6th DEELS Workshop

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Optimizing the BPM processor filter for the fast orbit correction

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ESRF | The European Synchrotron

Optimizing the BPM processor filter for the fast orbit correction

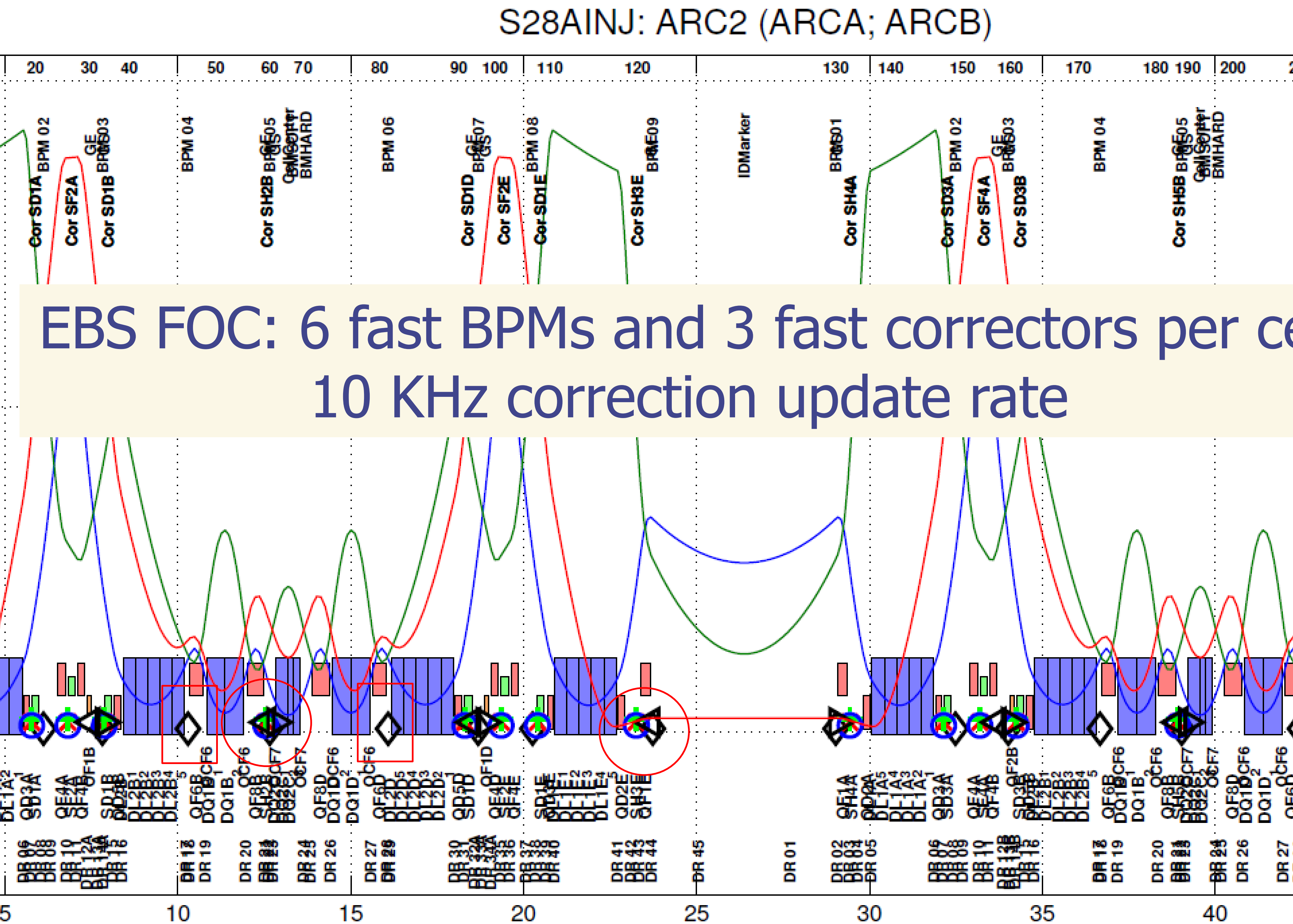
Issue: A lot of the digital signal processors used to treat the beam signals to generate beam position data, including the Libera, are using the same signal processing scheme as the one used for the so called SDR or Software Defined Receivers designed for radio communication application. Thought it does the job, taking into account the specificity of a storage ring beam signal and orbit correction requirements would allow a better use of the processor resource.

Issues: Why a Fast Orbit Correction

Fast sources of orbit distortion:

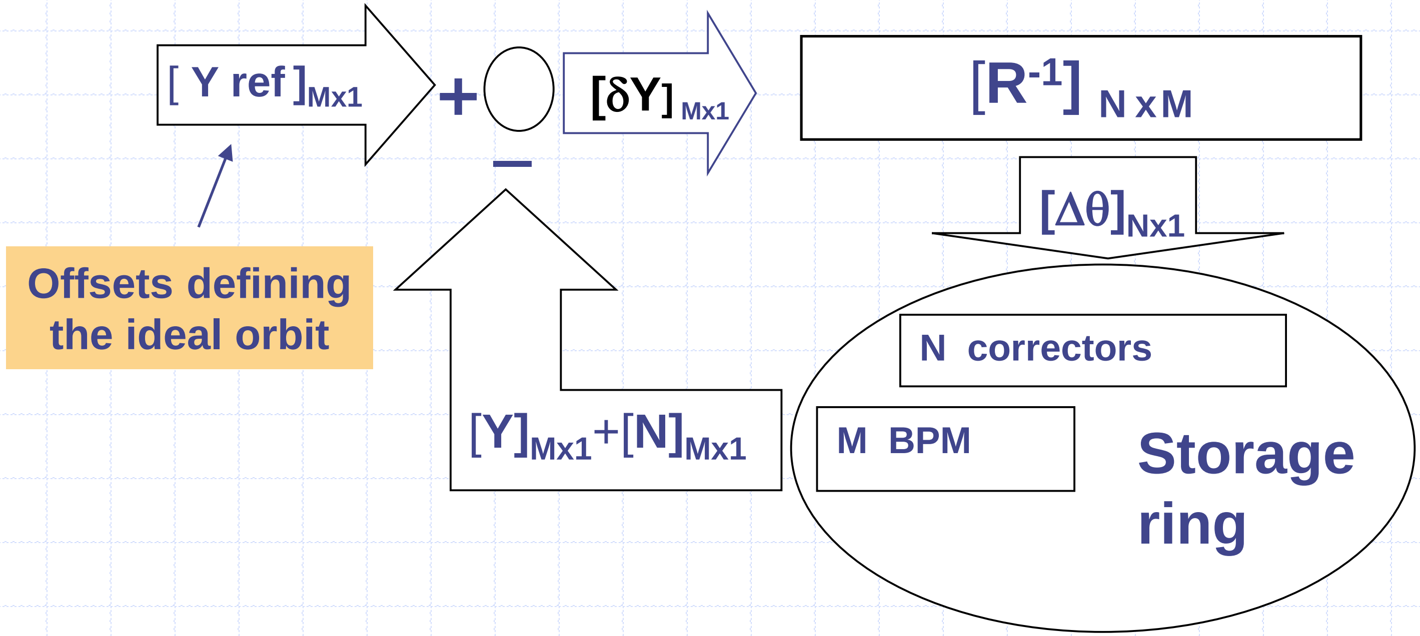
- *IDs gap changes*
- *Ground motion*
- *Water circulation-*
- *AC mains induced fields*
- *-Booster induced fields*

ESRF FOC parameters taken as an example.
It is not the any longer a state of the art system, but the issues are the same for more advanced designs


S28AINJ: ARC2 (ARCA; ARCB)
EBS FOC: 6 fast BPMs and 3 fast correctors per ce
10 KHz correction update rate

Fast orbit correction principle

- 10 KHz position sampling and correction setting (ESRF)
- Fast BPM number M=192 fast corrector number N=96



Orbit correction limitation

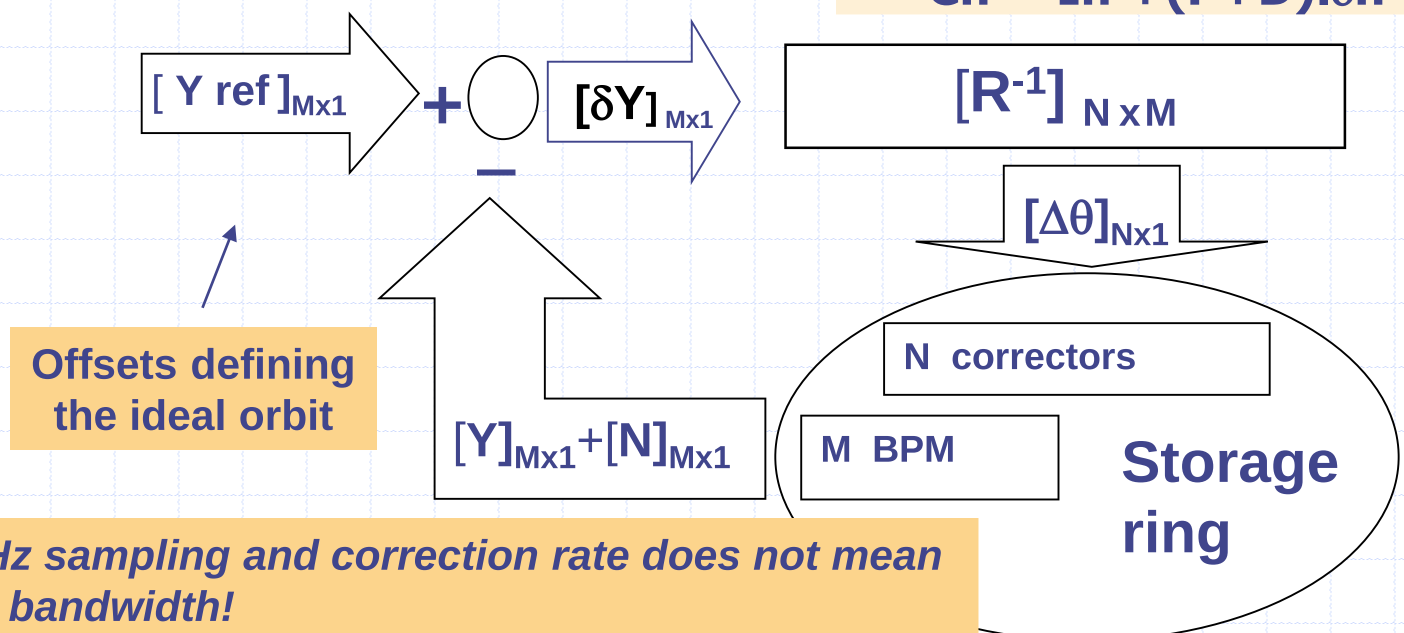
⑩ PID corrector :

$G = (P + j\omega_0/\omega + jD\,\omega)$

- **Sampled PID corrector :**

  $I_n = I_{n-1} + I.\delta_n$

  $C_n = I_n + (P+D).\delta_n - D.\delta_{n-1}$



10 KHz sampling and correction rate does not mean 5KHz bandwidth!

We are limited to about 150Hz:

By the latency due:

- **to the eddy current in the correctors**
- **to the signal processing in the Libera and the FPGA**

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Dynamic issues/ frequency range

Old ring:
IDs gap changes: below 1Hz
7 Hz 30Hz 60 Hz girders and magnet resonances
10Hz, 50Hz and 150 Hz lines (injector and AC main)

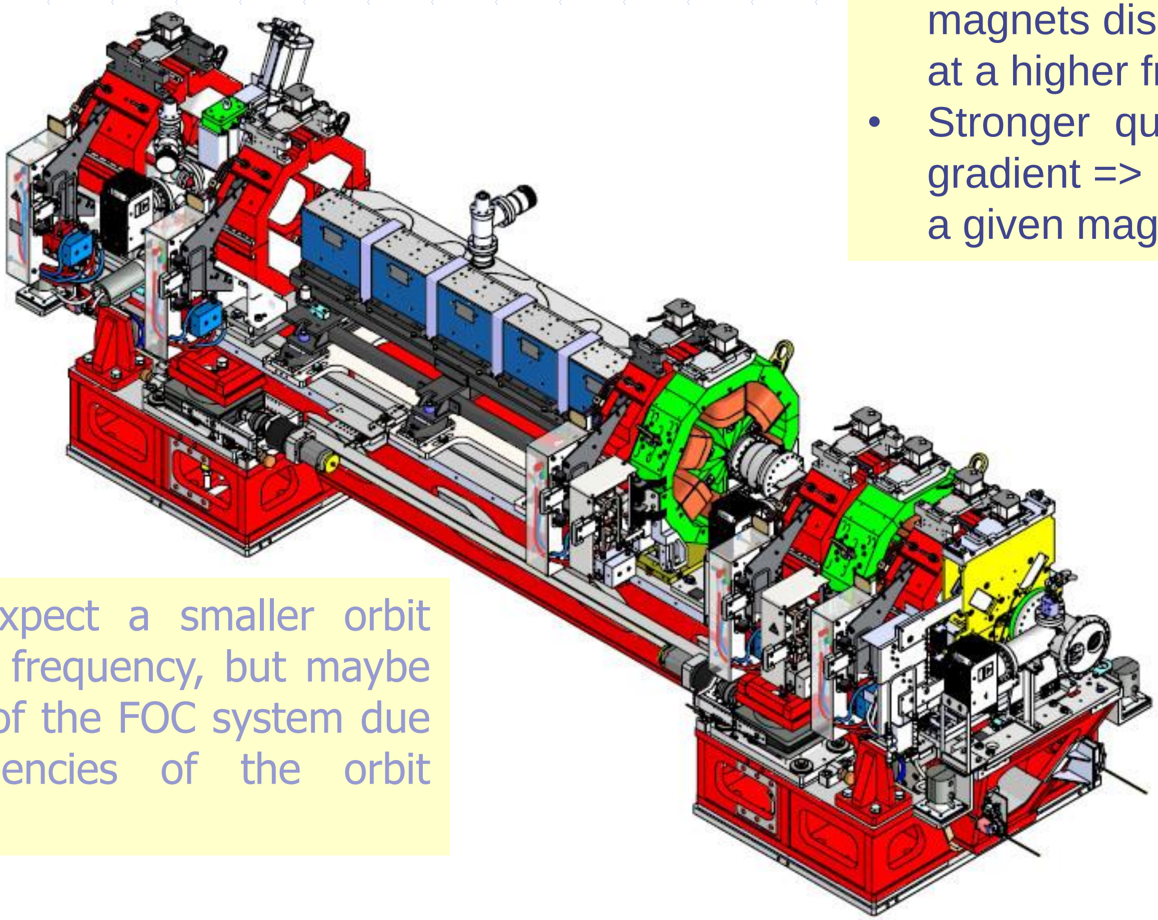
Fast H motion: 4μm   fast V motion: 1.5 μm

EBS ring:
IDs gap changes: below 1Hz
girders and magnet resonances shifted above 40Hz
10Hz, 50Hz and 150 Hz lines (injector and AC main)

Fast H motion: ?μm fast V motion ?μm (less than 1 μm ?)

NEW FAST ORBIT CORRECTION PERFORMANCE

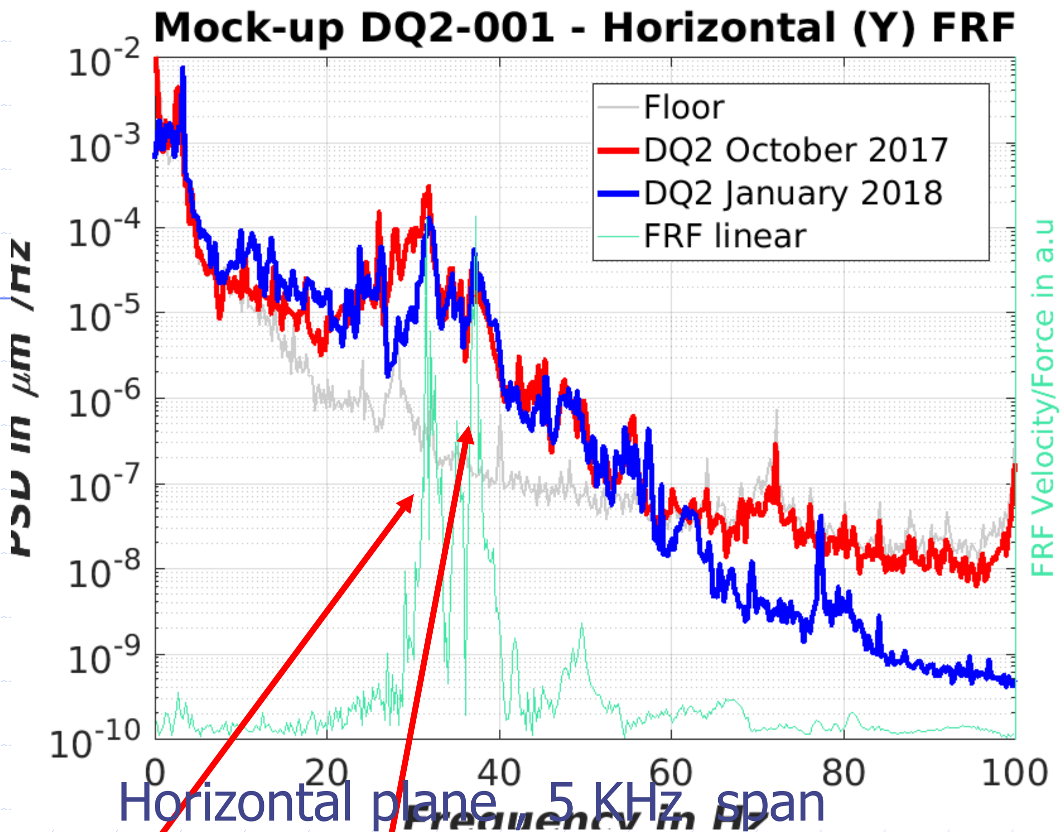
- Stiffer girders: smaller magnets displacement, but at a higher frequency
- Stronger quadrupoles fields gradient => Larger kicks for a given magnet motion



Eventually, we expect a smaller orbit distortion at high frequency, but maybe a reduced effect of the FOC system due to higher frequencies of the orbit distortions

DQ2-001 Magnet

(between Girders 2 and 3 - Front-end disconnected in 2018)



Horizontal plane , 5 KHz span

- Braodband amplification (TF $_{DQ2/floor}$) 1.4 (10/2017) → 1.2 (01/2018)
- Modes at 32Hz and 37Hz

Dynamic issues/ frequency range

ESRF corrector concept:

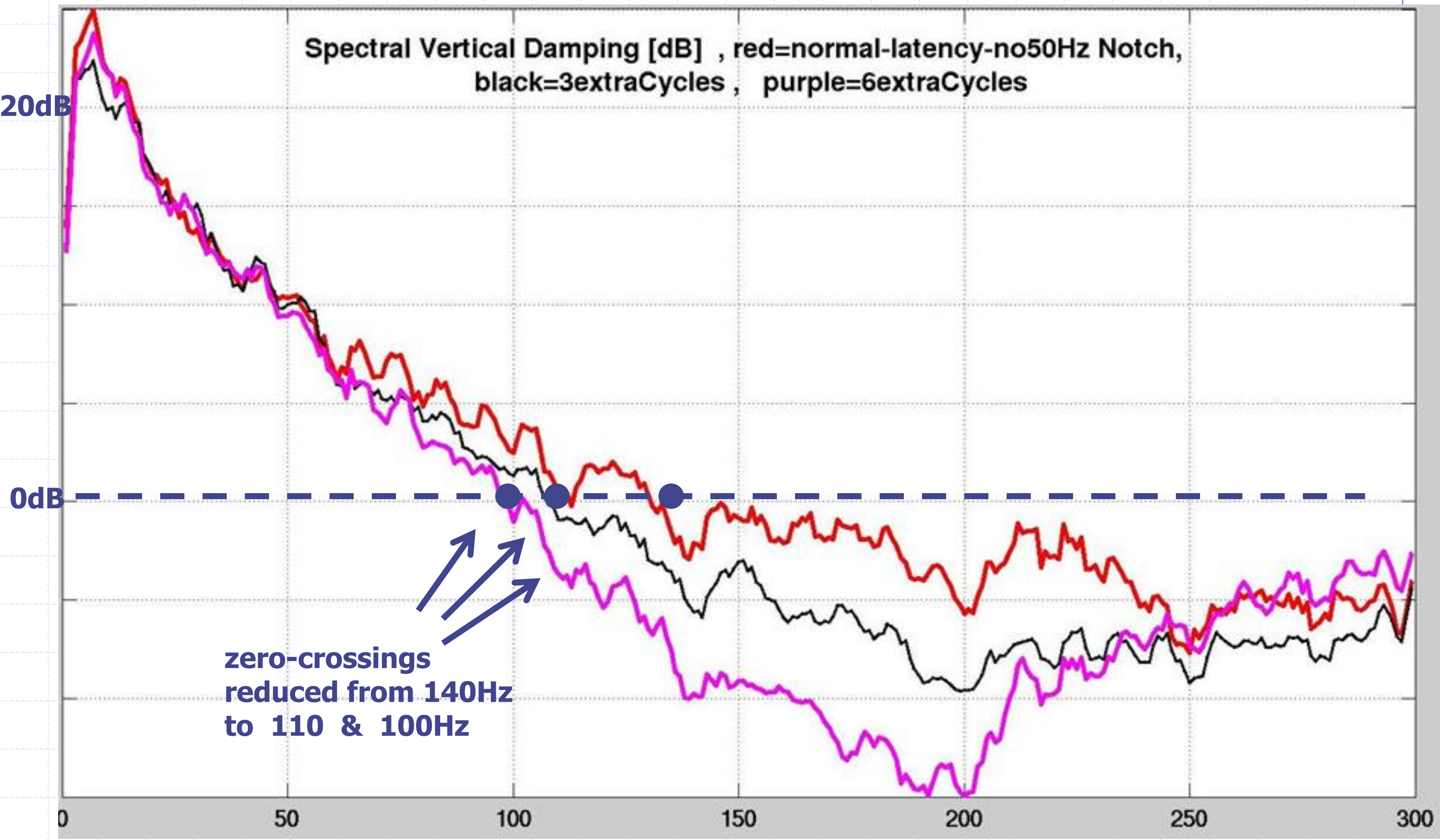
We use a so called PI corrector, with the addition of a dedicated narrow bandwidth 50Hz suppressor

Effect:

D, residual relative distortion at f, for a loop bandwidth f_c: $D=f/ f_c$

The limiting factor for f_c is the loop delay ...

The bandwidth sets the relative residual orbit distortion at low frequency


Spectral Vertical Damping [dB] , red=normal-latency-no50Hz Notch,
black=3extraCycles , purple=6extraCycles
20dB
0dB
zero-crossings
reduced from 140Hz
to 110 & 100Hz
0
50
100
150
200
250
300

Fast Orbit Feedback delay contributors (old ring)

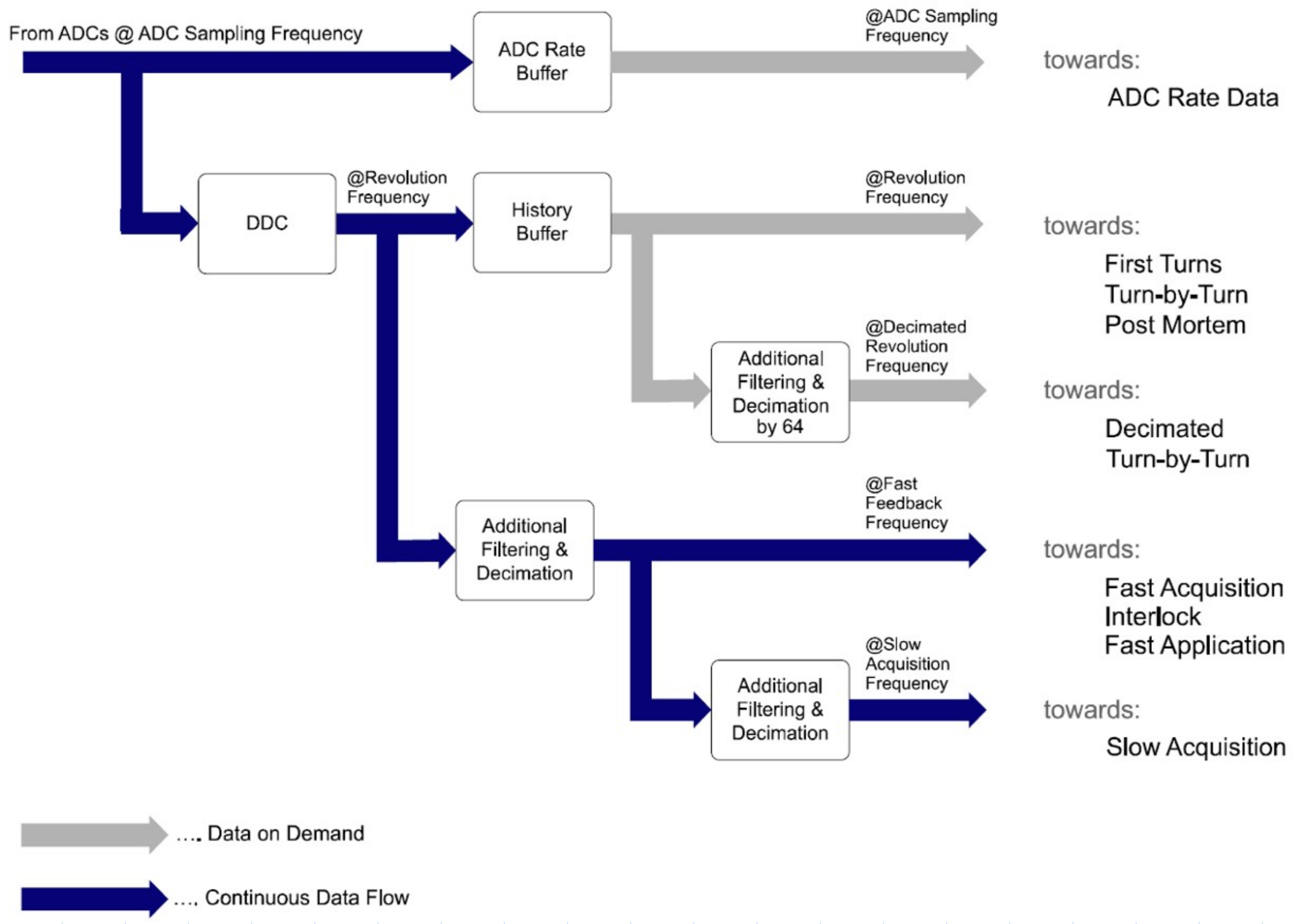
ESRF Fast Orbit Feedback timing

Group delay of the FIR (linear phase, 79 samples):	148 µs
Distribution of data around the ring (C.C.):	70 µs
Matrix multiplication 2*7*168 (based on Power PC):	4 µs*
PID controller:	1 µs
Write into PS controller:	20 µs
Power supply:	50 µs
Eddy currents in the sextupoles (correctors):	75 µs
Eddy currents in vacuum chamber:	265 µs
Total:	<683 µs

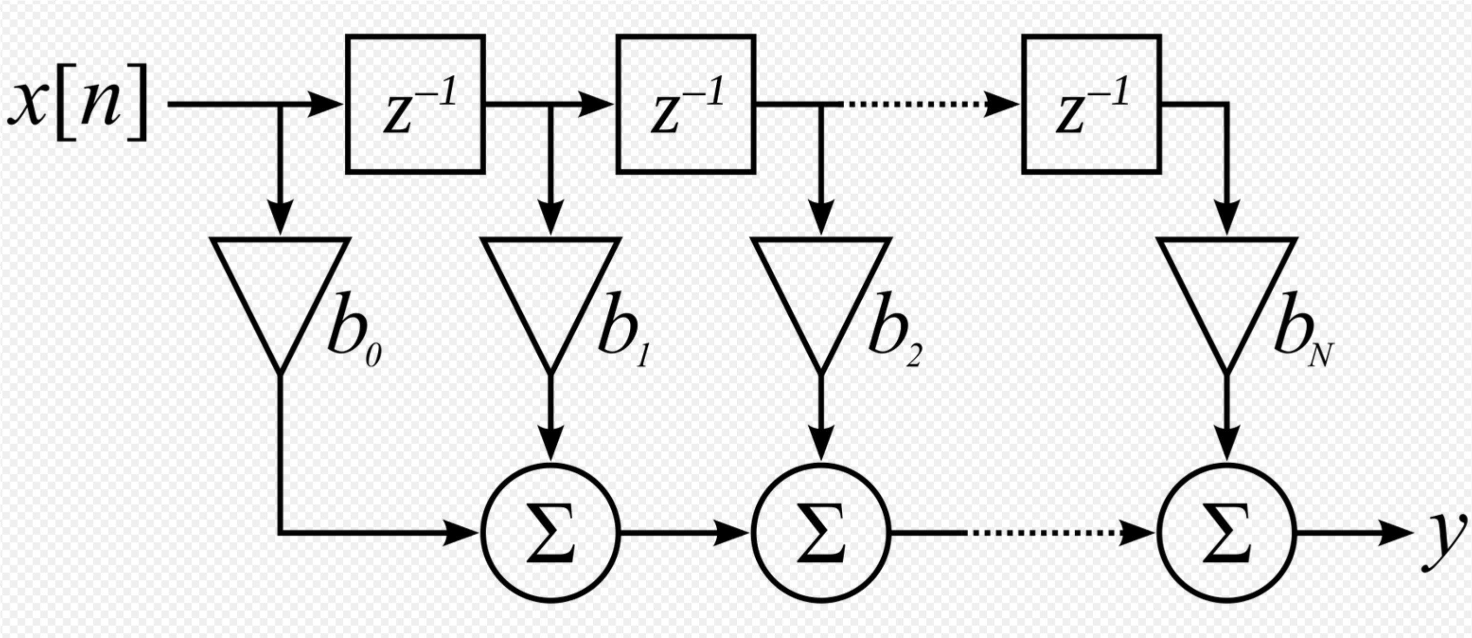
** Must be scaled according to the number of data and depends on the DSP engine (Power PC, FPGA, …)*

Will results in a phase shift of 45 degrees at 180Hz …

Libera Brillance signal processing

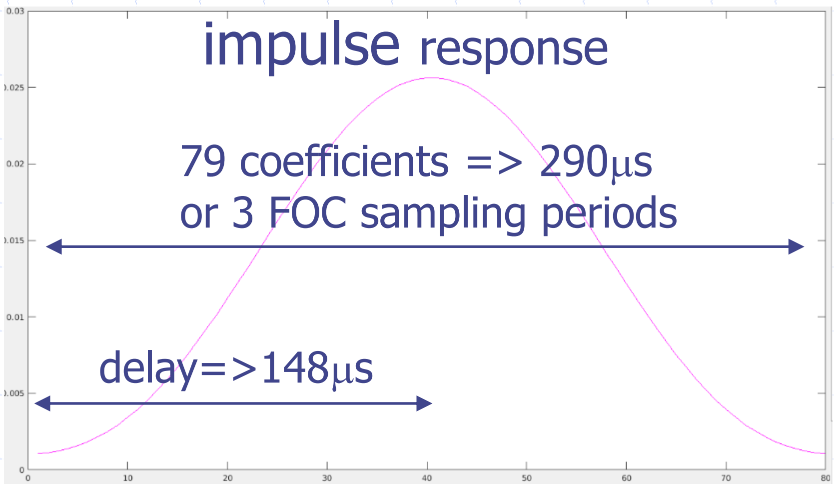


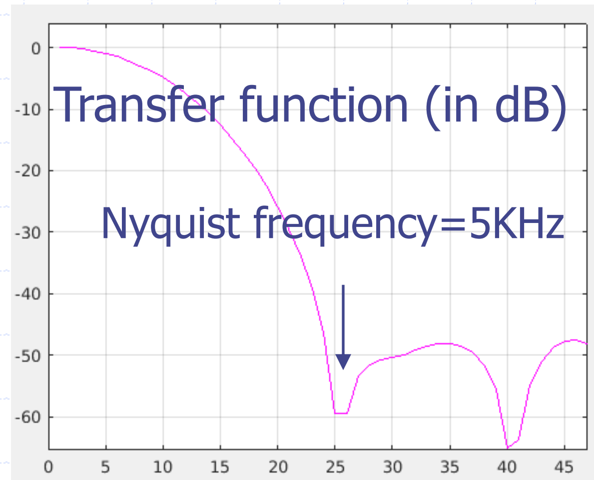
FIR (finite impulse response) filter



x[n]: turn by turn BPM data

Effect of the FIR of the FA output

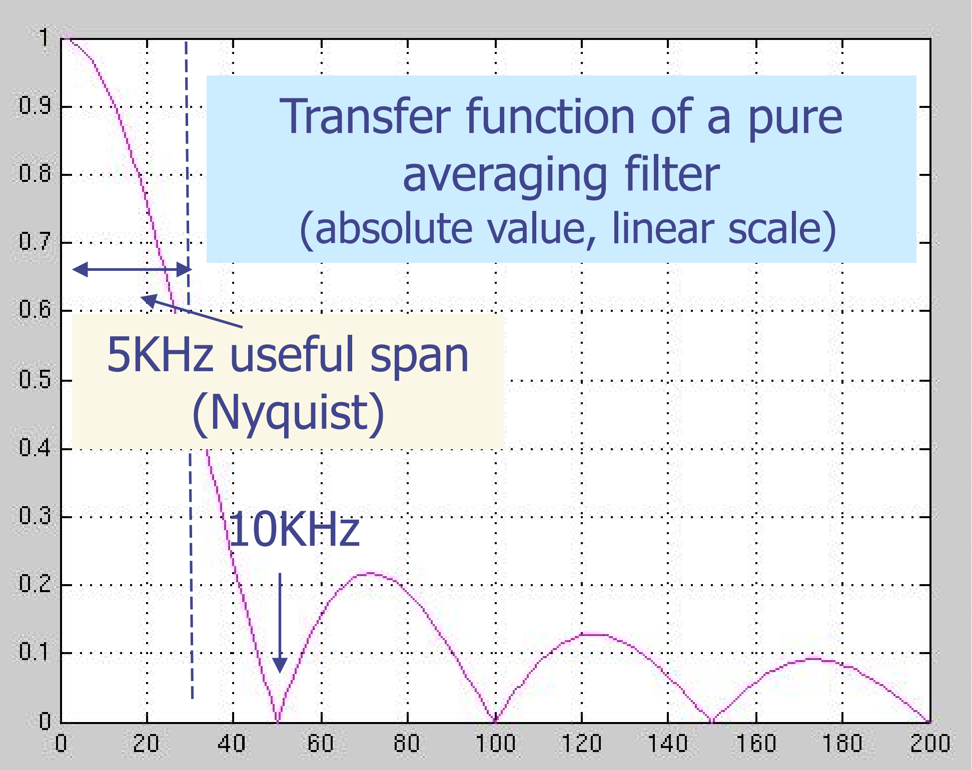




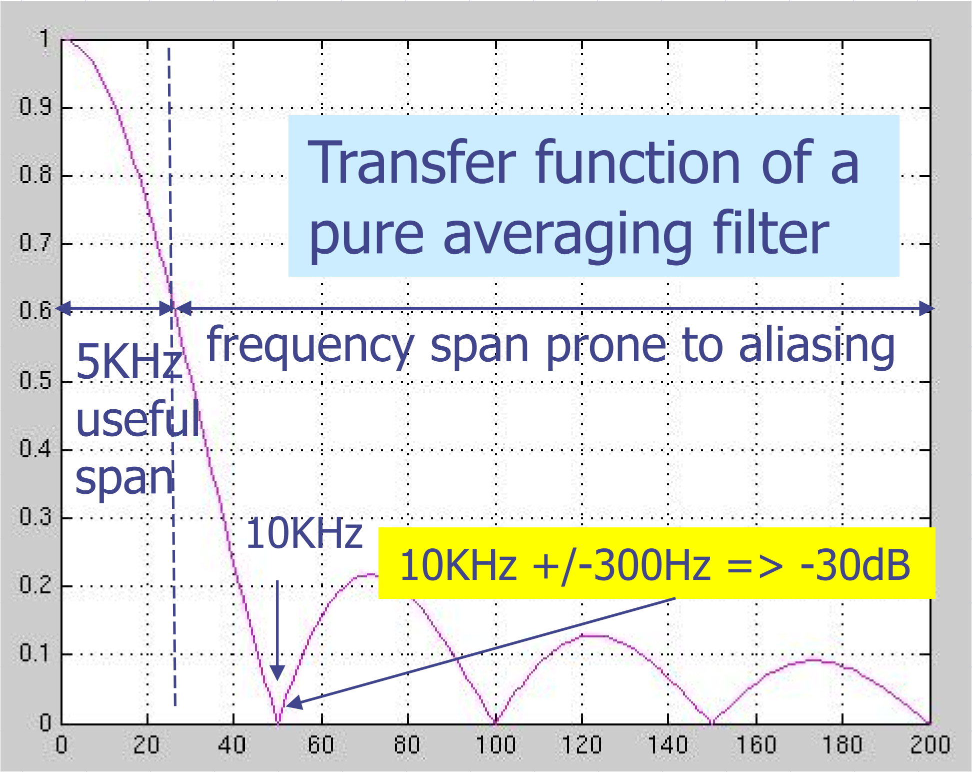
Very good selectivity => low aliasing due to the decimation: required for telecom application, but do we really need it?

Lowest delay limit: moving average filter

26 coefficients filter, all equals to one
Group delay of the FIR: 50 µs (three time lower!)



Undersampling effect

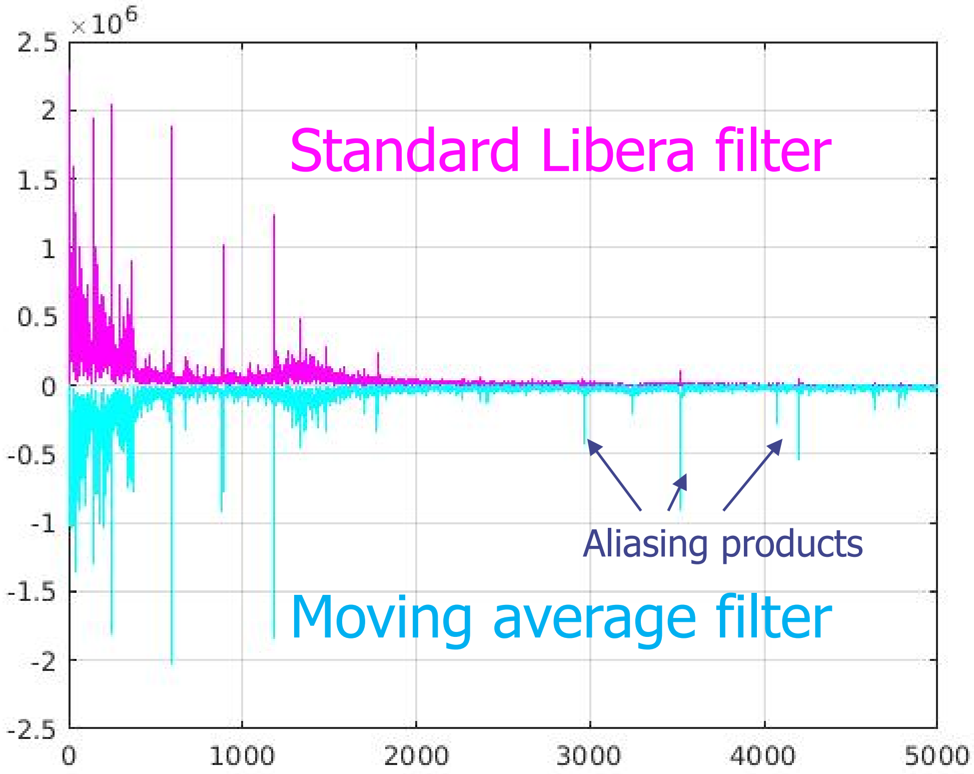


Spurious signals falling above the feedback cut off frequency

Extra filtering due to :

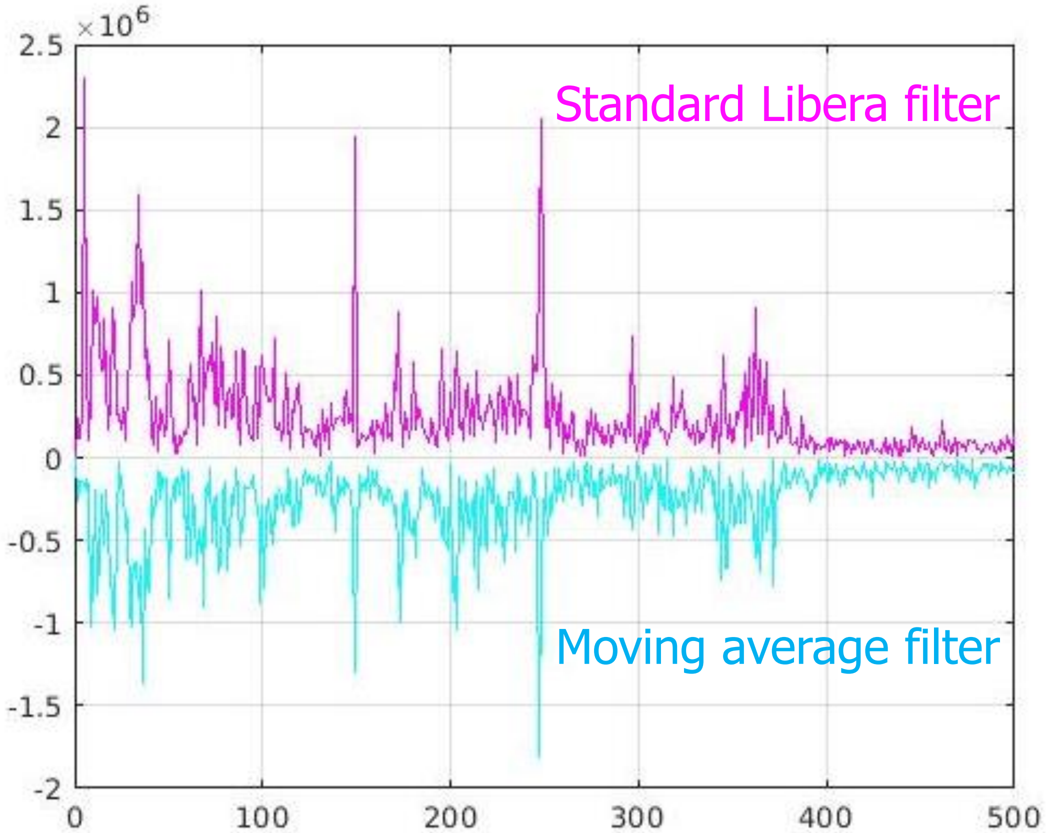
- Loop filter
- Limited bandwidth of the correctors

TEST on the old ESRF ring



Horizontal plane , 5 KHz span, FOC off

TEST on the old ESRF ring



Horizontal plane , 500 Hz span

Moving average filter:
No extra spurious lines in the useful frequency span

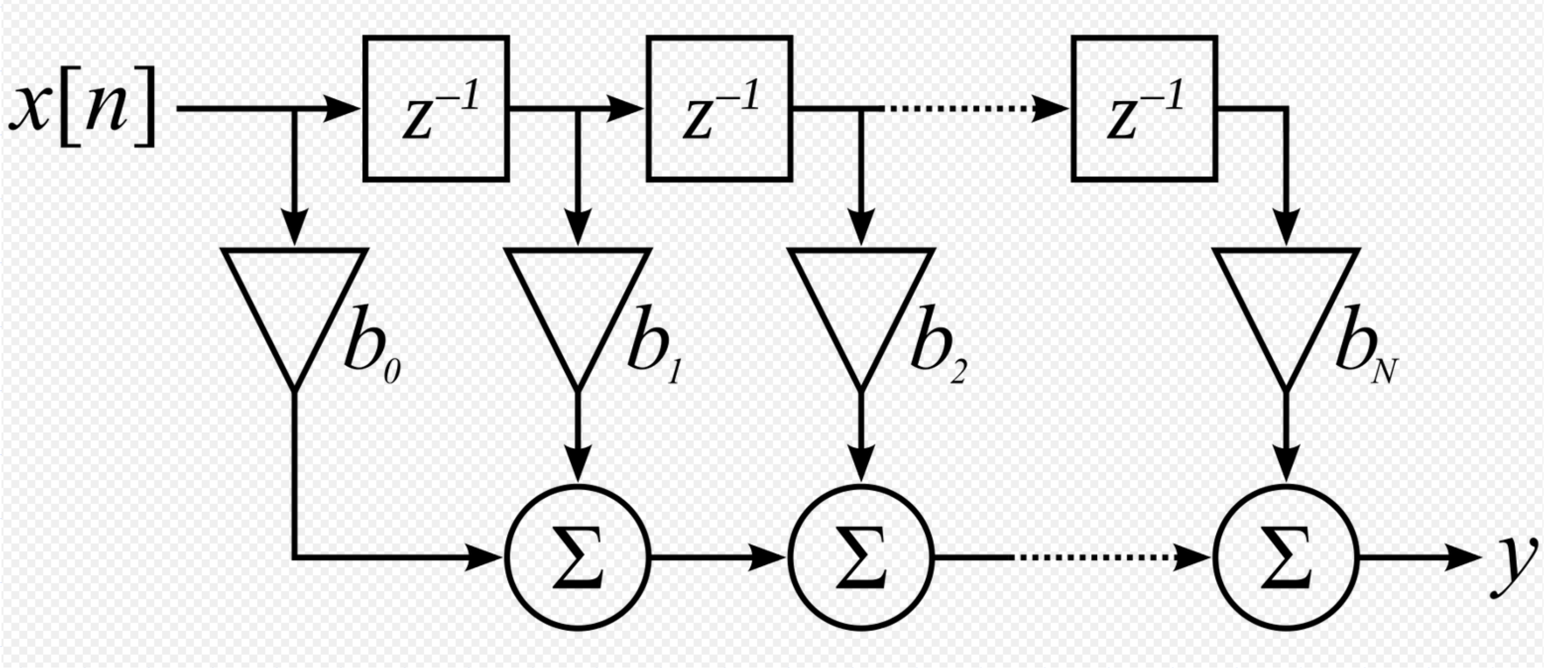
Achievable loop delay on the EBS FOC …

Group delay of the FIR :	50 µs
Distribution of data around the ring (C.C.):	70 µs
Matrix multiplication 2*7*168	4 µs
PID controller:	1 µs
Write into PS controller:	20 µs
Power supply:	50 µs
Eddy currents in the new correctors:	25 µs
Eddy currents in a 1.5 mm thick vacuum chamber :	80 µs*
Total:	<300 µs

* For the V correction only, H correction: 400µs

Will results in a phase shift of 45 degrees at 400Hz ...

Implementation in the FPGA

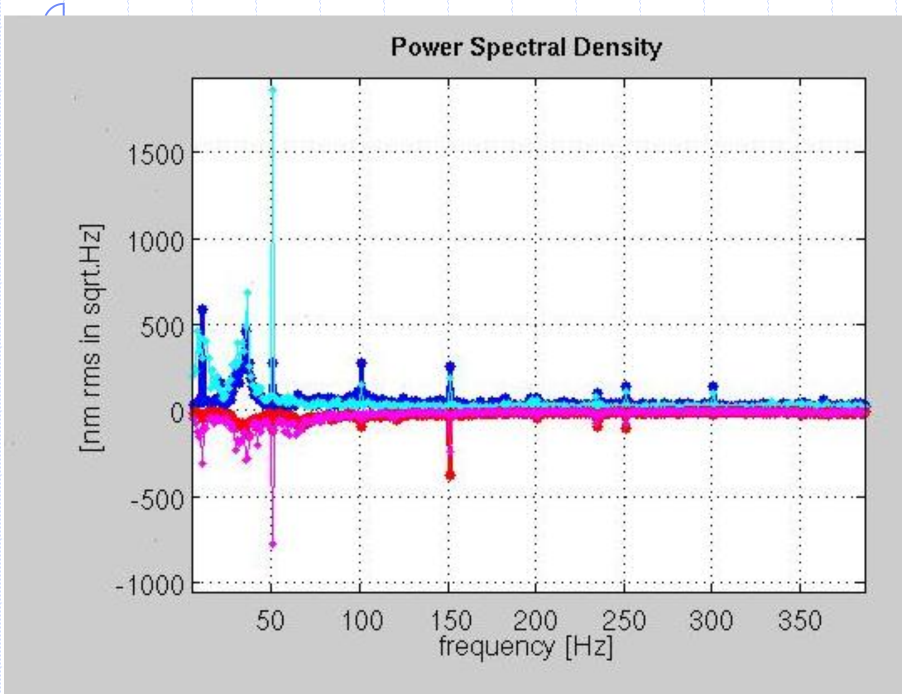


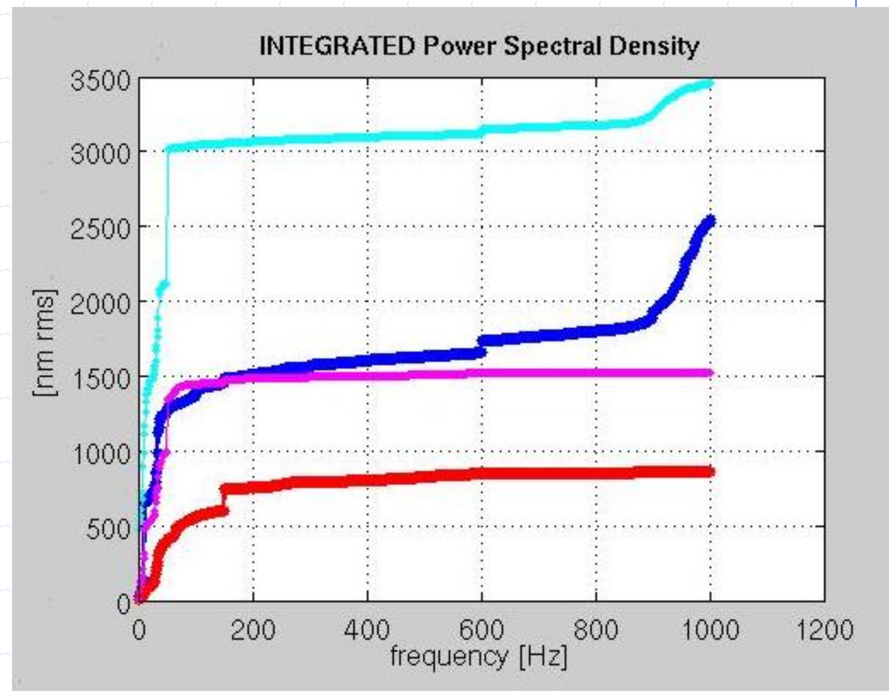
b_i= +or-1 so no multiplication needed, very low use of FPGA ressources


Thank you for your attention

Extra slides (if questions…)

Old ring situation
Quality of the correction up to 1KHz





- **Submicron vertical rms residual motion =>vertical motion < 10% of the vertical beam size.**

εxOFF=1.3 10^{-12}
εxON =1.3 10^{-13}
εxbeam =4 10^{-9}

εzOFF=3.5 10^{-13}
εzON =4.8 10^{-14}
εzbeam =4 10^{-12}

Shall we need to apply really fast orbit corrections?

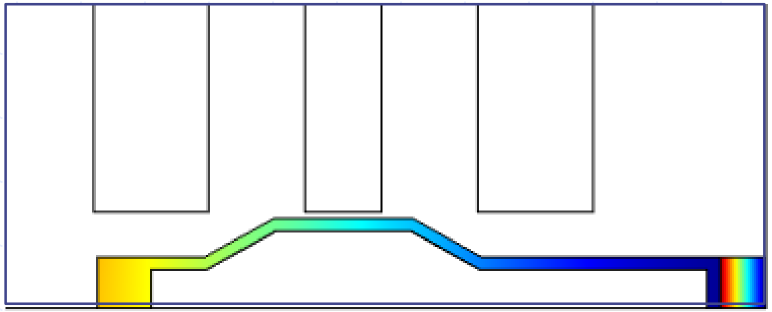
If we need a significant damping above 30Hz, the bandwidth of the present FOC may not be enough, but we may not need it …

By the way, modern rings with an optimized design of the girders and magnets (SOLEIL, ALBA, Diamond) are in this situation …

Sirius is aiming at a much larger bandwidth

EBS correctors chamber

Eddy current effect:
- Severe for the H correction : 400μs delay
- 6 time smaller for the V correction



Low delay FIR could make a difference for the vertical orbit correction