SOLEIL SYNCHROTRON

SOLEIL New Platform for Fast Orbit Feedback

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Summary

- **Context and specifications**
- **New platform insight and installation**
- **Test results**
- **New identification features**

Context and specifications

Synchrotron SOLEIL

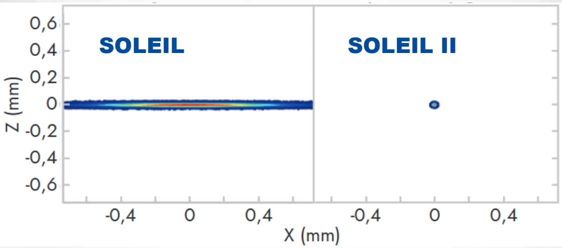
3rd generation light source

- In operation since 2006
- France, 20km south of Paris
- 29 Beamlines in operation

Upgrade to SOLEIL II

- 4th generation
- TDR ongoing
- Shutdown scheduled for mid-2027
- Lower emittance (< 100 pm.rad)

Energy	2.75 GeV
Circumference	355 m
Revolution period	1,18 µs
Number of cells	16
Beamlines	29



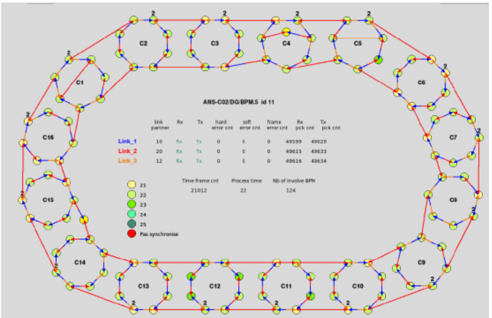
Simulation of a source point dimension before and after the upgrade

Context and specifications

- Upgrade obsolete BPM electronics ahead of SOLEIL upgrade
- Move FOFB application out of the BPM electronics
- Toward a very flexible platform:
  follow years of evolutions.

Current BPM electronics: Libera electron

Current PSC: Itest BILT (correction magnet) Power Supply Controller



Schematic of the current BPM dedicated network

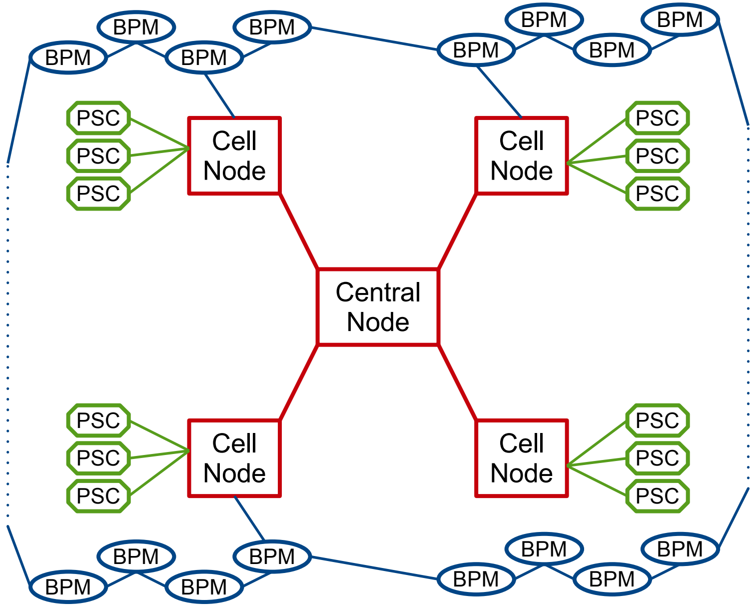
	Actual FOFB	Future FOFB
# BPM	122	180~200
# Corrector	50 H & V	44~60
Data rate	10 kHz	100 kHz
Correction BW	200 Hz	1 kHz
Loop Latency	350 µs	100µs
Stability	10 % of beam size 20 µm H ; 0.8 µm V	2-3% of beam size 50 nm H & V

	Evolution	Impact
2024	FOFB running on new platform	Same performances
2025	Added features	Faster lattice identification.
2026	New BPM electronics	Loop latency reduced, data rate increased, correction bandwidth increased
2028	SOLEIL II, new PSC	Loop latency reduction, dimension reduction, SOLEIL II performances
2028 +	New correction algorithm	Increased performances

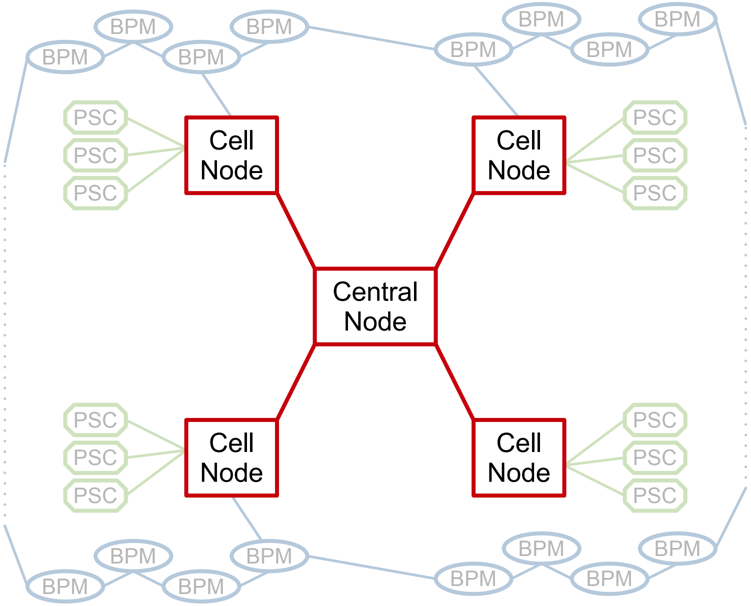
New platform insight and installation

New platform insight

- New platform: 5 Node systems connected in a star topology
- 122 BPMs
- 100 PSCs



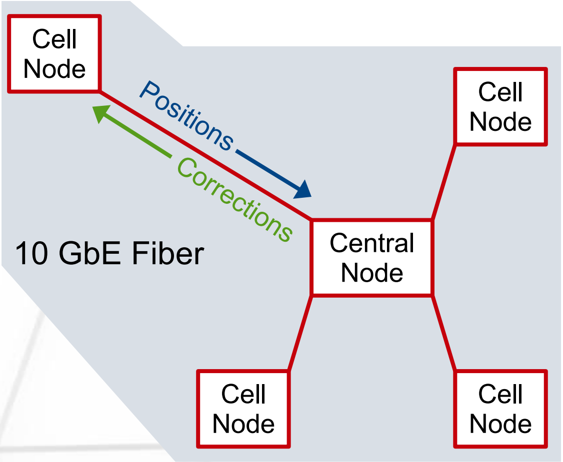
Central & Cell Nodes



New platform insight

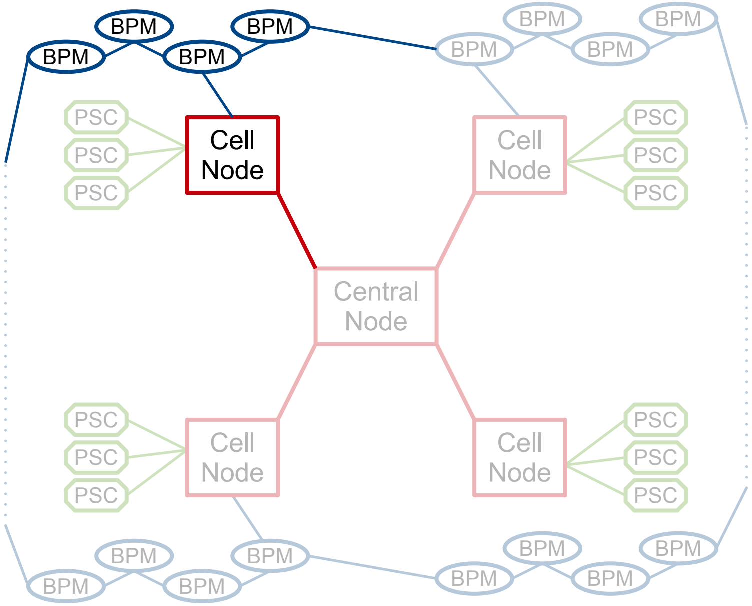
Central & Cell Nodes

- Node system: MTCA chassis
  Main part: SoC-FPGA AMC board
- Connected by dedicated fibers, SFP module connected to FPGA
- Position and Correction packets inside Ethernet frames, 10 Gbps
- One frame up-down transfer per loop cycle (10 kHz for current BPMs)
- Measured up-down latency < 4,5 µs



MTCA chassis Node (front and back)

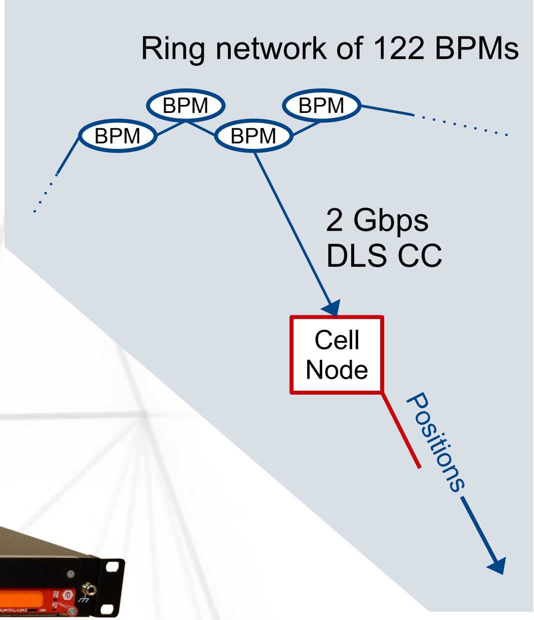
BPM position grabbing



New platform insight

BPM position grabbing

- Each Cell Node connected to BPM dedicated communication ring (DLS Communication Controller)
- Copper wire SFP module, read only connection
- Capture and forward position data of ¼ (~30) of the BPMs
- Group of position numbered (loop iteration number)



Actual BPM electronics: Libera electron

Cell Node (front)

BPM position packet

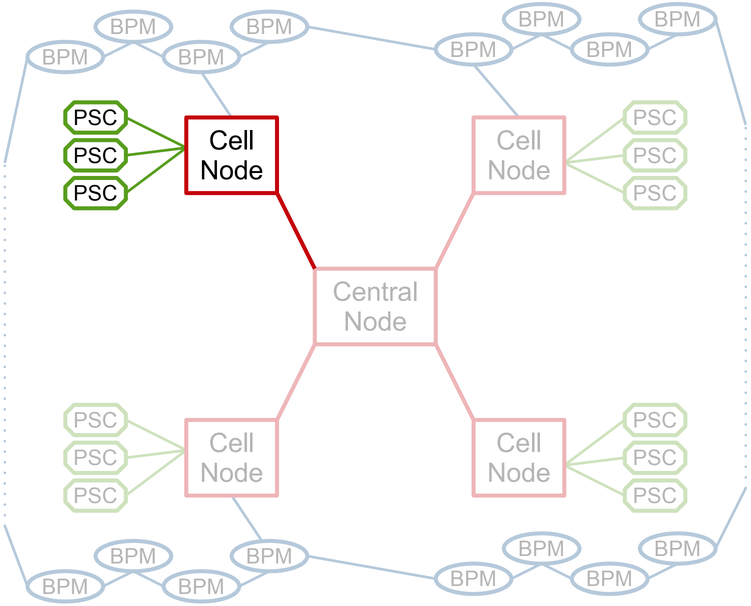
P. ID	N	Timestamp	BPM ID	X Pos.	Y Pos.	*repeated*	BPM ID	X Pos.	Y Pos.
1	1	8	2	4	4		2	4	4

ETH L1/L2

Preamble	Start Frame Delimiter	Destination MAC	Source MAC	Length		CRC	Interpacket Gap
7	1	6	6	2	*max 1522*	4	12

Ethernet Frame with encapsulated positions packets

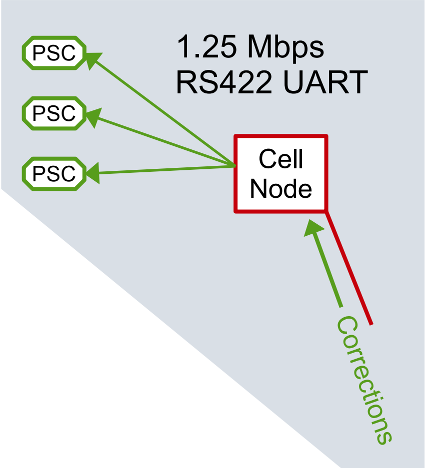
Correction transmission

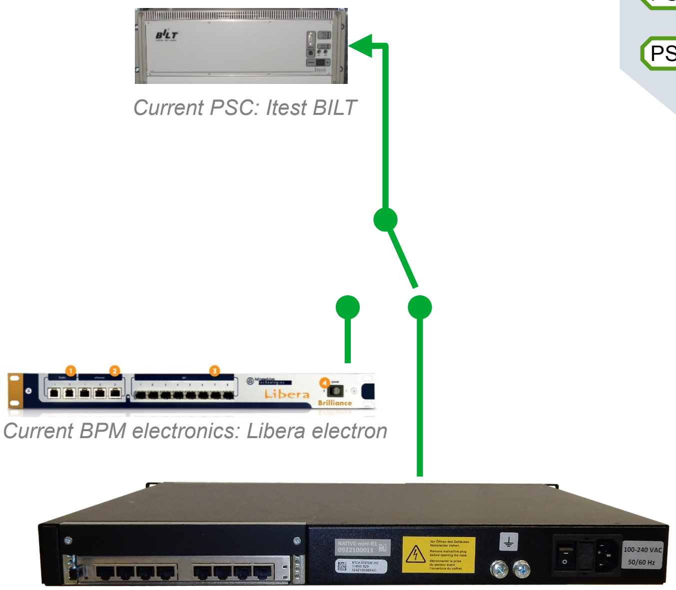


New platform insight

Correction transmission

- Each Cell Node connected ¼ (~25) PSC
  in local cell cabinet and three neighbouring cells
- Regular RJ45-CAT6 cable,
  RS422 UART 1.25 Mbps
  4 link pairs per cable, 80m max.
- CACTUS: Custom RTM with 32 TX drivers
  To be decommissioned with the PSC for SOLEIL II.
- Quick PSC driver switching: current/new platform
  Electromechanical relays, powered from central location.

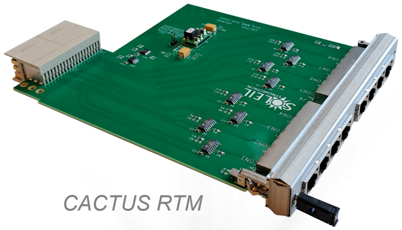




Current PSC: Itest BILT

Current BPM electronics: Libera electron

Cell Node (back)



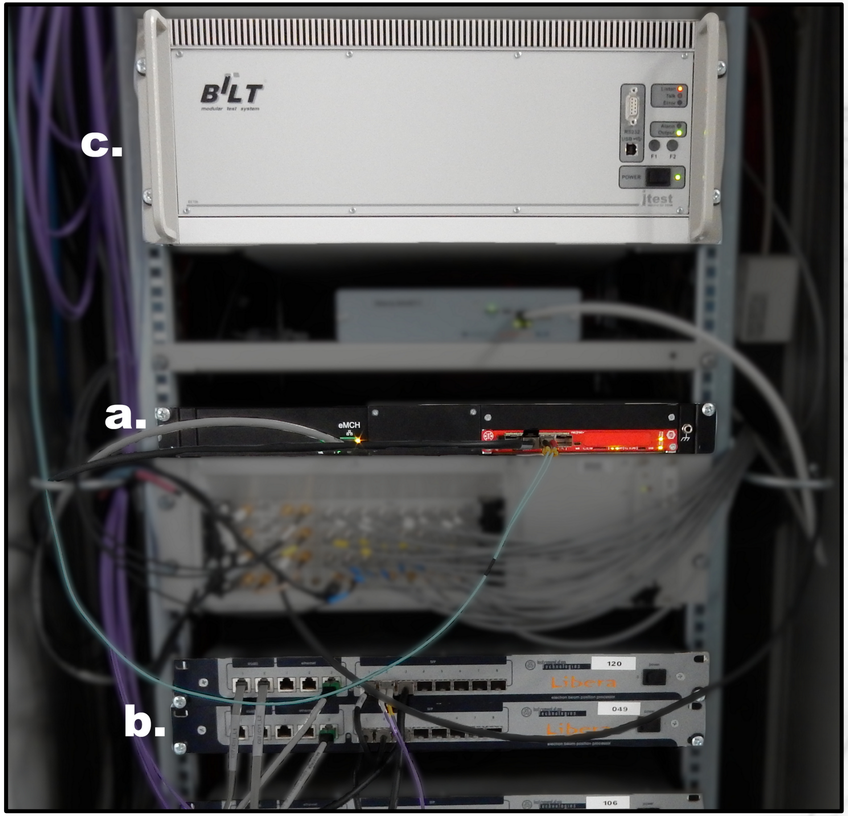
CACTUS RTM

Correction packet	P. ID	N	Timestamp	PSC ID	Corr. Value	*repeated*	PSC ID	Corr. Value

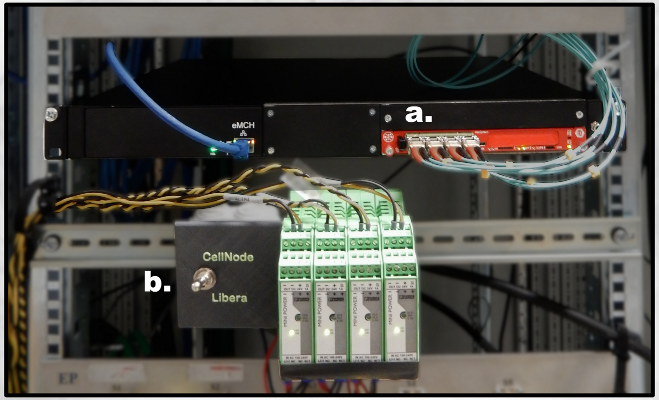
ETH L1/L2	Preamble	Start Frame Delimiter	Destination MAC	Source MAC	Length		CRC	Interpacket Gap
	7	1	6	6	2	*max 1522*	4	12

Ethernet Frame with encapsulated correction packets

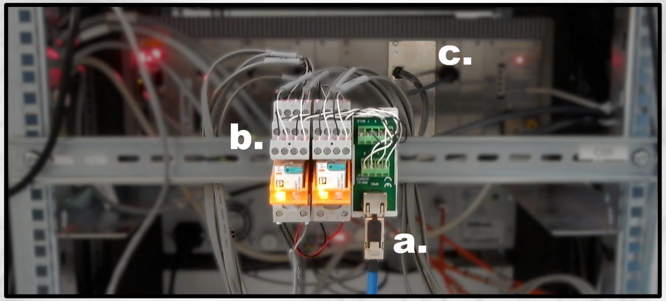
Installation pictures



A Cell Node rack cabinet
a. Cell Node with fiber connection to Central Node and copper connection to BPMs. Connections to PSC on the back, not seen.
b. BPM electronics.
c. Power Supply Controller.



Central Node rack cabinet
a. Central Node with outgoing fiber to CellNodes
b. Switch lever and power supplies to relays



A cell rack cabinet
a. Incoming RJ45 CAT6 cable from a Cell Node going to a breakout panel
b. Electromechanical relays. Inputs from RJ45 breakout and BPM electronics, output to PSC
c. Power Supply Controller.

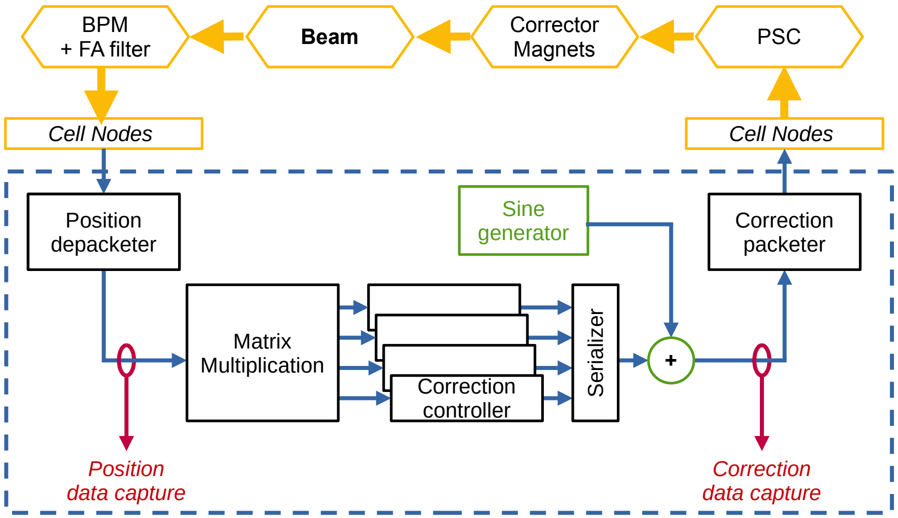
Central Node insight

Same current algorithm

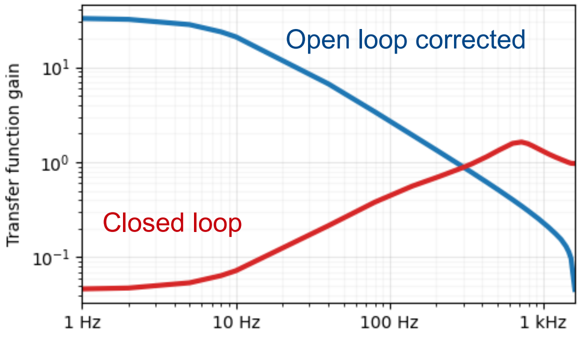
- Orbit Response Matrix inversed with SVD, Tikhonov regularization
- Correction controller is an 8 Hz low-pass filter (Perturbation attenuated by inverse of this filter)

Added functionnalities

- Add a per PSC sine signal
- Triggered data capture



Blue dashed rectangle: Central Node detailed correction algorithm.
Yellow blocks show the complete loop

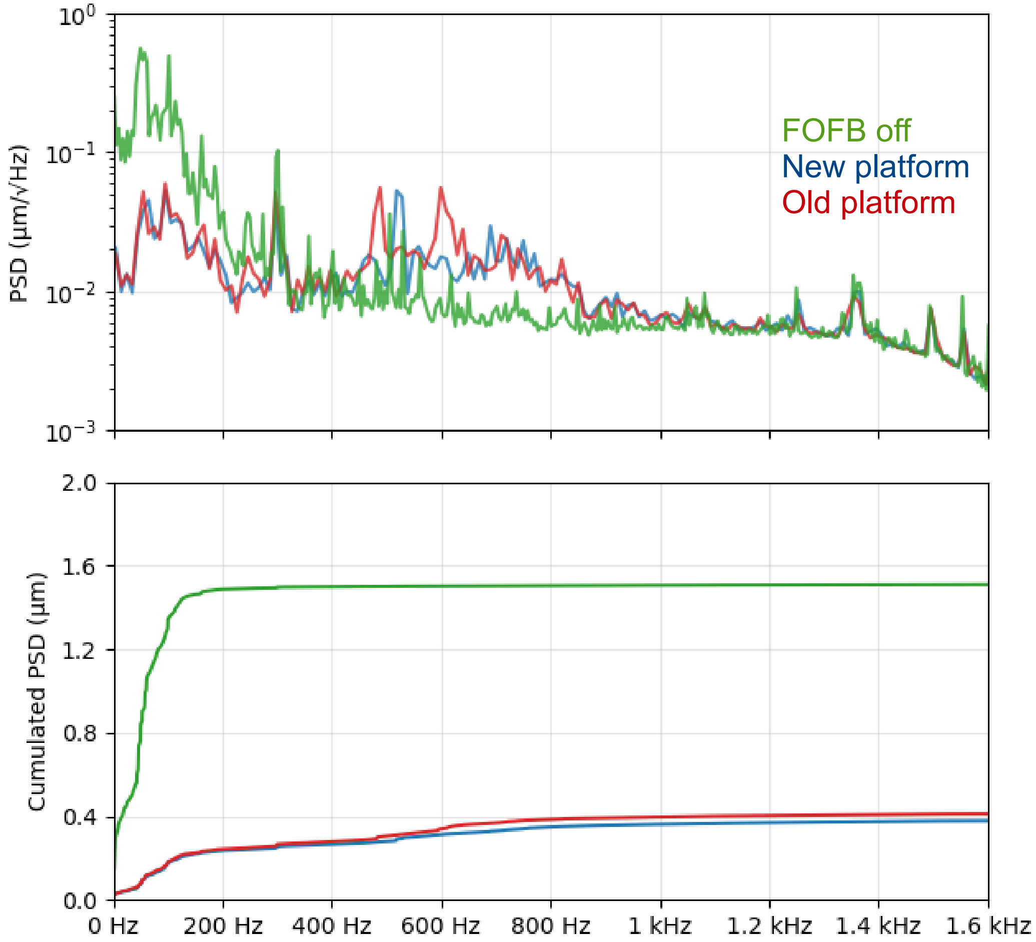


< Simulation of Transfer function Gain
Input: sine generator
Output: correction controller

Test results

Machine tests

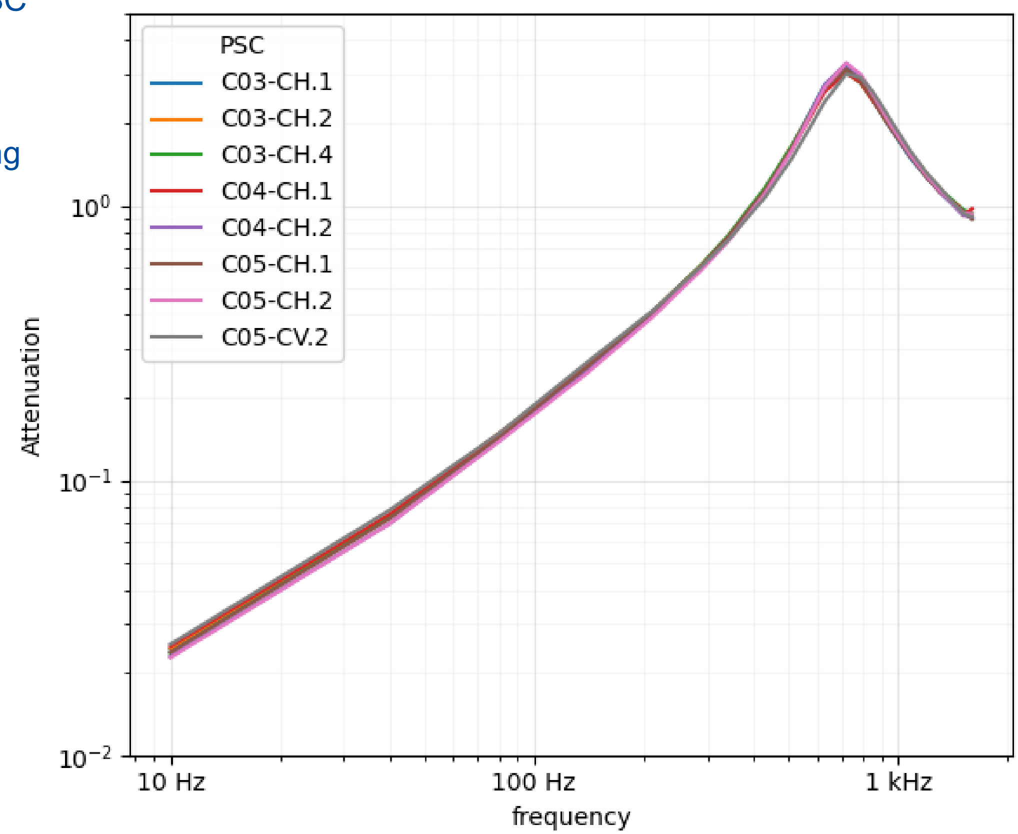
- **Loop successfully closed !**
  Beam successfully accumulated up to 450 mA with the new platform running the FOFB
- Mean orbit position PSD
  x-plane, 450 mA stored beam.
  → Same performances reached.
- Latency slightly decreased: resonance overshoot moved to higher frequencies



Position PSD and integrated PSD, for x plane.

Efficiency measurement

- Use on-board sine generator to inject perturbation on one PSC
- Compute Discrete Time Fourier Transform (DTFT) of mean orbit at this frequency
- Repeat at several frequencies, with and without FOFB running
- Compute attenuation factor: 5 at 100 Hz, overshoot crossover at 400 Hz

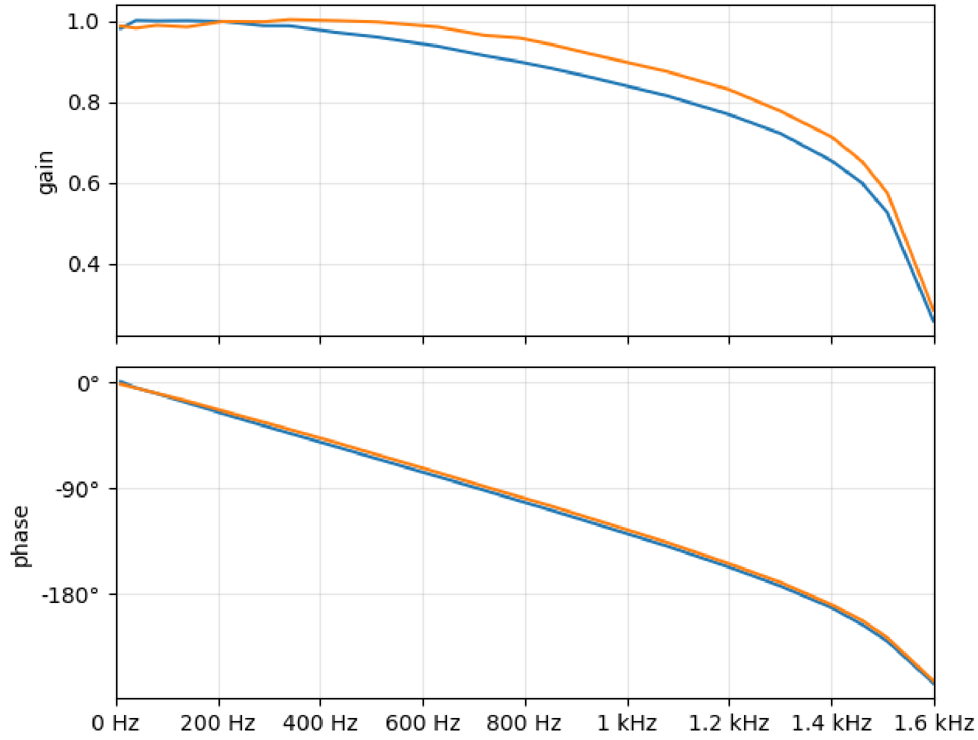


FOFB efficiency for several PSC

New identification features

Transfer function identification

- **Open loop measurement**: corrector not running
- Transfer Function of the overall system:
  PSC → CM → Beam → BPM
- Driving 1 PSC at different frequencies.
  Capture 100 periods of data.
- Discrete Time Fourier Transform (DTFT) at each frequency.
  → Obtain TF module and phase
- BPM/PSC gain depends on the ORM
- Select and mean on 10 most significant BPM.
  Further normalize by gain at 210Hz.

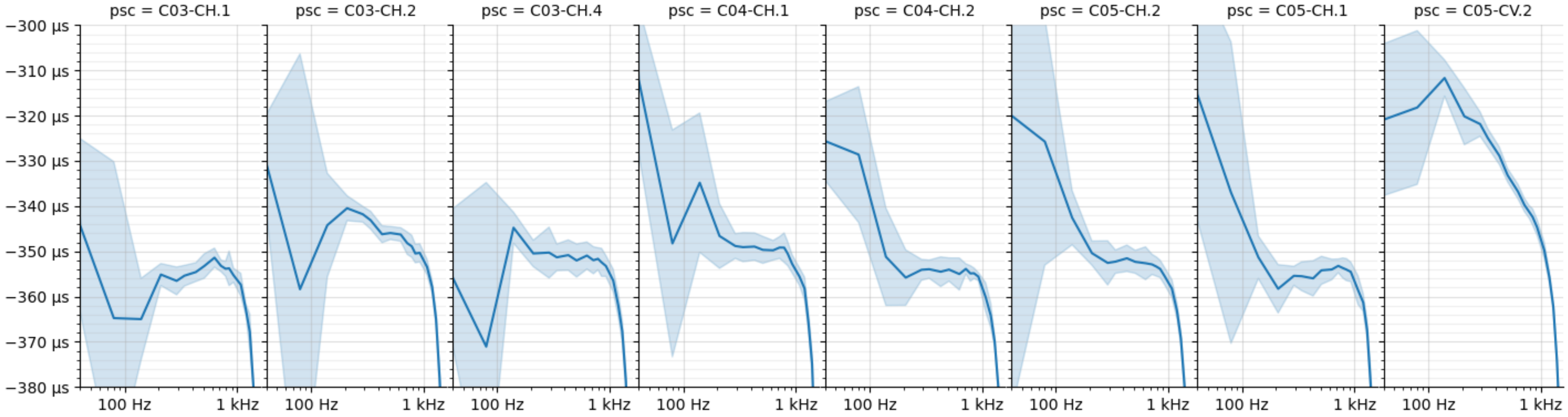


Bode plot of the measured transfer function. Blue and orange are one horizontal and one vertical PSC respectively.

Transfer function identification

Delay observation

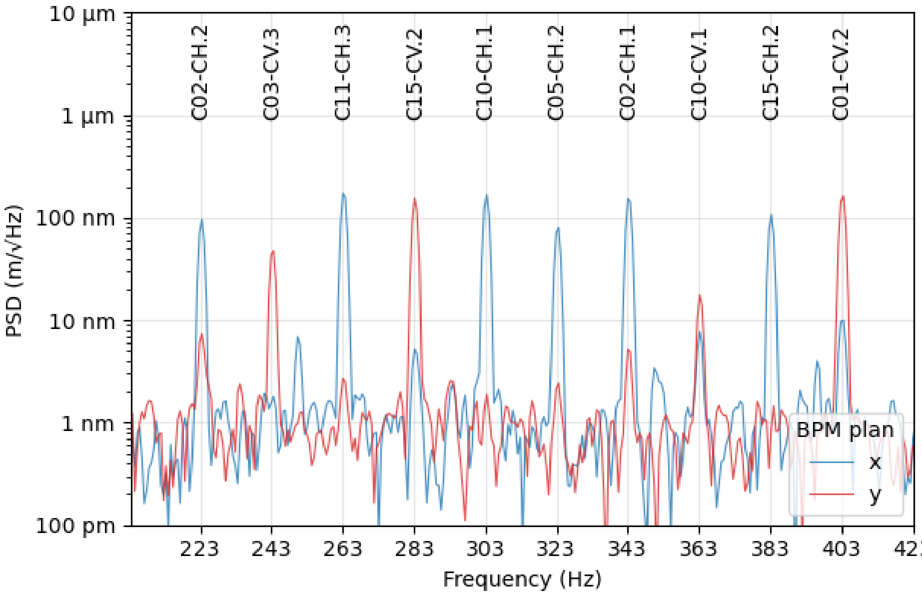
- Measured Constant latency of ~ 354/332 µs (X/Y plane)
- At low frequencies: measure uncertainty due to spectral occupation
  At high frequencies: phase shift
- The only Y PSC tested shows a phase shift.
  We will investigate this behavior on other Y PSC.
- Difference X/Y probably due to the vacuum chamber geometry.



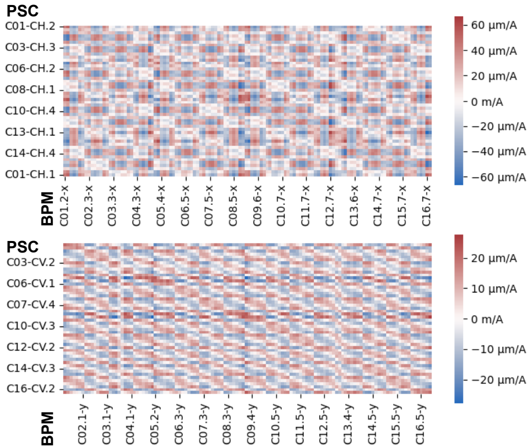
Observing delay vs frequency by PSC. Mean delay with ±std band.

Orbit Response Matrix Fast identification

- **Open loop measurement**: corrector not running
- Driving 10 PSC at 10 different frequencies, 20 Hz spaced
- Perform 10 group captures → get the 100 PSC
- DTFT at each frequency: obtain module and phase
- Deduce ORM coefficients
- Overall capture takes < 2 minutes



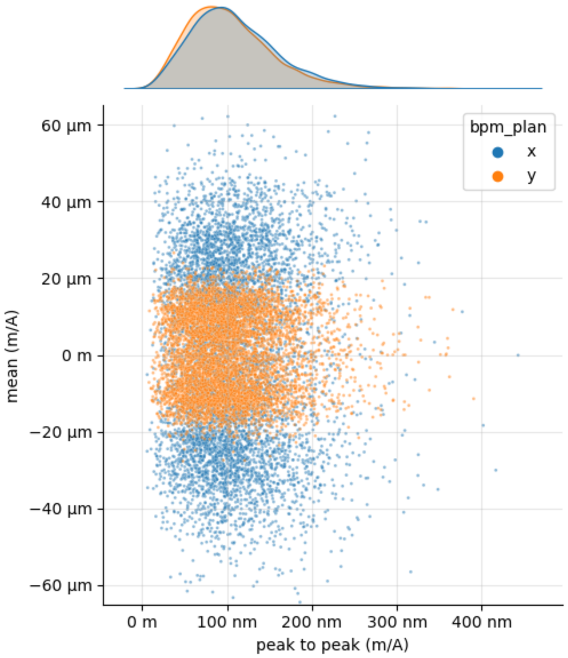
Driving ten PSCs with different frequencies, observing mean PSC over all BPMs. Sampling 10 kHz, duration 1.5 s, blackman window.



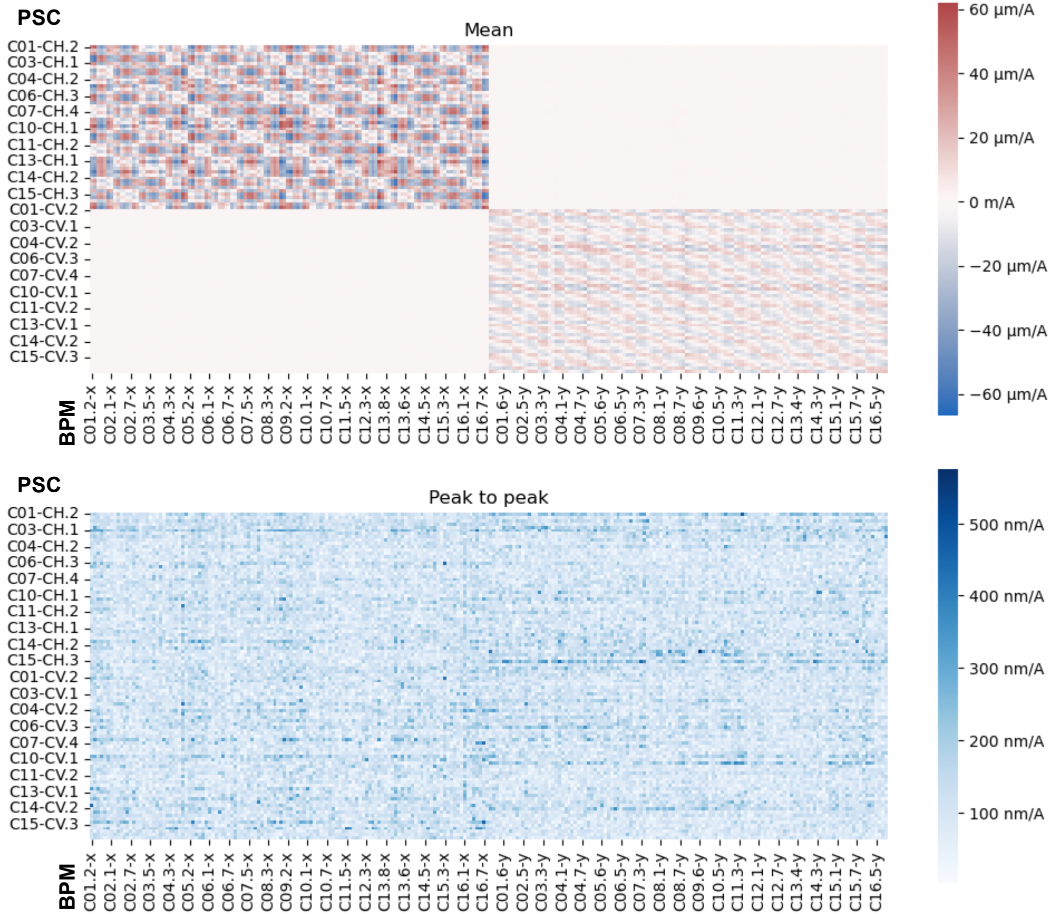
< Obtained orbit response matrix

Orbit Response Matrix Fast identification

- **Repeatability** over 4 measures
- Different frequencies, PSC distributions
- Max peak to peak = 440 nm/A
- Repeatability will be compared to present DC method



Orbit response coefficients distribution, by mean value and peak to peak statistics over 4 measures.

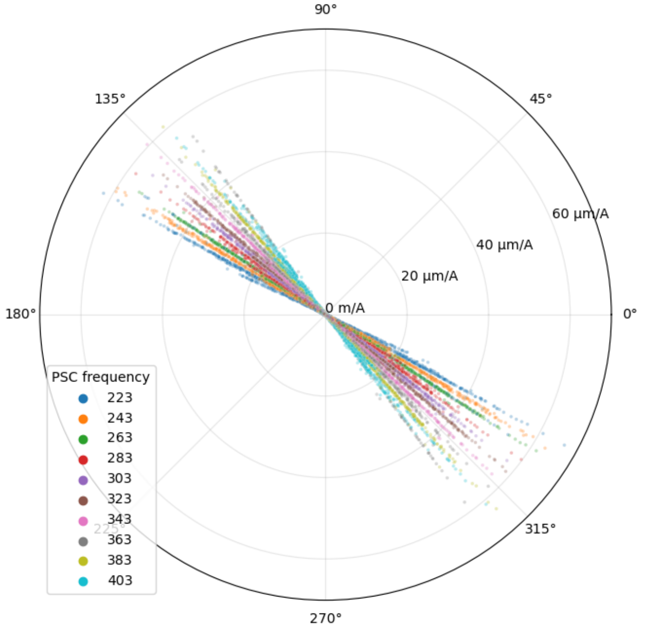


Orbit Response Matrix obtained with harmonic analysis. Mean and peak to peak statistics over 4 measures.

Orbit Response Matrix Fast identification

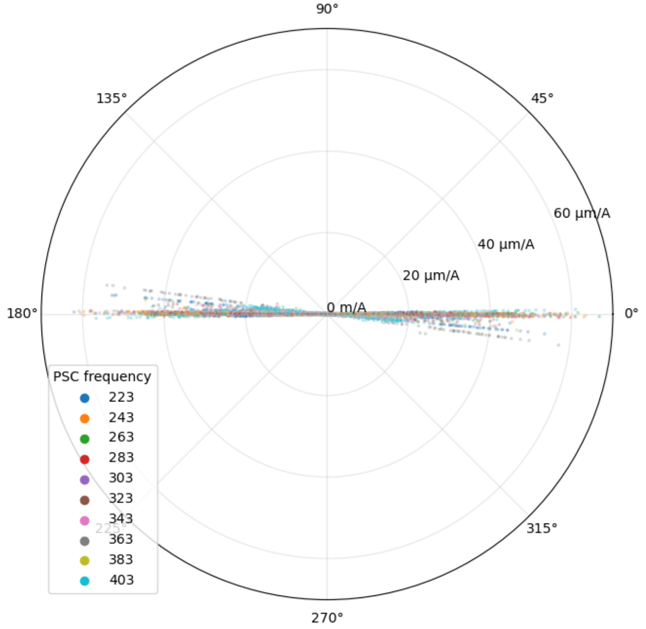
Measurement corrections

- on **angle**: compensate constant delay: 354/332 µs (X/Y plane)
  Angle of complex coefficient depends to delay and PSC frequency
  This is another way to measure constant delay
- on **module**: non constant Transfer Function over the frequency band of measurement.
  Each PSC TF estimated by a 1st order slope



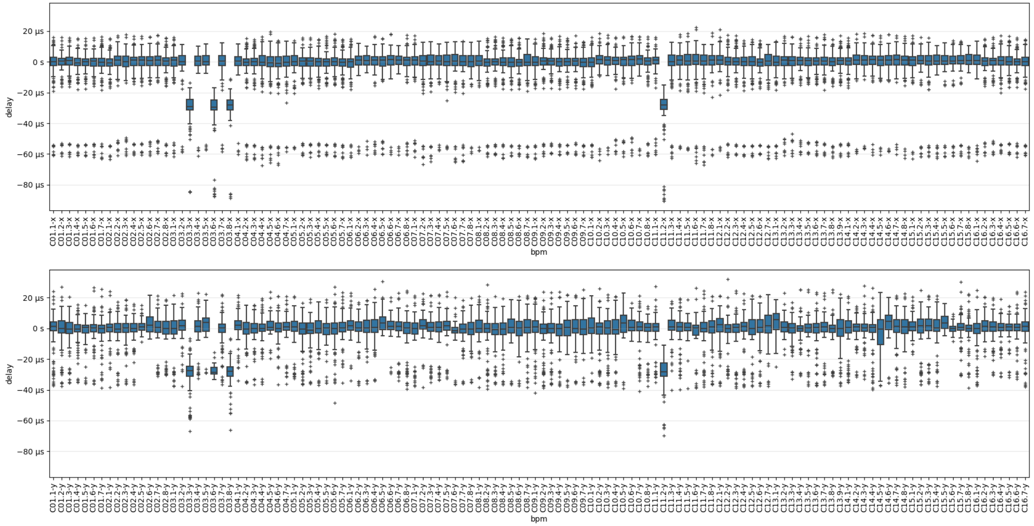
Constant delay compensation

$$e^{2i\pi f_{PSC} T_{delay}}$$

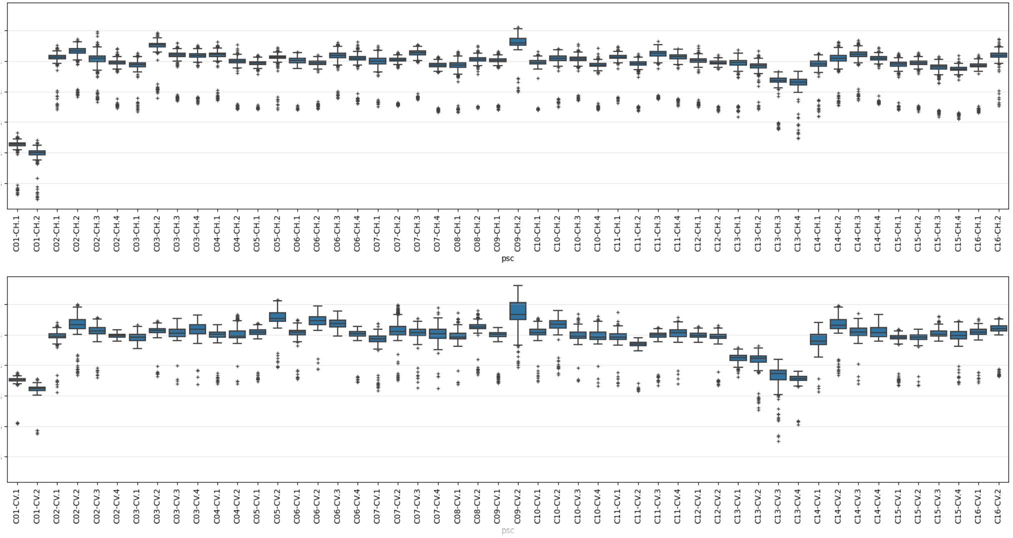


Coefficients on the complex plane, before and after delay compensation.

Orbit Response Matrix Fast identification



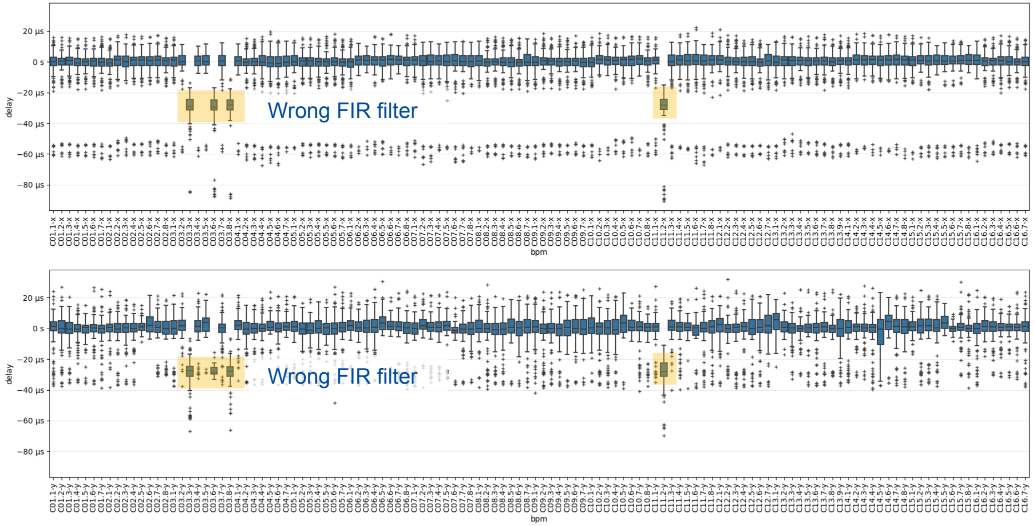
Per BPM observed delay, X (upper) and Y (lower)



Per PSC observed delay, X (upper) and Y (lower)

- Observing per BPM and per PSC delay offset from 354/332 µs (X/Y plane)

Orbit Response Matrix Fast identification



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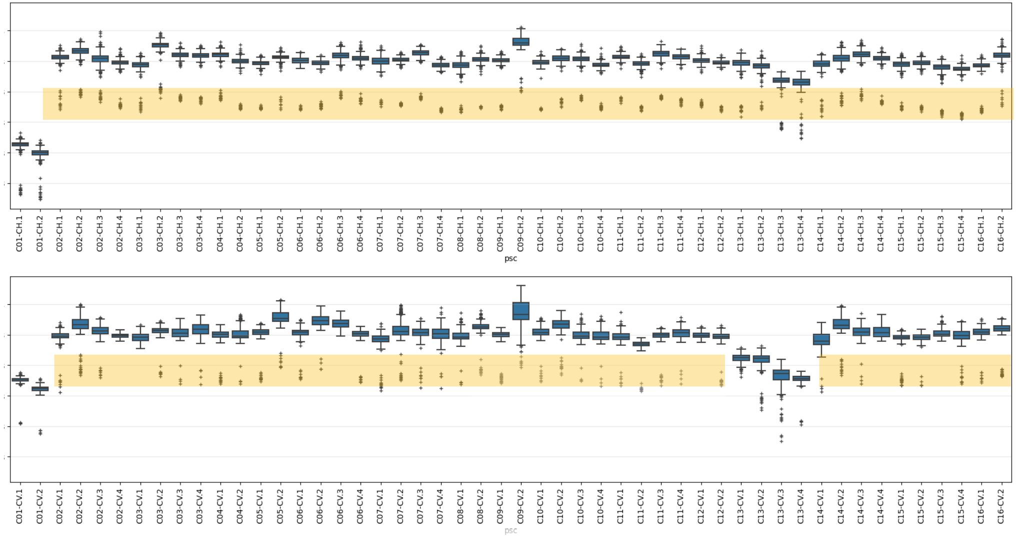
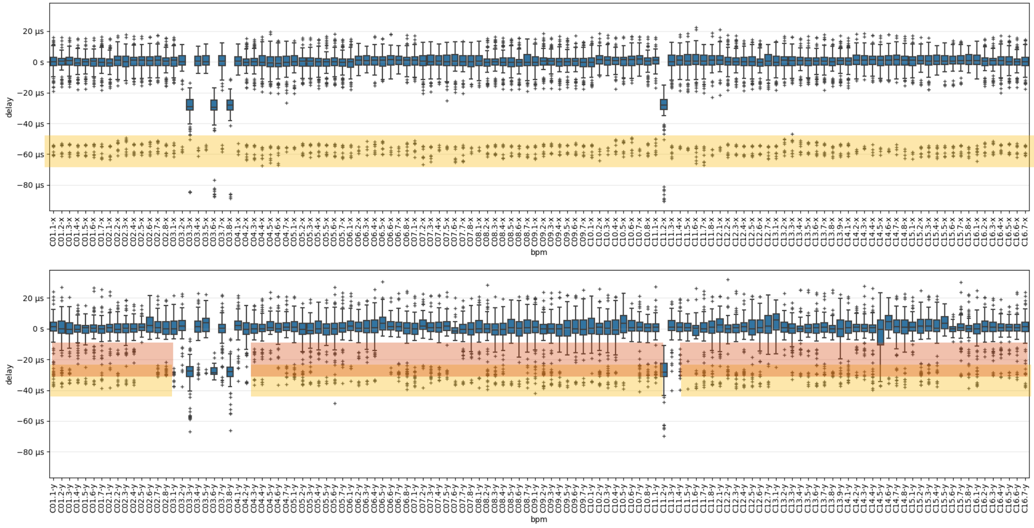


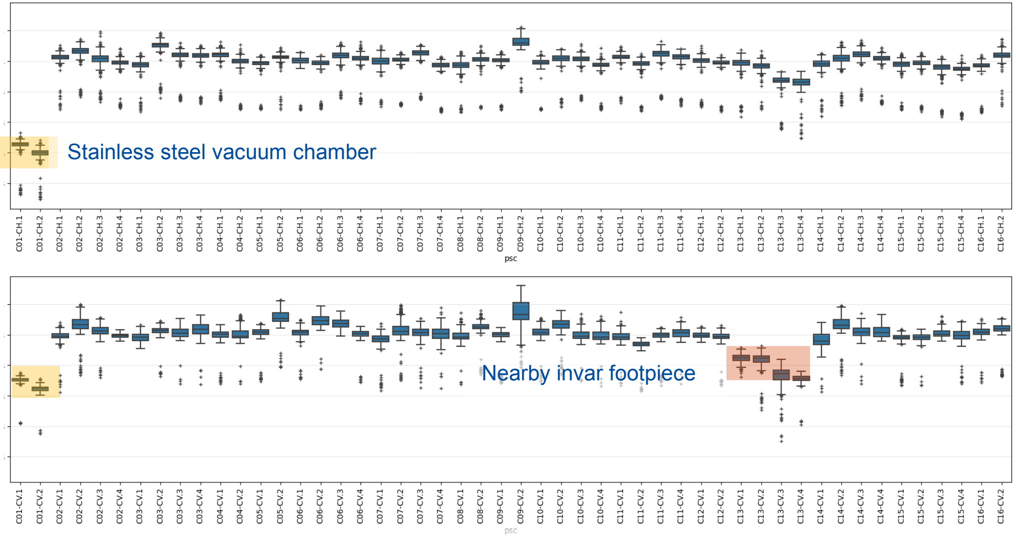
Per PSC observed delay, X (upper) and Y (lower)

- Observing per BPM and per PSC delay offset from 354/332 μs (X/Y plane)
- 4 BPMs outliers spotted and corrected (wrong FIR filter)

Orbit Response Matrix Fast identification

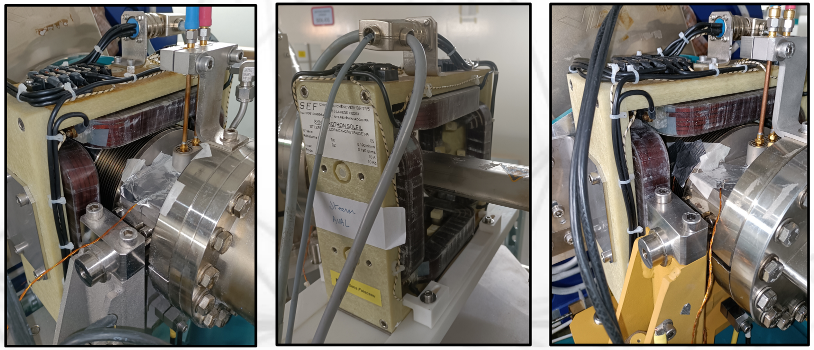


Per BPM observed delay, X (upper) and Y (lower)



Per PSC observed delay, X (upper) and Y (lower)

- Observing per BPM and per PSC delay offset from 354/332 µs (X/Y plane)
- 4 BPMs outliers spotted and corrected (wrong FIR filter)
- Some PSC show additional latency
  → C01 Injection zone, Corrector Magnets over stainless steel vacuum chamber
  → C13 Corrector Magnets nearby Invar bpm footpiece
- We will further investigate these PSC with a full Transfer function identification

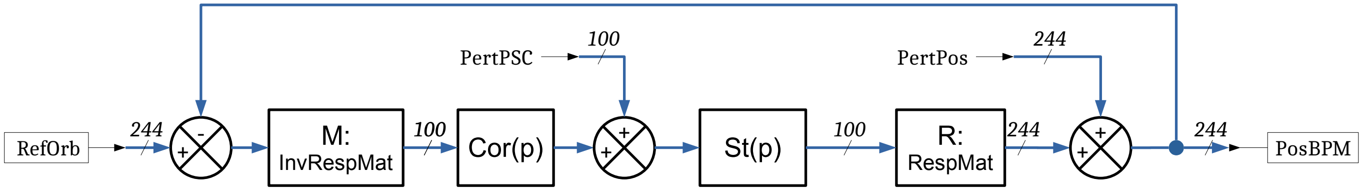


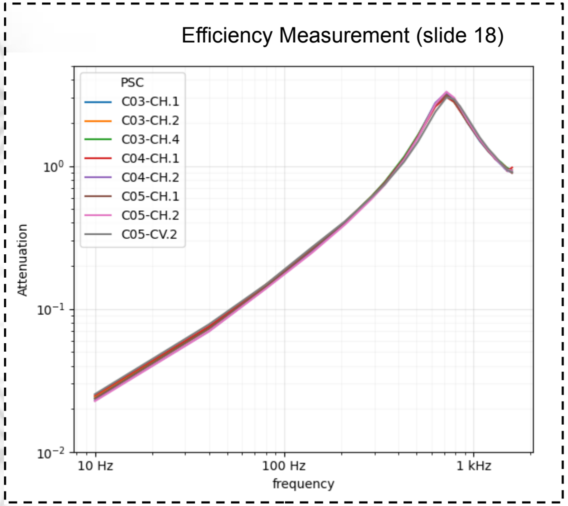
***Left**: regular CM over bellows, **Center**: C01 CM, **Right**: C13 CM with Invar yellow footpiece*

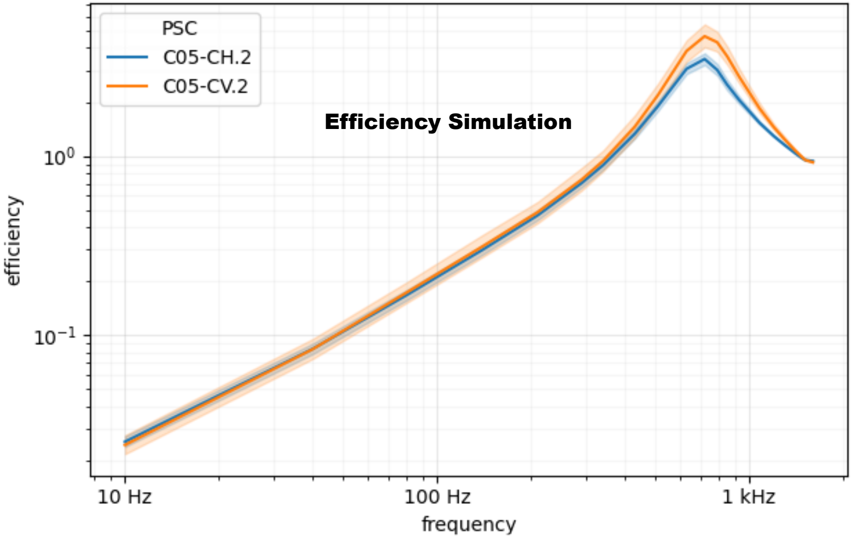
From identification to loop model

Simulation and Measurements

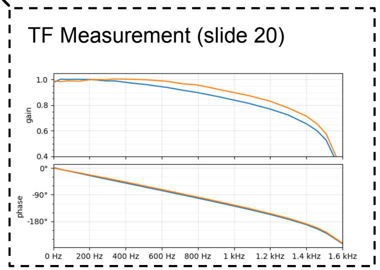
- Closed-loop model
- FOFB efficiency model
- Helpful for future corrector design
  Higher order, lag-compensation...







FOFB efficiency as computed by model



Conclusion

- The new platform is installed and can operate during dedicated machine shifts
- Loop successfully closed and performances reached
- **New features** to help diagnostics, identifications and future developments
- Next step: deploy the Control System devices to allow daily operation (SOFB / FOFB interaction)

Thank you for your attention