CNPEM
Brazilian Center for Research in Energy and Materials

LNLS sirius
Brazilian Synchrotron Light Laboratory

Commissioning and Optimization of the SIRIUS Fast Orbit Feedback

International Conference on Accelerator and Large Experimental Physics Control Systems
Feedback Systems & Optimisation

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SIRIUS Status

- SIRIUS is the Brazilian 4th generation synchrotron light source

- Operation for regular users: since **March 2023**
  - **6 beamlines in operation**
  - 4 beamlines in commissioning
  - 4 beamlines in installation or construction

- Fast Orbit Feedback (FOFB)
  - Commissioning throughout October 2022
  - In operation for users: since **November 2022**

Storage Ring Parameters	
Beam Energy	3 GeV
Circumference	518.4 m
Lattice	20 x 5BA
Current, top up	350 mA (currently 100 mA)
Horiz. emittance	250 pm.rad

Outline

SIRIUS FOFB Design and Actuators

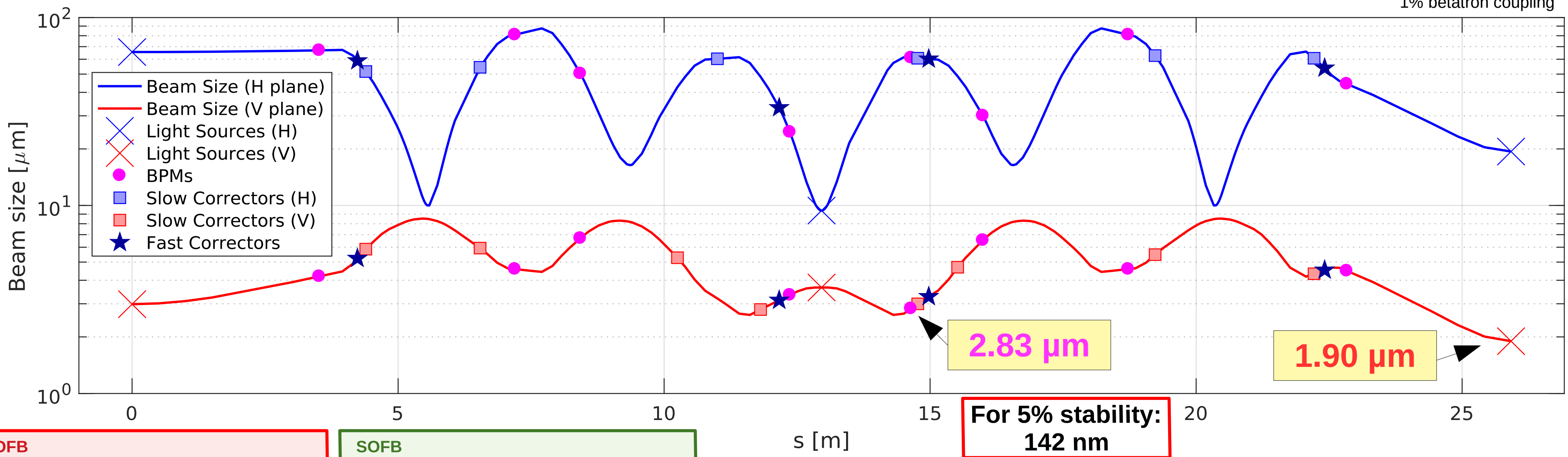
SIRIUS BPM and FOFB Hardware and Software

Commissioning

Performance Results

Conclusion

Fast Corrector Placement Per Sector



For 5% stability: 142 nm

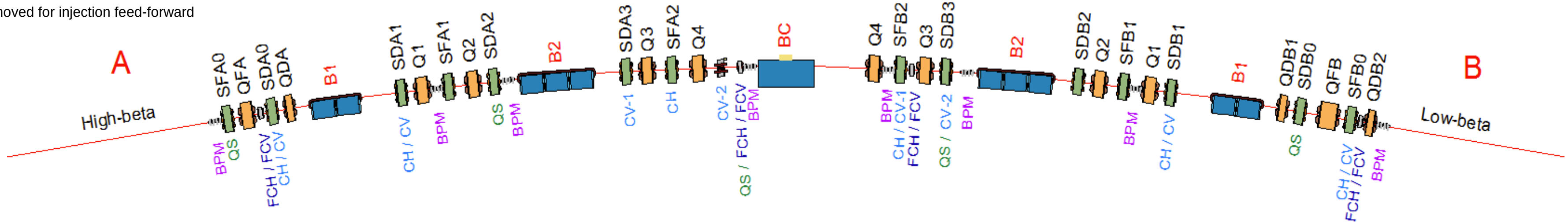
FOFB

- **160 sensors (20 x 4 BPMs x 2 planes)**
- **161 actuators***
  - 80 horiz. correctors (20 x 4)
  - 80 vert. correctors (20 x 4)
  - RF frequency (not used)

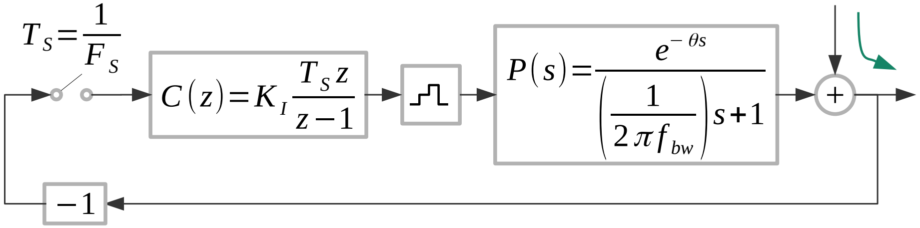
SOFB

- **320 sensors (20 x 8 BPMs x 2 planes)**
- **281 actuators**
  - 120 horirz. correctors (20 x 6)
  - 160 vert. correctors (20 x 8)
  - RF frequency

*4 correctors temporarily removed for injection feed-forward



SIRIUS Fast Orbit Feedback Design

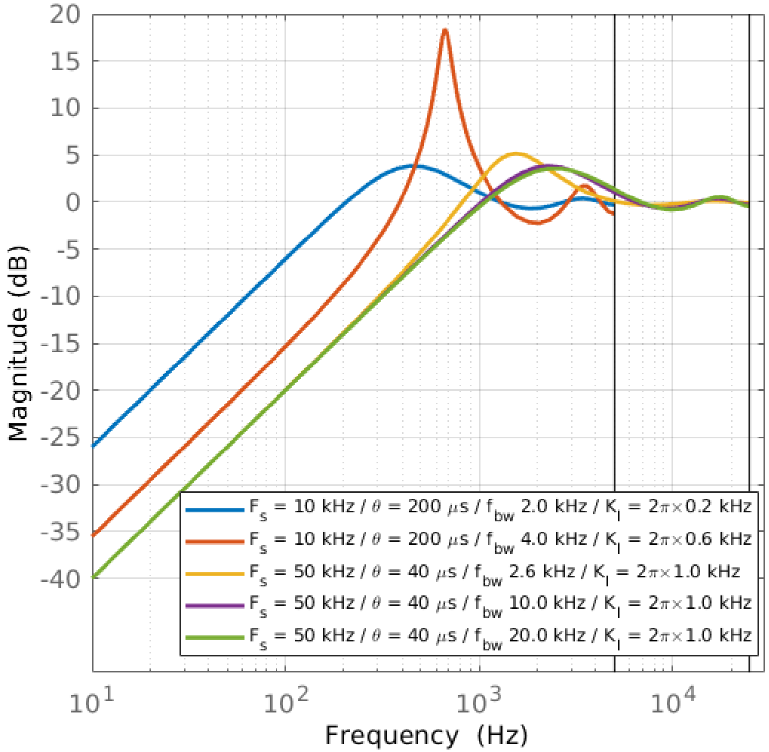


- Targeting disturbance rejection crossover frequency of **1kHz**

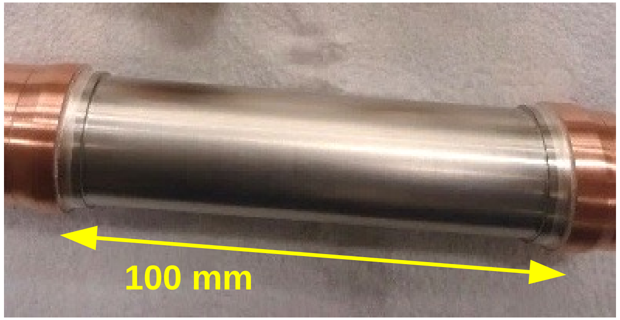
- Principles:
  1) Minimize delay! High loop update rate: **48kHz**
  2) High bandwidth power supplies, magnets and vacuum chamber
  3) Real-time processing in FPGAs and tight hardware integration
  4) Few BPMs, just enough for exact correction in light sources

- Let's pursue making the delay the dominant dynamics:
  - Shape actuators' response if needed
  - Accelerator-wide data distribution delay is the true fundamental limit

- Integral controller is enough – one knob, easy tuning
  - Actuators' response shaping does the rest of the job

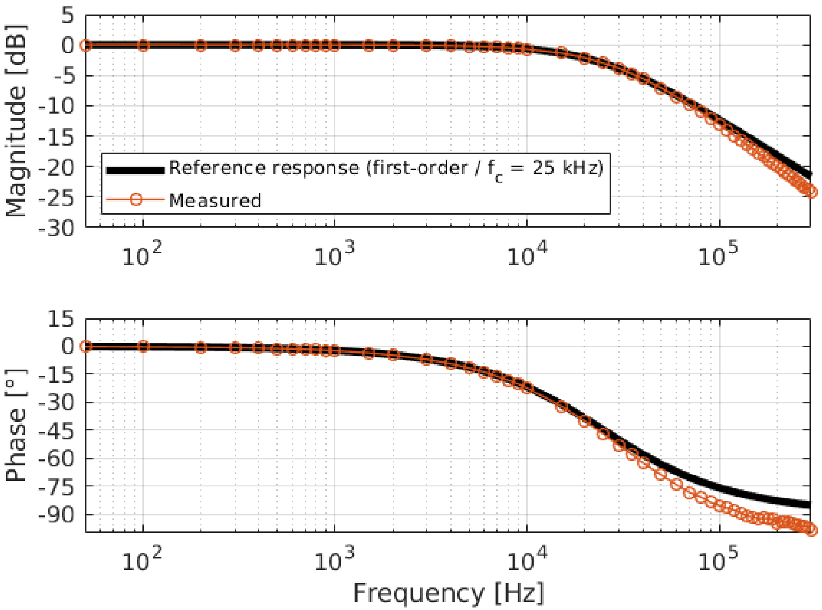


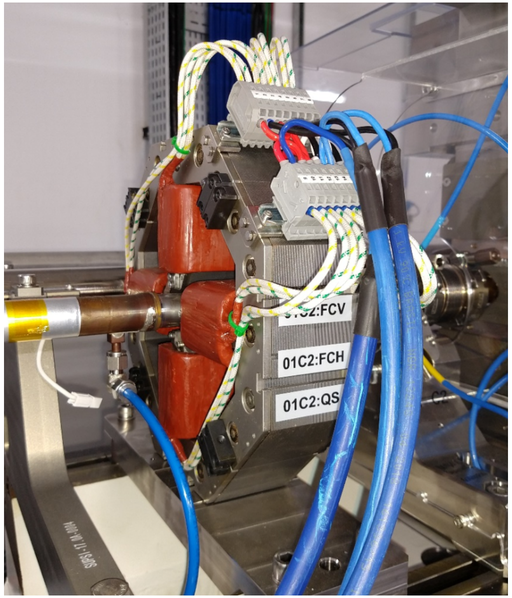
Fast Orbit Corrector – Vacuum Chamber and Magnet



Fast corrector vacuum chamber

- **0.3 mm** stainless steel vacuum chamber





Fast Orbit Corrector Magnet

- 0.5 mm FeSi steel lamination
- L = 3.3 mH (standard) or 6.6 mH (45° rotated)
- R = 0.08 ohm (standard) or ~0.18 ohm (45° rotated)
- **Current:** 1 A (standard) or 0.71 A (45° rotated)
- **Deflection @ 3 GeV:** 30 µrad

SIRIUS BPM and FOFB Electronics Hardware Overview

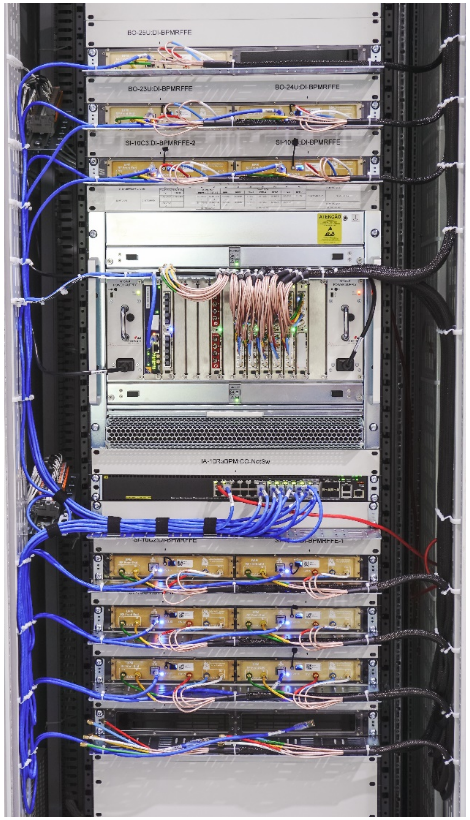
BPM/FOFB Rack Front View

RFFE Modules

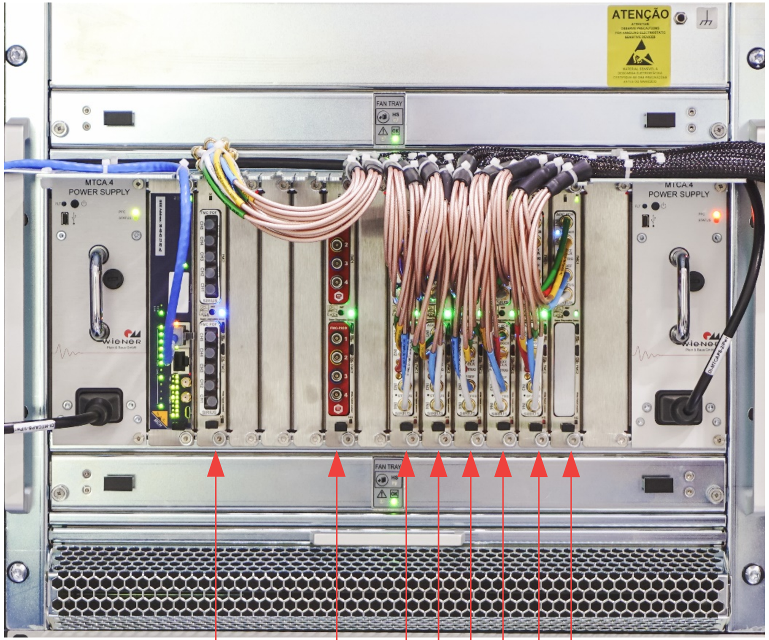
MicroTCA.4 crate

Ethernet switch

RFFE Modules



BPM/FOFB Rack Rear view



Timing event receiver

Storage Ring BPM Digitizers

XBPM Digital Picoammeters (FMC by CAENels)

Booster Electron BPM RF digitizers

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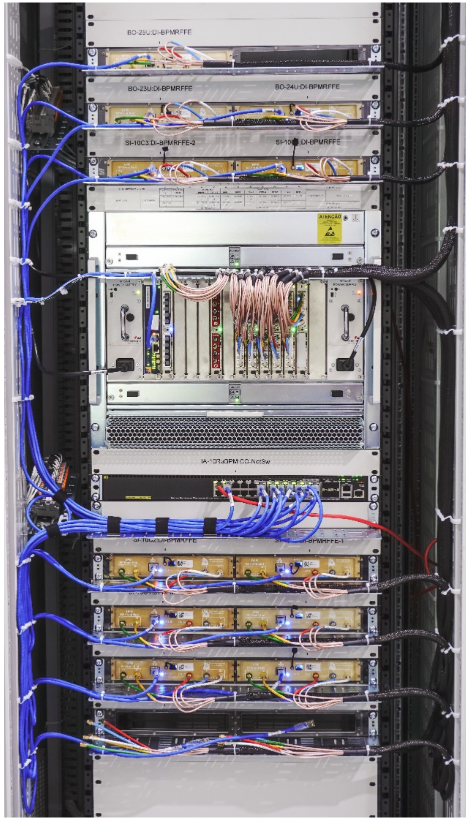
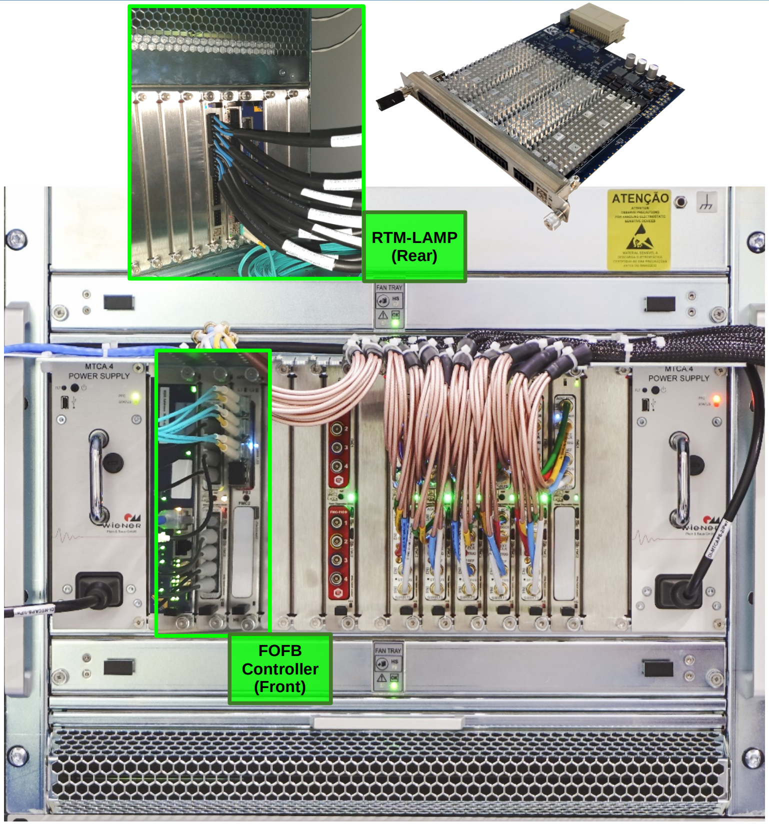


BPM/FOFB Rack Rear view

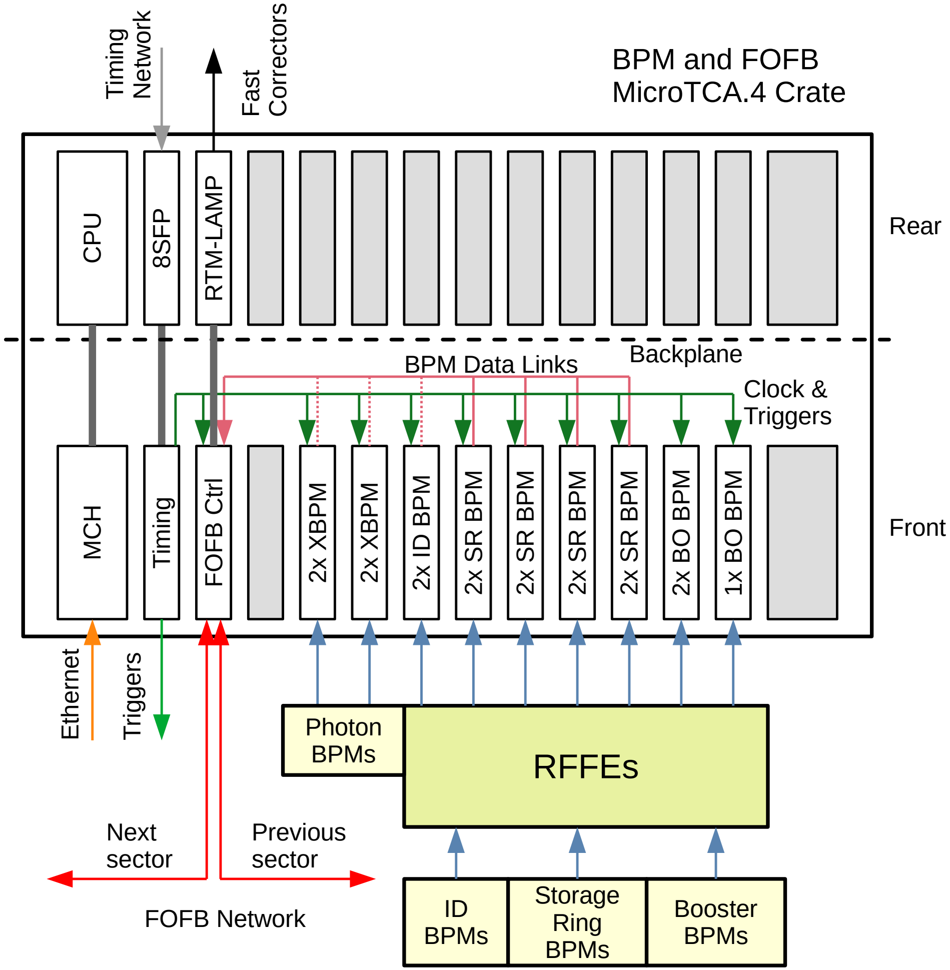


Licensed under
CERN Open Hardware License

Link to open hardware projects in backup slides

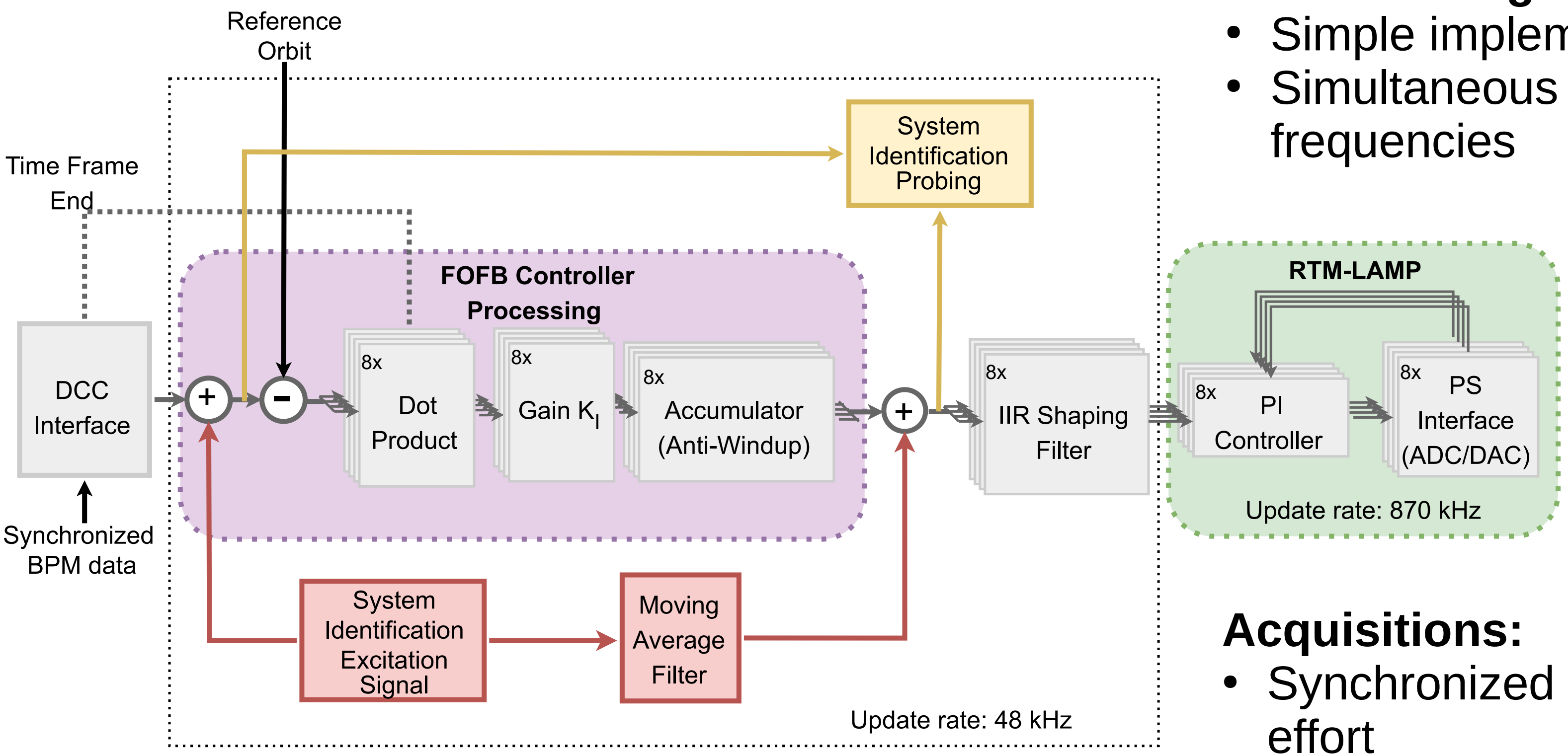
open source hardware

SIRIUS BPM and FOFB Electronics Hardware Overview



- **Customized Diamond Communication Controller (DCC)**
- **Low-latency network**
  - Configured **13.44 μs** time frame for 160 BPM readings
- **Network topology**
  - Full mesh interconnect inside the crate (custom backplane)
  - Ring topology between the 20 accelerator sectors

FOFB Processing



Excitation signal: PRBS

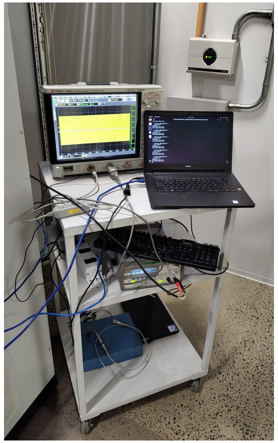
- Simple implementation
- Simultaneous excitation of multiple frequencies

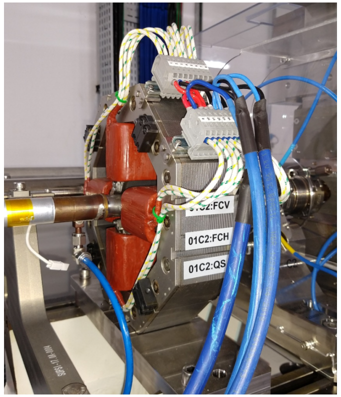
Acquisitions:

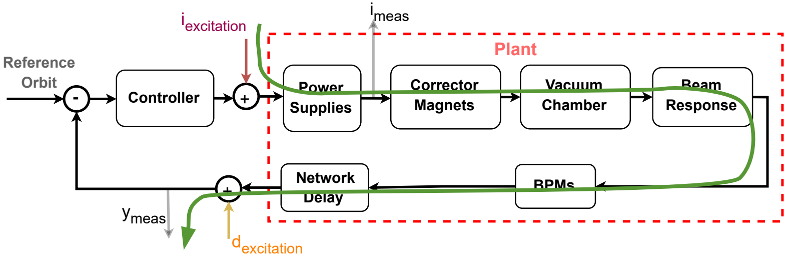
- Synchronized orbit and control effort
- Up to 1 million samples at 48kHz

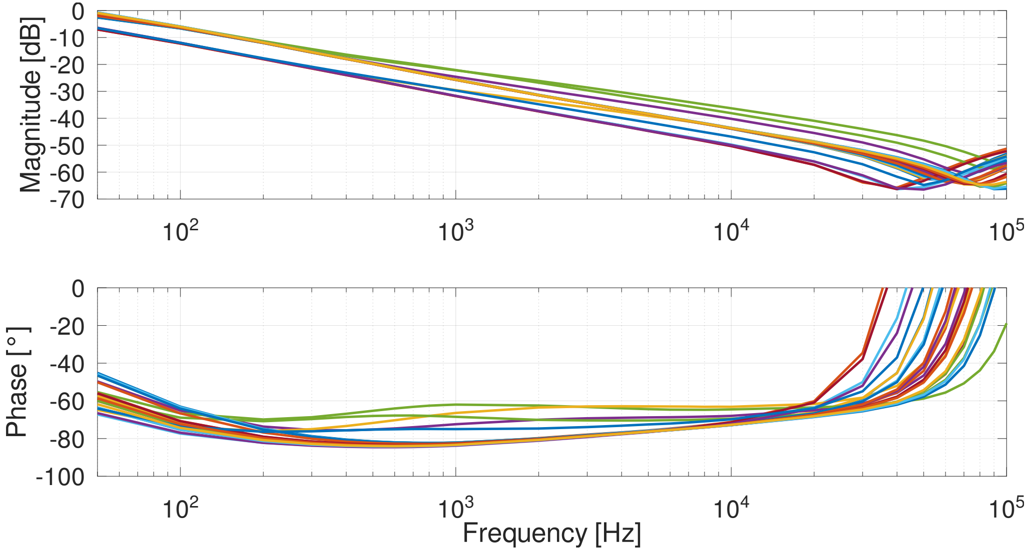
System Identification – Open Loop

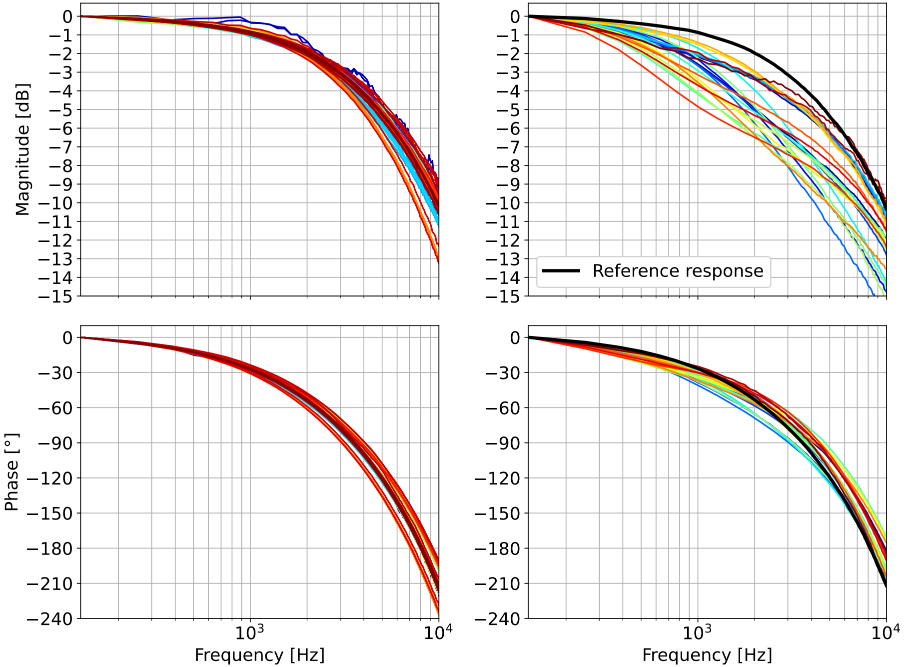
	Open Loop
PRBS length (N)	127 (7)
PRBS step duration	3
Mov. Average length	2
Frequency grid step	126.5 Hz





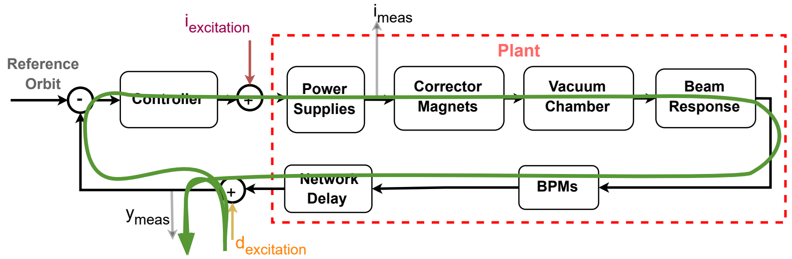


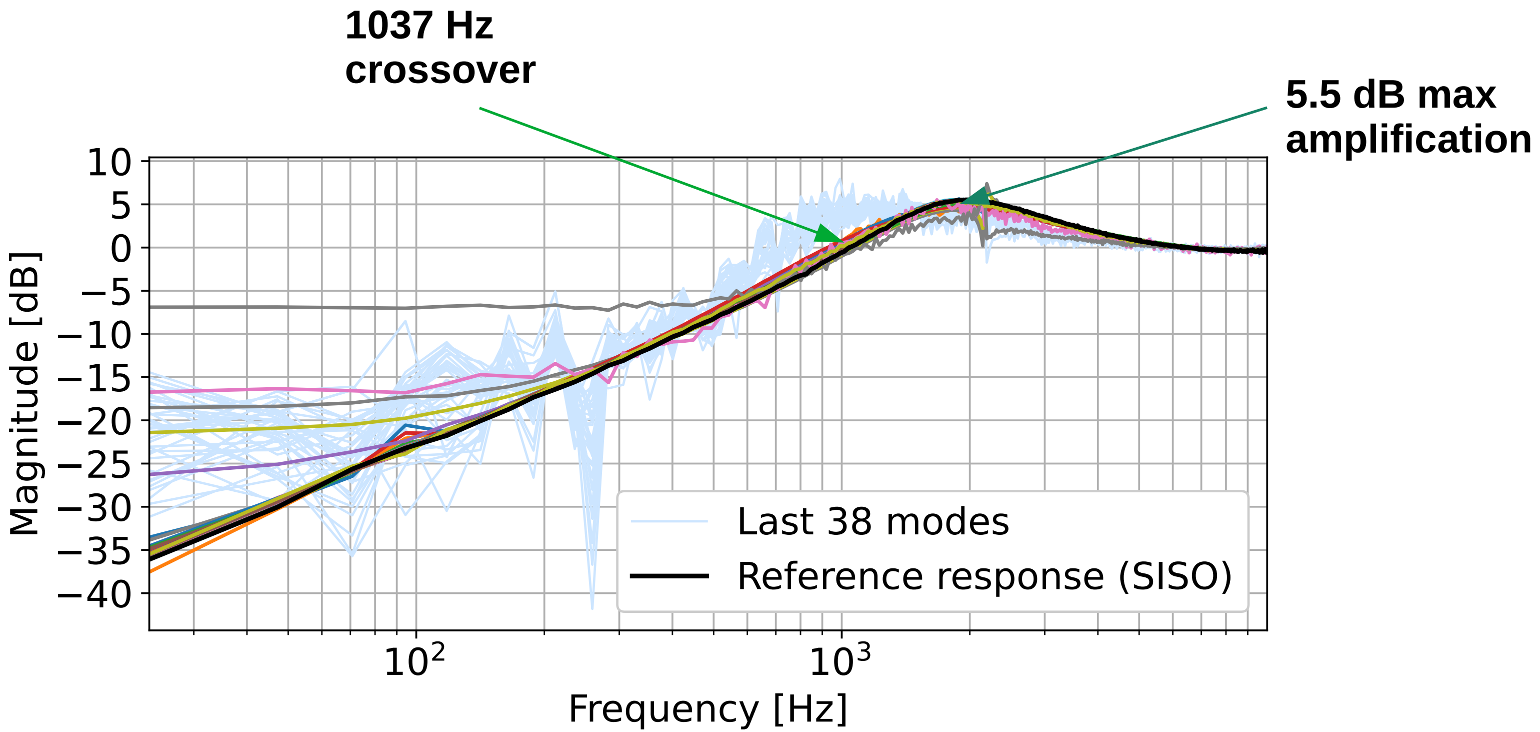




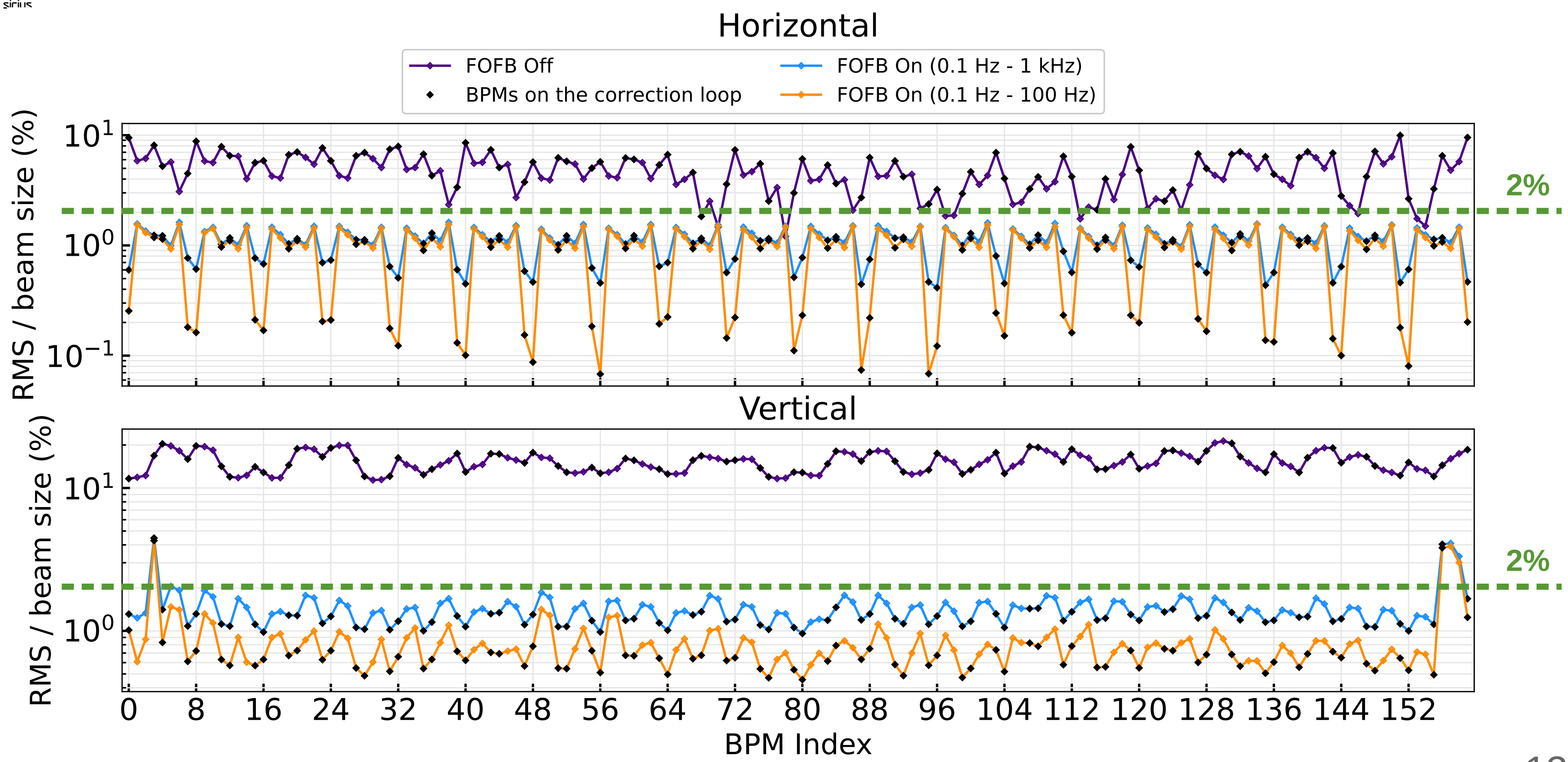
System Identification – Closed Loop

	Closed Loop
PRBS length (N)	511 (9)
PRBS step duration	4
Mov. Average length	N/A
Frequency grid step	23.6 Hz





Achieved Orbit Stability



Conclusion

- One year experience of SIRIUS FOFB operation was reported
  - Evolution of diagnostics tools, interlocks and improvements in the user experience
  - Embedded system identification was key to fully characterize the loop and check stability margins

- The target **1 kHz** disturbance rejection crossover frequency has been achieved

- Orbit stability (0.1 Hz to 1 kHz RMS) with FOFB ON is **2% relative to beam size** in both planes in out-of-the-loop BPMs

- General improvements in the system's reliability and user experience for operation are foreseen. Major performance improvements are expected to come from equalization of actuator responses and update rate increase.

Brazilian Center for Research in Energy and Materials

Thank you!

Brazilian Synchrotron Light Laboratory

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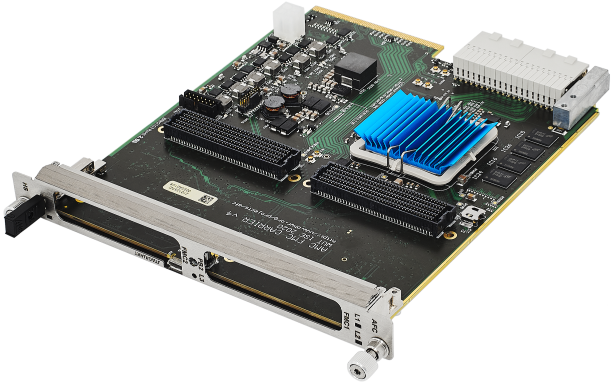
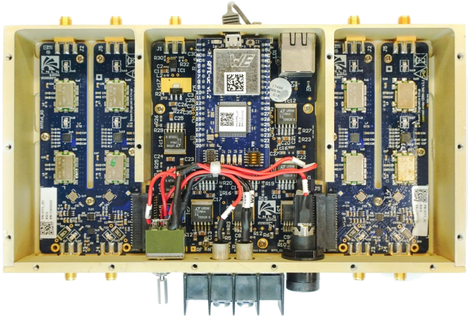
Backup Slides

LNLS Open Hardware Designs

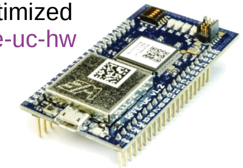
AMC FMC Carrier
Generic FPGA board
www.ohwr.org/projects/afc



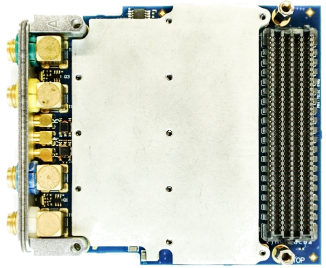
Sirius BPM RF Front-end
4-ch BPM analog front-end
github.com/lnls-dig/rffe-hw



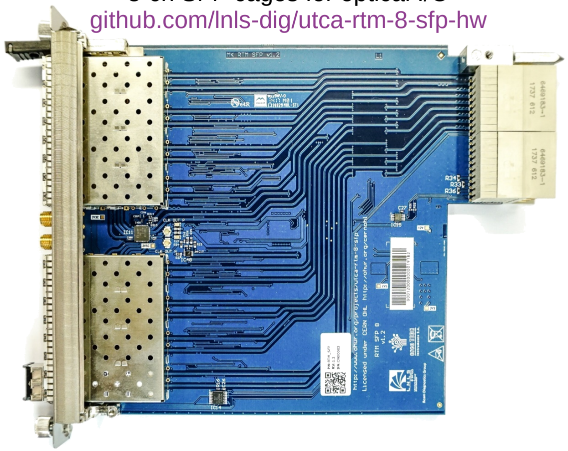
Sirius BPM RFFE microcontroller
Mbed clone, noise-optimized
github.com/lnls-dig/rffe-uc-hw



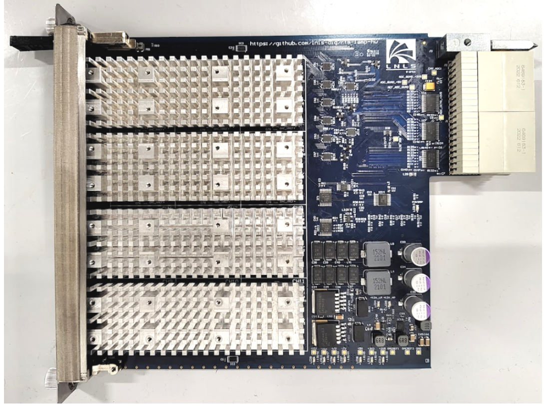
FMC ADC 250 MS/s
16-bit 4-ch fast ADCs
github.com/lnls-dig/fmc250-hw



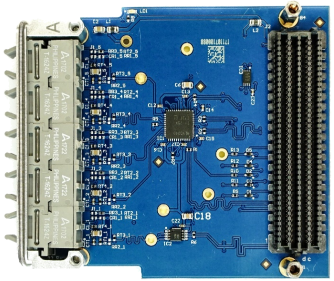
SFP RTM
8-ch SFP cages for optical I/O
github.com/lnls-dig/utca-rtm-8-sfp-hw



Linear Amplifier RTM
12-ch linear power amplifier
github.com/lnls-dig/rtm-lamp-hw

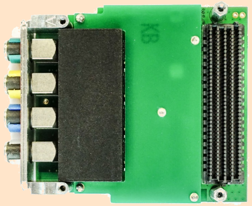


FMC 5POF
5-chanel plastic optical fiber I/O
github.com/lnls-dig/fmc-5POF-hw

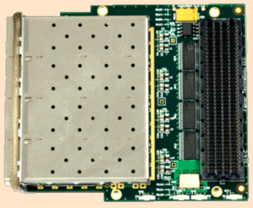


NOT OPEN DESIGNS
Used in combination with AFC

FMC-Pico-1M4
4-channel fast picoammeter
By CAENels



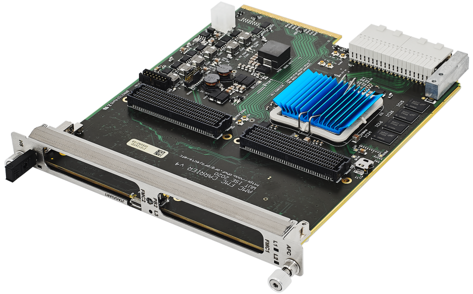
FMC-S14
4 SFP cage for optical I/O
By Faster Technology



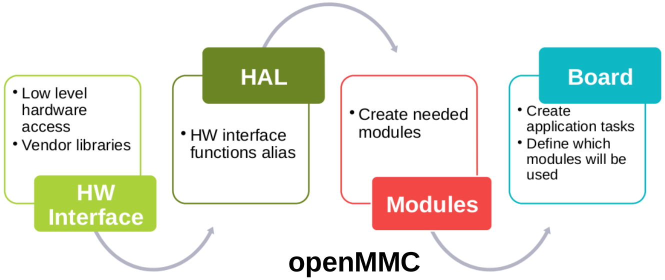
LNLS Open Hardware Designs

- **AMC FMC Carrier (AFC) – a cheap and versatile open hardware MicroTCA.4 FPGA board**
  - Based on “cheap” FPGA device (< 200 USD): Xilinx Artix-7 200T
  - Used in 4 different applications at Sirius by selecting different I/O cards (FMC modules) and accompanying gateware
  - From v1 to v3.1 in partnership with Creotech (Poland) / Technosystem (Poland) jumped in 2021 to iterate to v4 and on
  - Potential users in GSI (Germany), CERN (Europe), FRIB (USA),
  - Design available at: https://www.ohwr.org/project/afc
  - Licensed under CERN Open Hardware License (CERN OHL)

AMC FMC Carrier (AFC)

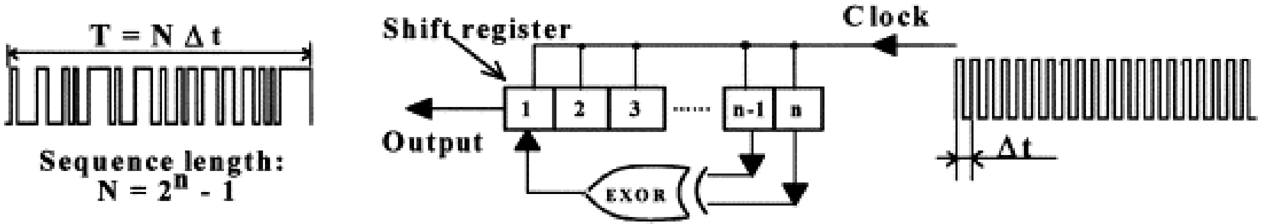


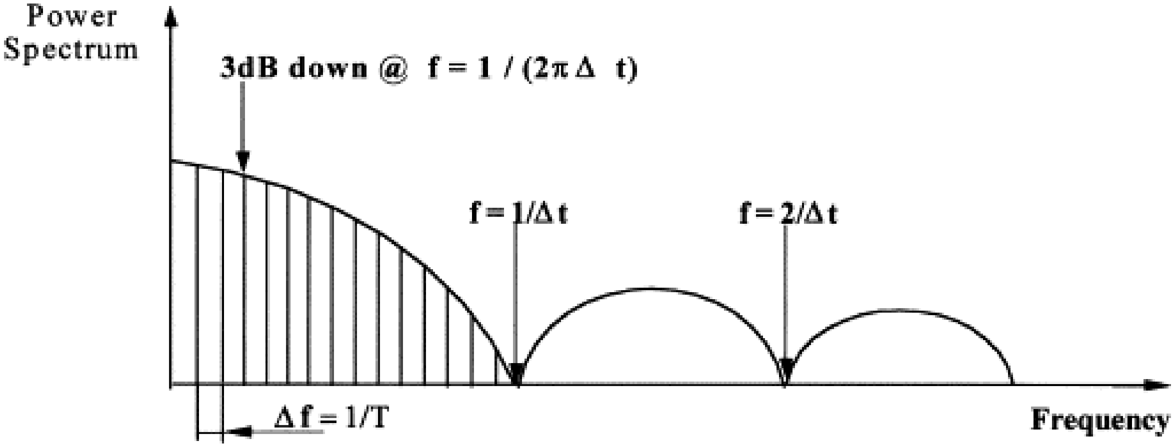
- **openMMC – a MicroTCA.4 Module Management Controller (IPMI-compliant)**
  - Built on top of FreeRTOS
  - Adopted by LNLS (Brazil), CERN (Europe), GSI (Germany), Diamond Light Source (UK), Creotech (Poland), Lemote (China), Digitek Engineerin (Pakistan)
  - Code contribution from a variety of partners (e.g.: port to STM32 from CERN & DLS)
  - Code available at: https://github.com/lnls-dig/openMMC
  - Licensed under GPL v3



openMMC

Pseudorandom Binary Sequence





M.E.H Amrani, R.M Dowdeswell, P.A Payne, K.C Persaud,
Pseudo-random binary sequence interrogation technique for gas sensors