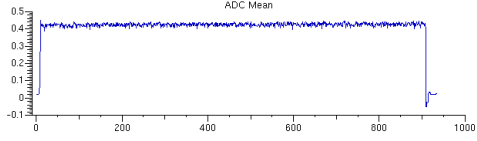
A snapshot of the behaviour of the complete fill

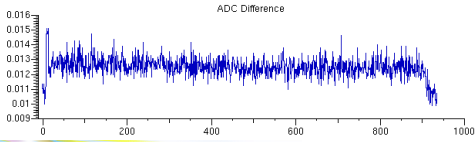


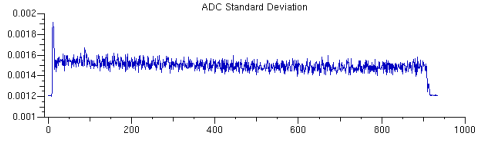
The MMS unit accumulates statistics for every bunch,
which are then read out periodically (the default interval is 200 ms) and used to display:

- Overall extent of beam motion (max − min)
- Standard deviation of beam motion
- Average beam position





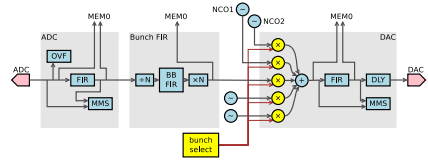




Sample size: 100,000 turns, note standard deviation ≈ 10 % peak-to-peak

Bunch By Bunch Output Control

Fine control over every bunch



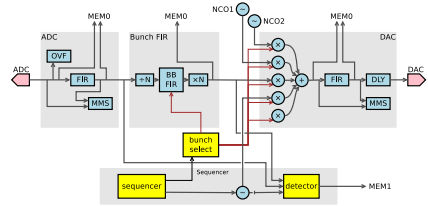
The following settings can be controlled independently for each bunch.

- Feedback from the bunch by bunch FIR
- Two separately programmed “fixed frequency” NCOs
- One NCO controlled by the Sequencer
- One NCO controlled by the Tune PLL unit

For each of these settings the output can be enabled or disabled and the gain set independently.

Sequencer and Bunch Select

Programmable control over excitation and behaviour



The Bunch Select unit selects for each bunch:

- Which of 4 FIRs to use on that bunch
- What combination of outputs for that bunch (NCOs and FIR)
- Individual bunch gain controls

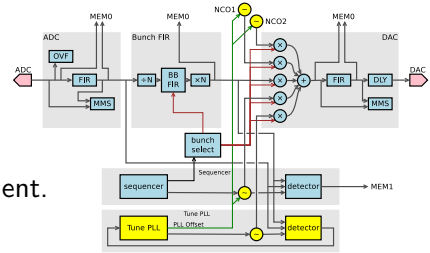
The Sequencer provides up to 7 states to control:

- Sweep control (NCO frequency range, sweep rate, etc)
- Which of 4 bunch configurations to use

The Super Sequencer repeats a sequencer experiment for up to 1024 different frequency offsets; this is particularly useful for mode scan experiments.

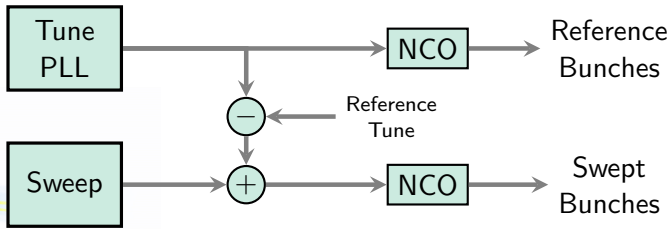
Tune PLL

Compensating for Tune motion



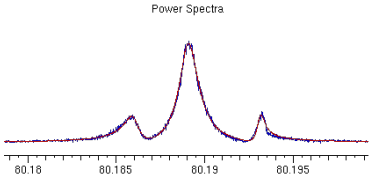
This system tracks the synchrotron tune on selected bunches of the fill. for a rapidly updating tune measurement.

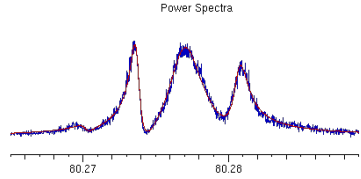
- Tune disturbance is global
- Can use PLL to track tune on part of fill.
- Tune offset then dynamically compensates tune sweep.
- Can now perform very long sweeps on low current parts of fill.

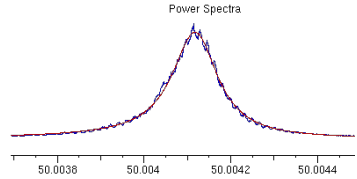


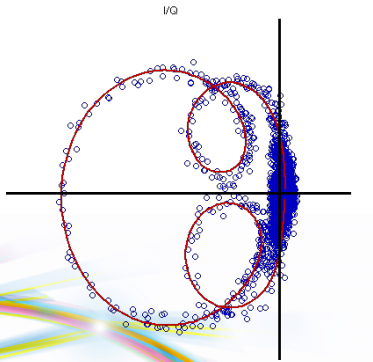
Tune Sweep

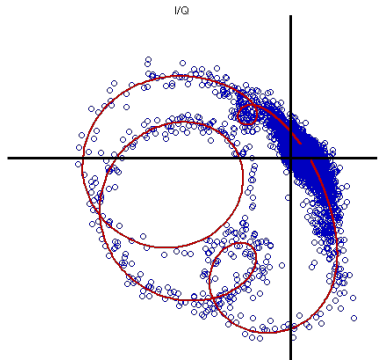
Examples of horizontal, vertical, and longitudinal tune sweeps with fitted models.

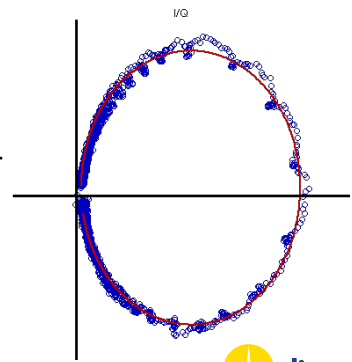






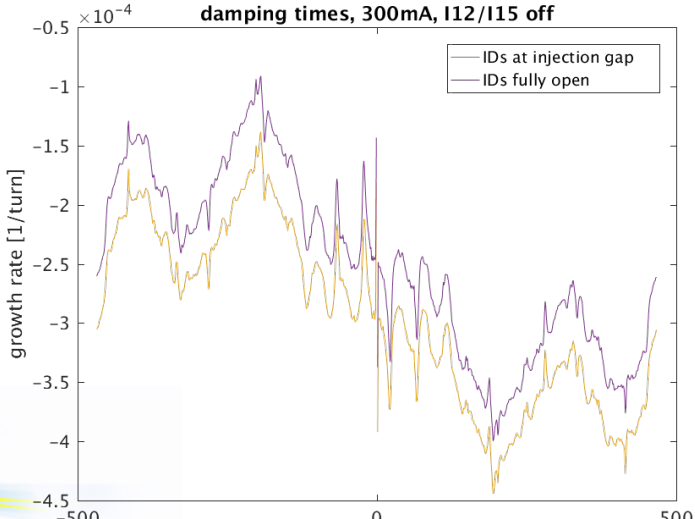






Longitudinal Mode Sweep Experiment

Rate of growth against excitation mode



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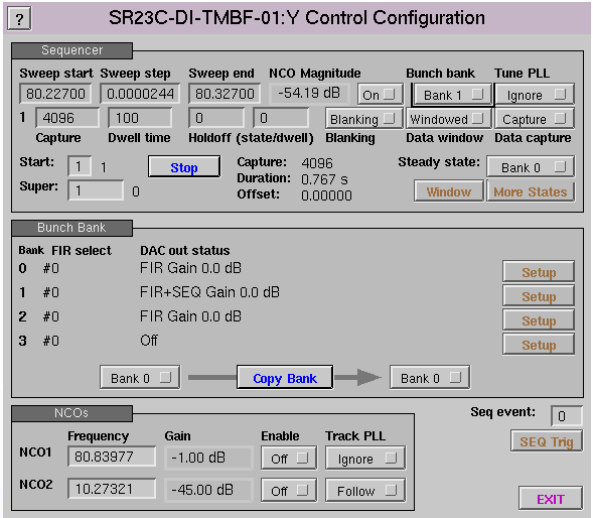
EPICS Control System

Sequencer Setup for Sweep



Summary

Work still to be done for Diamond 2

- Create copy of MBF system for operation on Booster.
- The Libera Front End is no longer available from iTech; it looks like we'll need to build our own for the Booster.
- The Booster RF phase will move during the ramp: a much faster version of DORIS may be needed to track this.