Sistema de correção de órbita rápida para o anel de armazenamento do Laboratório Nacional de Luz Síncrotron (LNLS)

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Outline

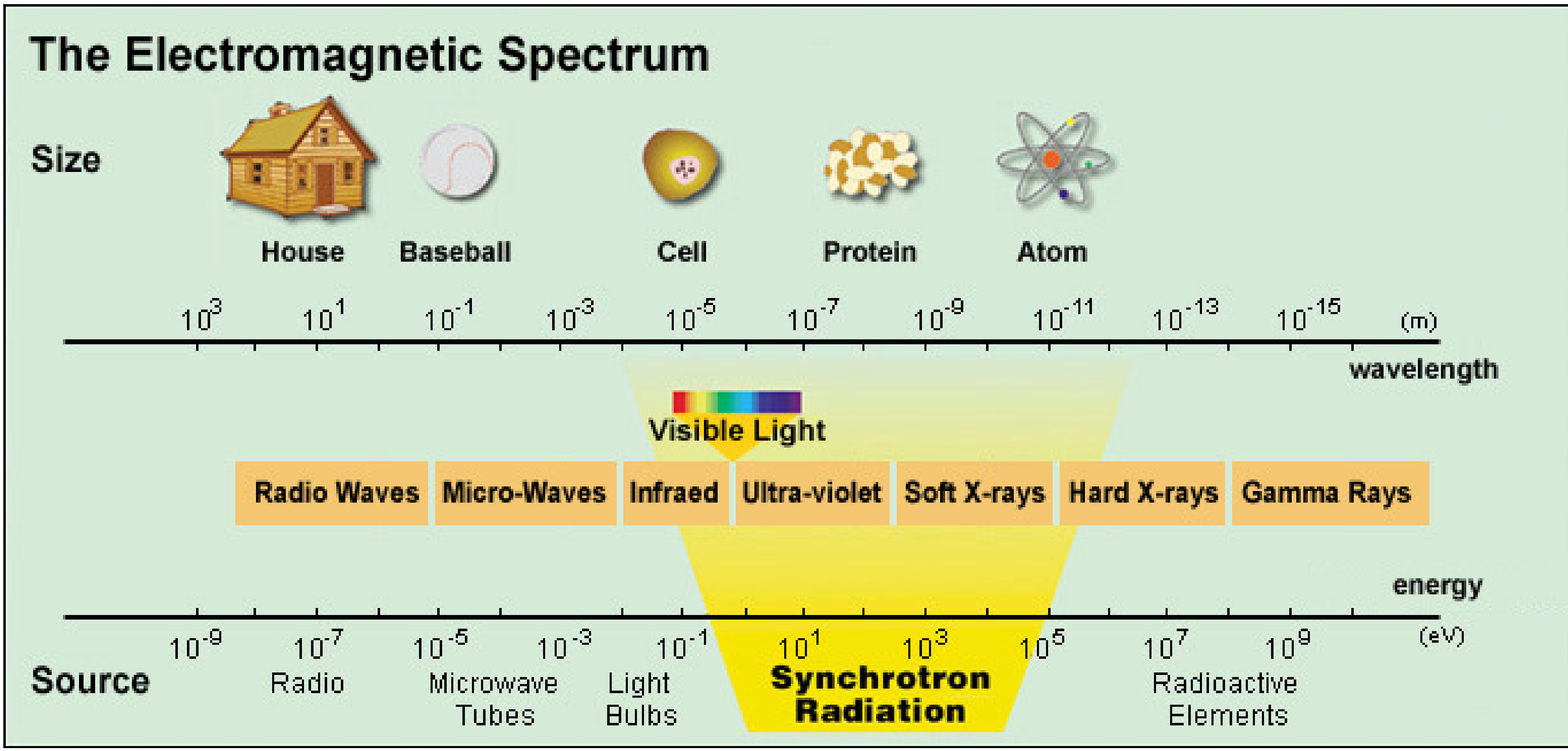
- *What is Synchrotron Radiation?*
- *LNLS storage ring and beamlines*
- *Synchrotrons around the world*
- *Beam stability requirements*

- *Orbit correction system in operation (bandwidth, architecture)*
- *New topology proposed by NI*
- *Requirements (speed, time synchronization and reliability)*
- *Software architecture*

- *New orbit correction system performance*
- *New orbit correction system: future steps*

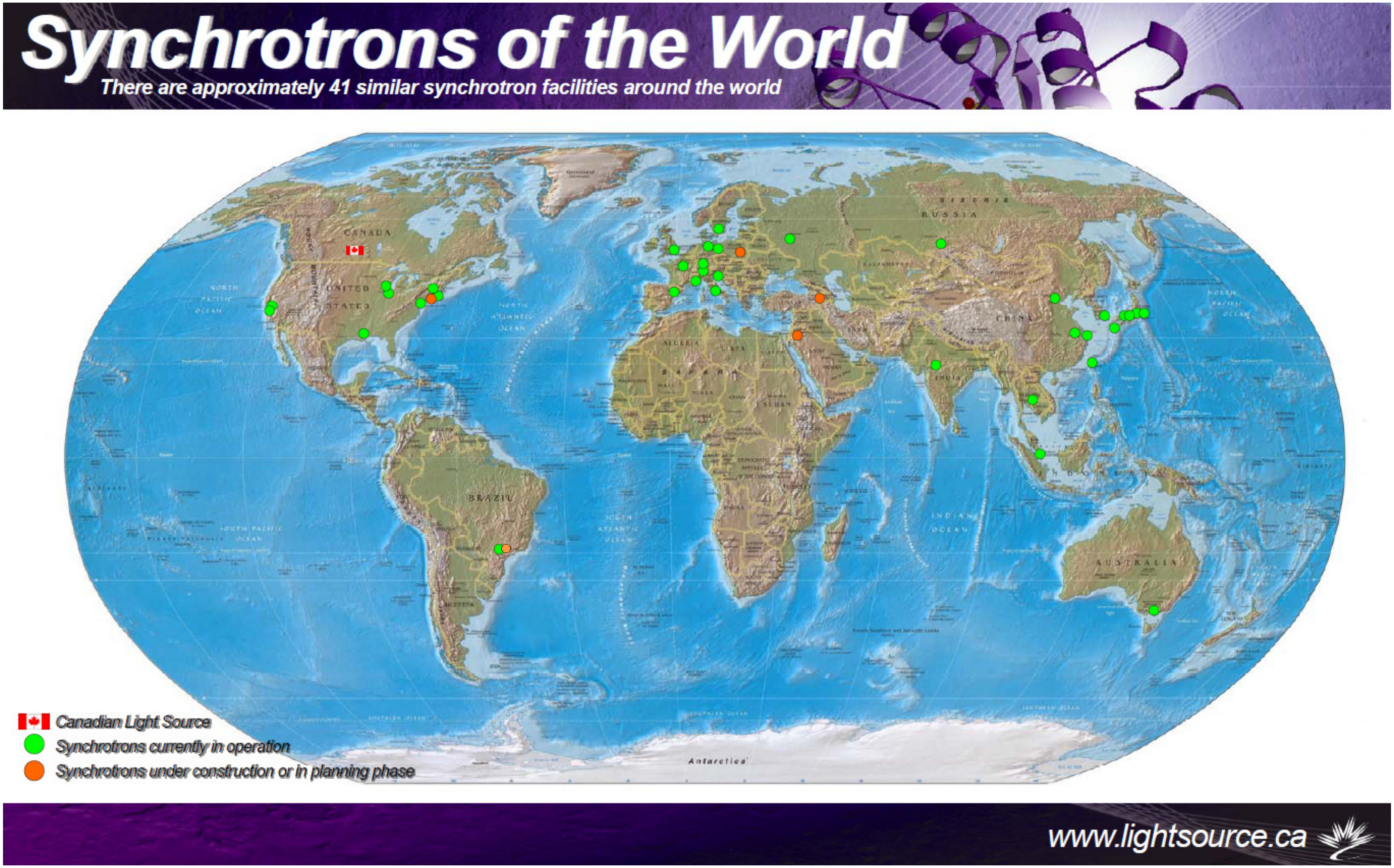
- *Final remarks*

What is Synchrotron Radiation ?



Pictures from Taiwan National Synchrotron Radiation Research Center (NSRRC) website

Synchrotrons around the world



Pictures from Canadian Light Source (CLS) website

LNLS storage ring and beamlines

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The LNLS UVX storage ring

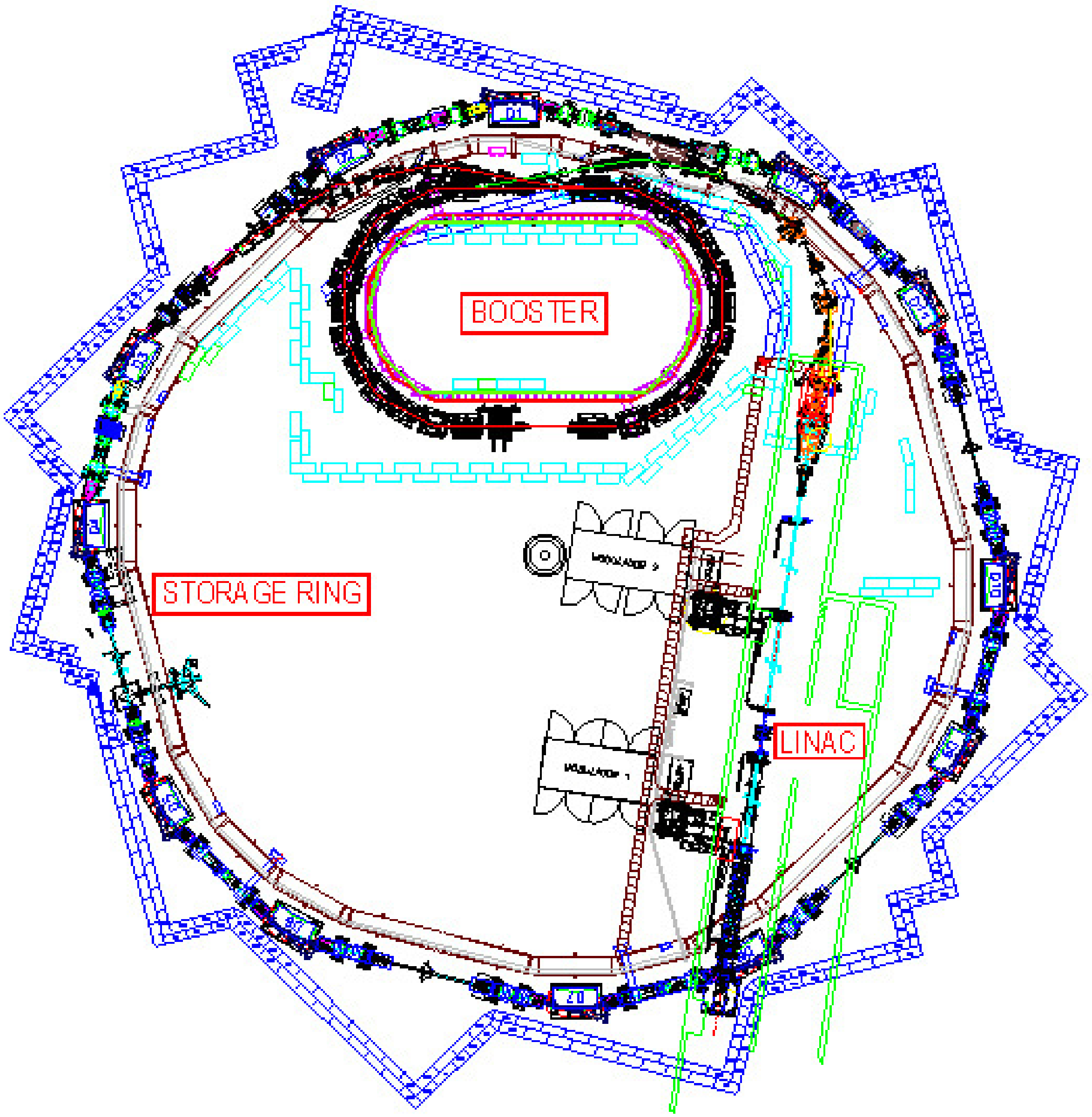
UV/Soft X-Ray beamlines

- 4 operating
- 1 for diagnostic

Hard X-Ray beamlines

- 11 operating
- 1 under construction
- 1 for diagnostic

The LNLS UVX storage ring

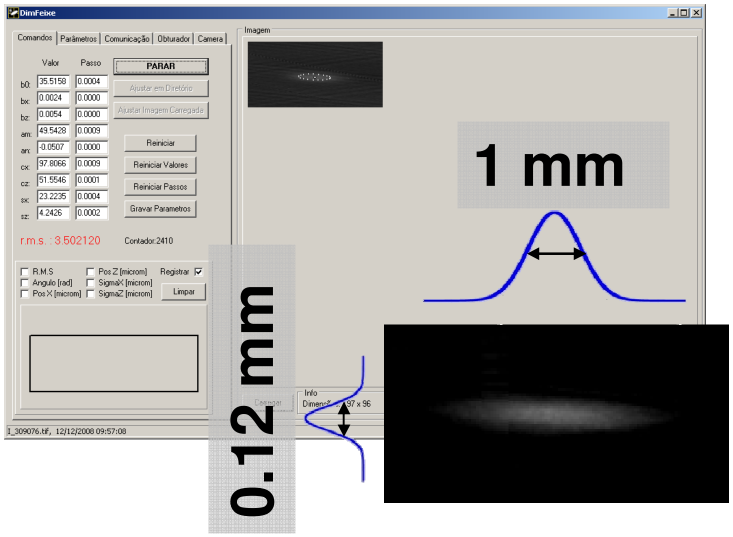


LNLS Storage Ring Main Parameters		
Operating energy	1.37	GeV
Injection energy	500	MeV
Circumference	93.2	m
Revolution frequency	3.22	MHz
Revolution period	311	ns
RF frequency	476	MHz

BEAM STABILITY

Beam stability requirements

The LNLS UVX storage ring beam size



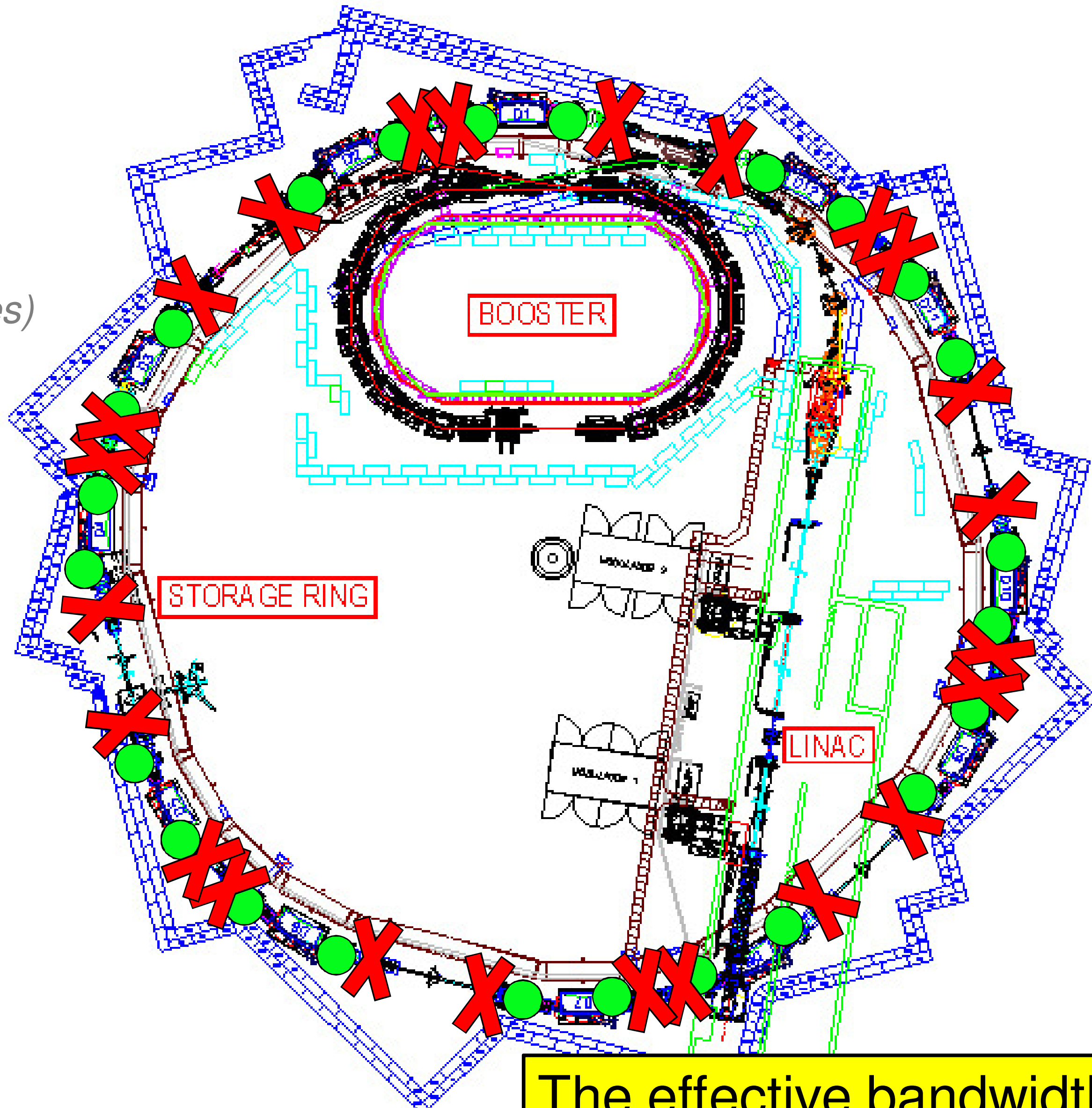
"Position and pointing accuracy on small apertures and samples requirement: few percent of beam size and divergence."

BEAM STABILITY ISSUES AT LIGHT SOURCES
R.O. Hettel
SSRL, Stanford Linear Accelerator Center, Stanford CA 94309, USA

Orbit correction system

Beam Position Monitors
(horizontal and vertical planes)

steering magnets
(for horizontal and vertical planes)

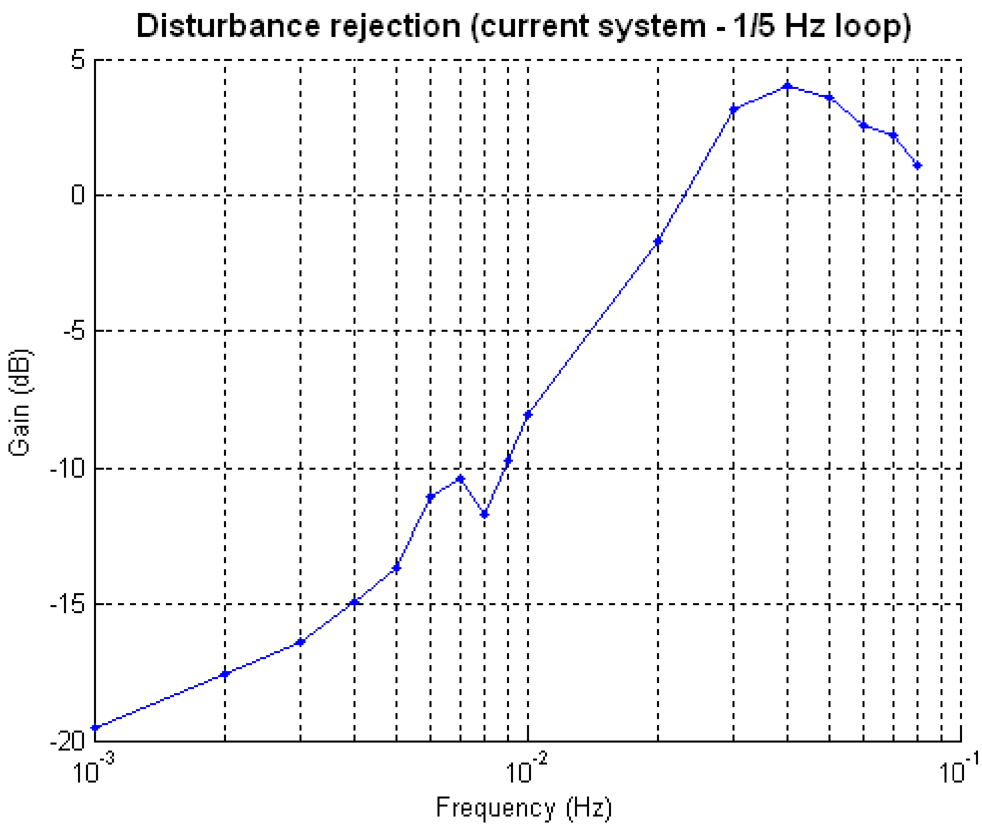


The effective bandwidth of the system is << 1 Hz

Orbit correction system bandwidth

LNLS

The effective bandwidth of current system is << 1 Hz.
Only disturbances with thermal causes are well compensated.



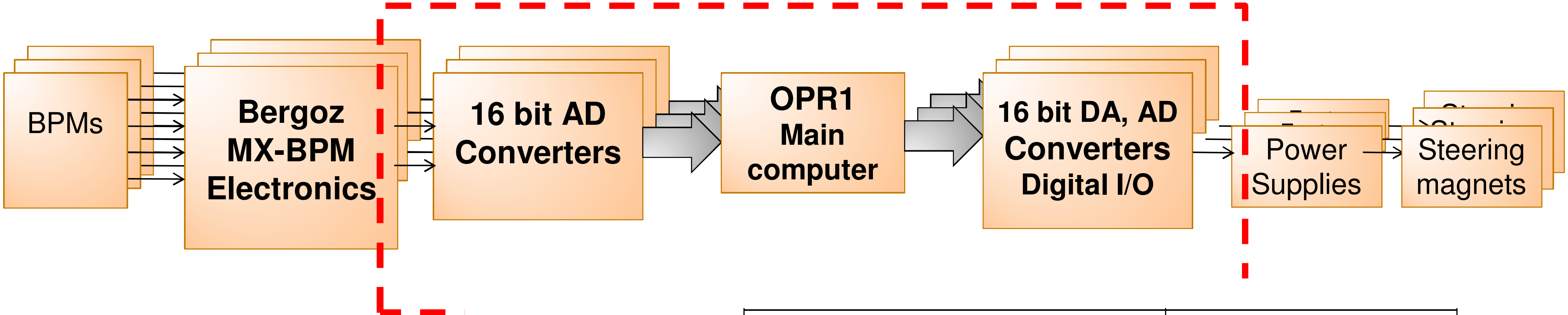
Test performed for the horizontal BPMs and correctors.

99% attenuation @ 1 mHz

No effect @ 20 mHz

Orbit correction system: current architecture

Tests with National Instruments hardware/software



Main Requirements

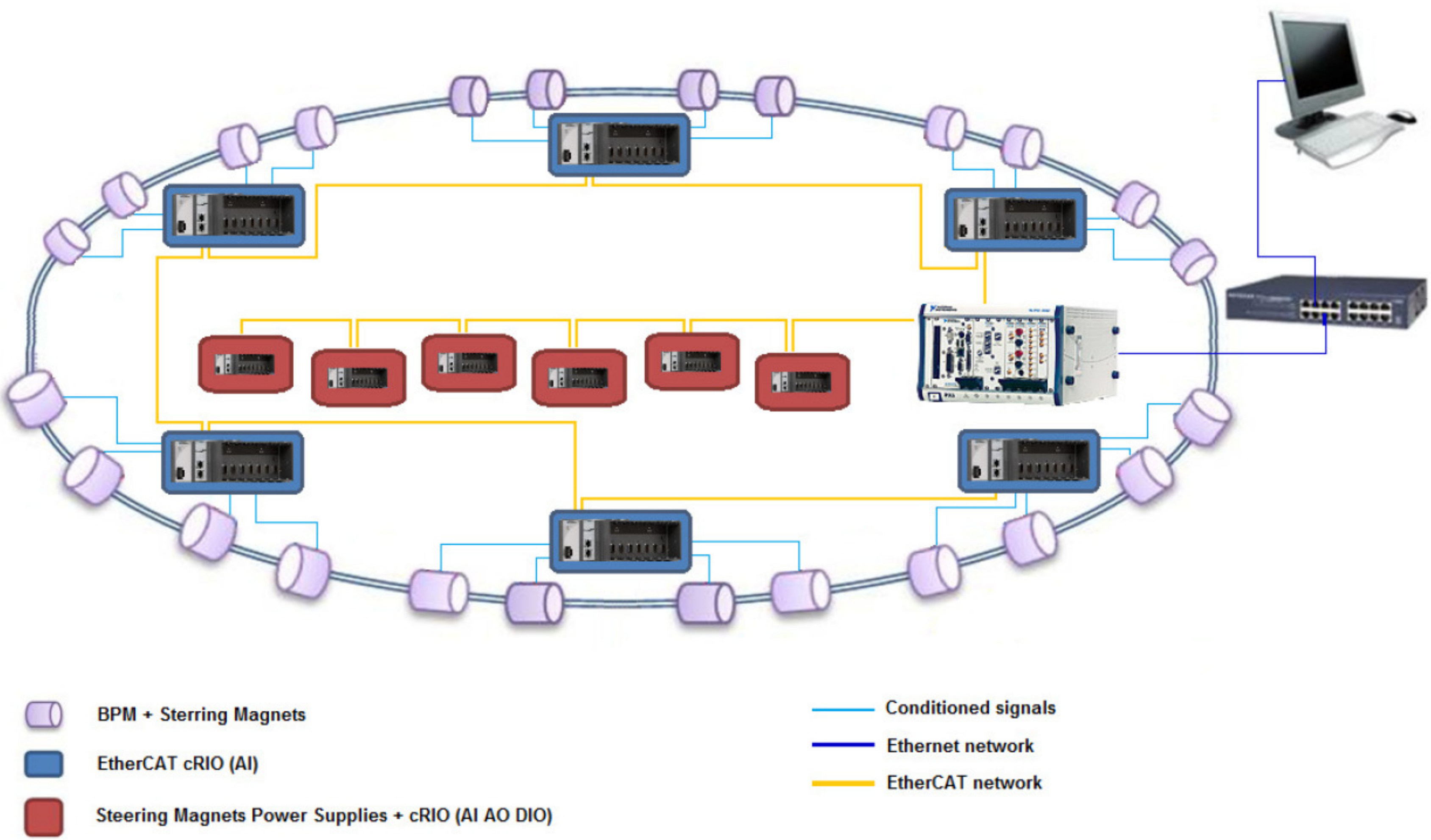
Analog Inputs	> 50
Analog Output	> 42
I/O Resolution	≥16 bits
Analog I/O Range	±10V
I/O Sampling Rate	>> 1 KS/s
Correction Speed	> 1 kHz
Control Algorithm Complexity Matrix Size (MIMO)	50 x 48 (maximum)*
Available Budget	R$ 50k

Table 1- *Main control system features.*

**The matrix dimension can change depending on how many sensors and actuators are being used in the orbit control. A typical dimension is 50 x 42.*

New topology proposed by National Instruments

New orbit control system topology: 2 EtherCAT loops with 6 cRIO chassis each and 1 PXI Real-Time Controller



RESULTS OF THE BENCH TESTS

New orbit correction system requirements

Besides the main requirements mentioned, 3 characteristics are essential to FOFB *(Fast Orbit Feedback)* systems:

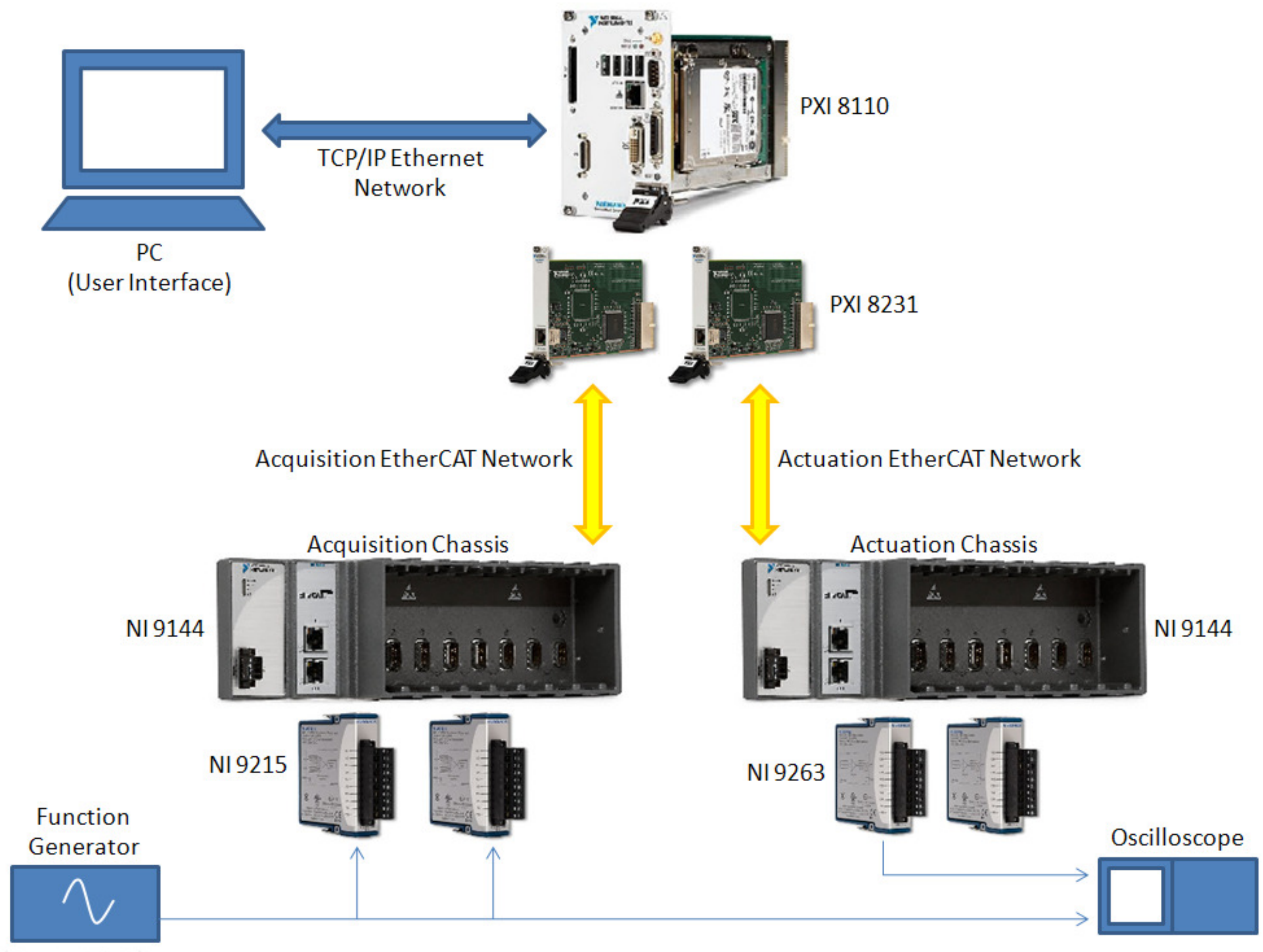
- **Overall speed:** the state-of-the-art fast orbit feedback systems operate @ 10 k readings/writings per second

- **Time synchronization:** among input readings and output writing operations

- **Reliability**

Overall speed

Experimental setup for the feedback loop rate and real-time execution.



In this test the variables were read several times in order to simulate the reading load expected when using all six acquisition chassis (48 fixed-point analog inputs, with 20 bits representation).

In the actuation side, a similar strategy were used.

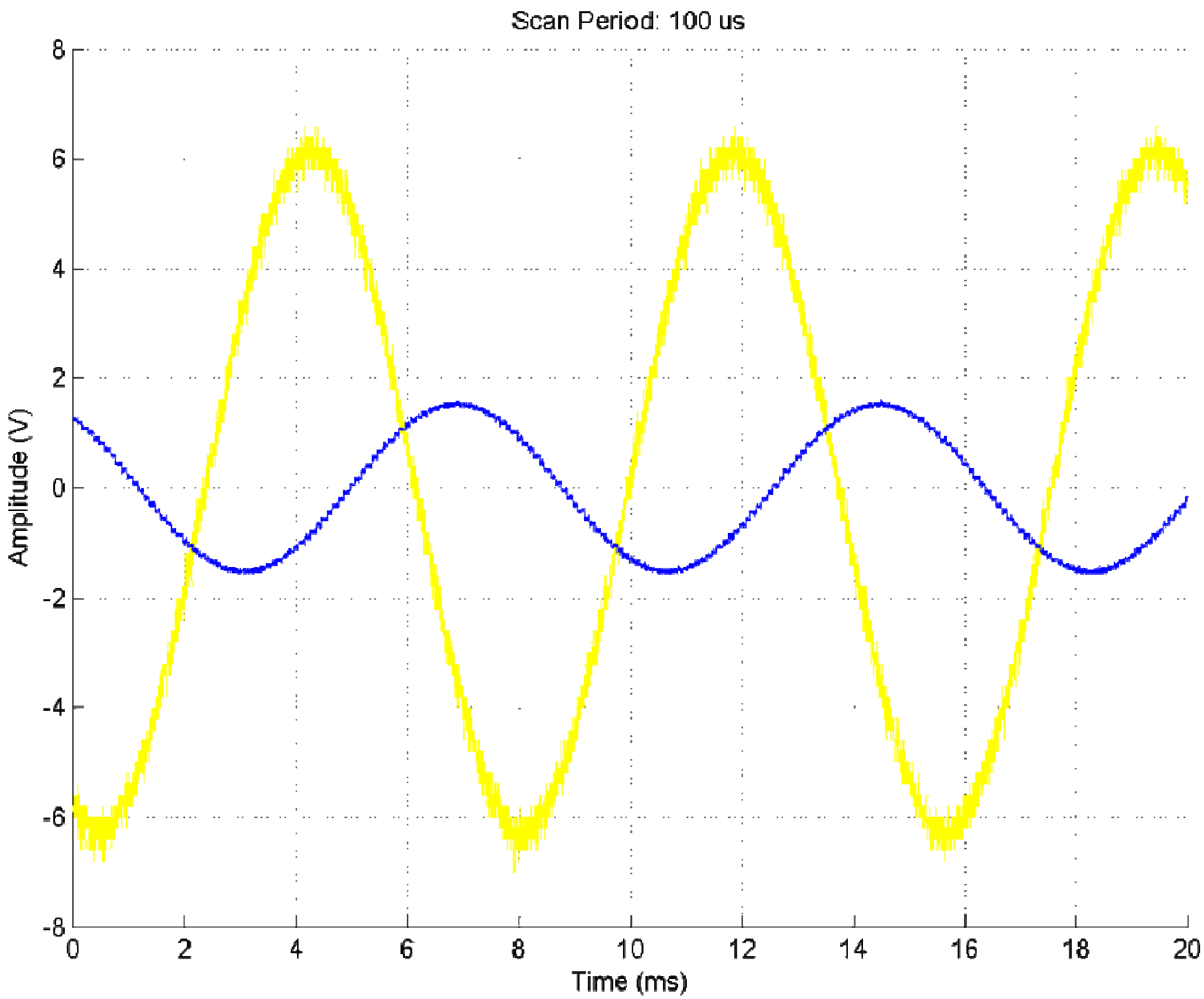
2 tests were performed

-Only Reading and Writing tasks

- Reading, computing matrix multiplication and Writing

Overall speed *(just read and write operations)*

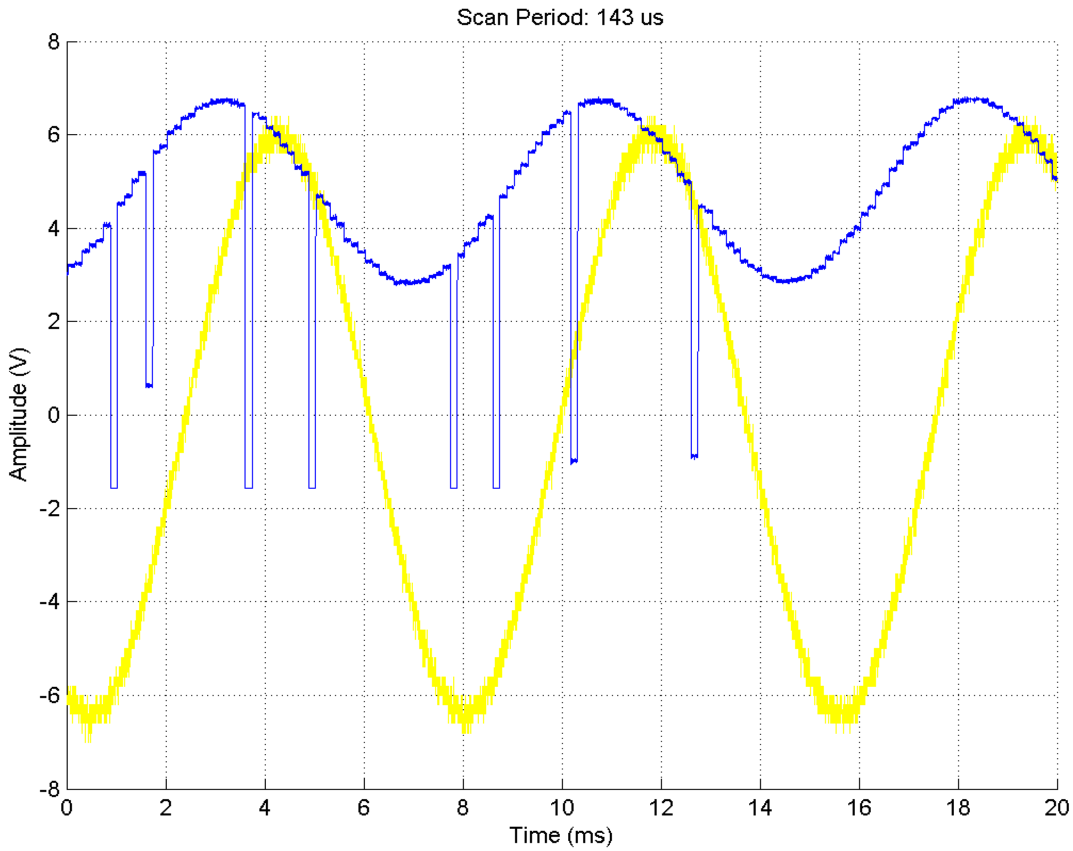
Waveform applied to the acquisition chassis (yellow) and the resultant signal without multiplying by the correction matrix, output by the NI 9263 module (blue).



At 100 μs, the PXI program runs properly!

Overall speed *(read, matrix multiplication and write operations)*

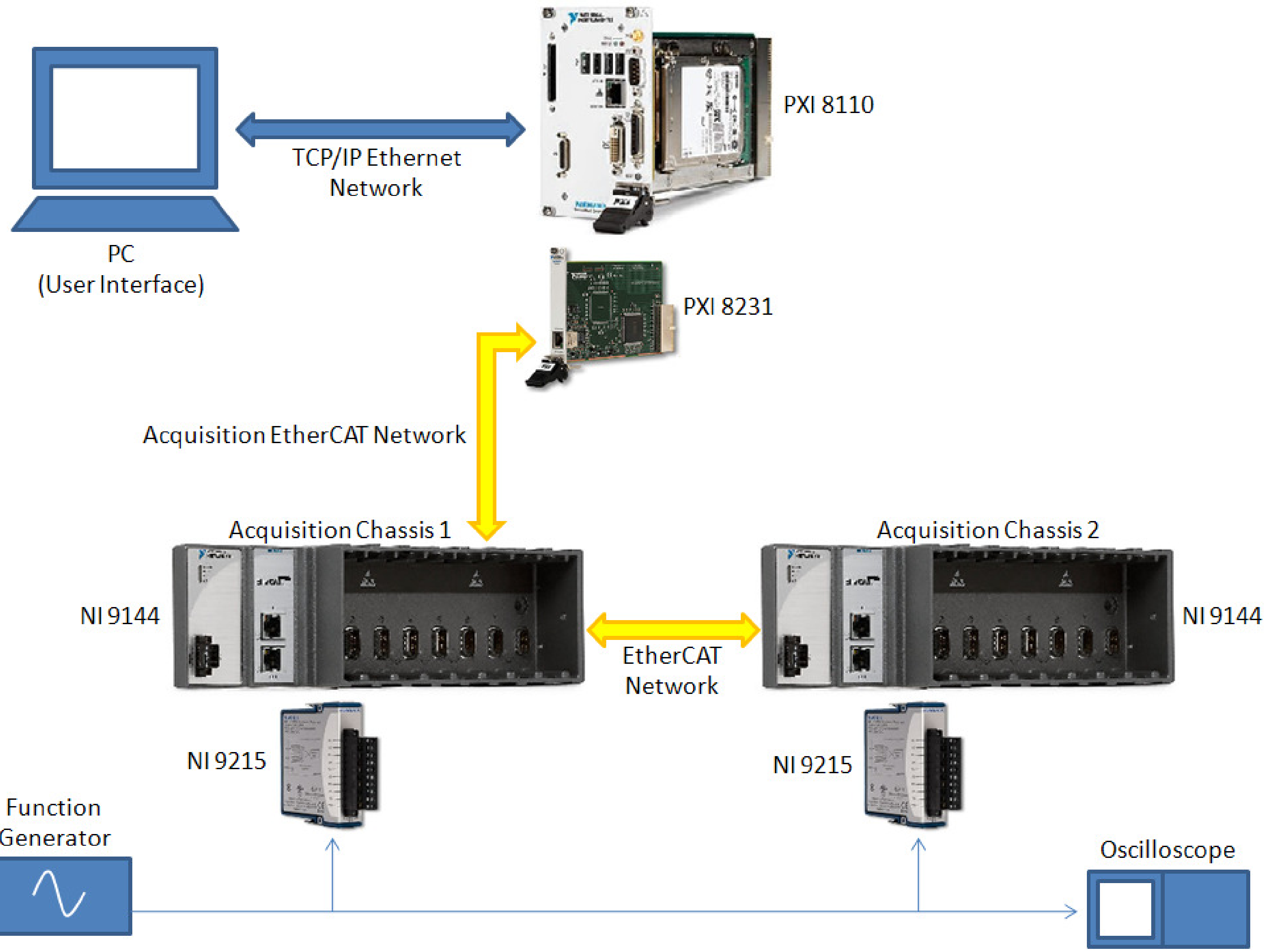
The system runs perfectly up to ~ 6 kHz. At 7 kHz, we observed that samples were lost, possibly indicating the incapability of PXI in reading all the variables at a scan period of ~ 140 µs



For real operation (with beam), we are using 2 kHz loop rate, but possibly we can reach 5 kHz.

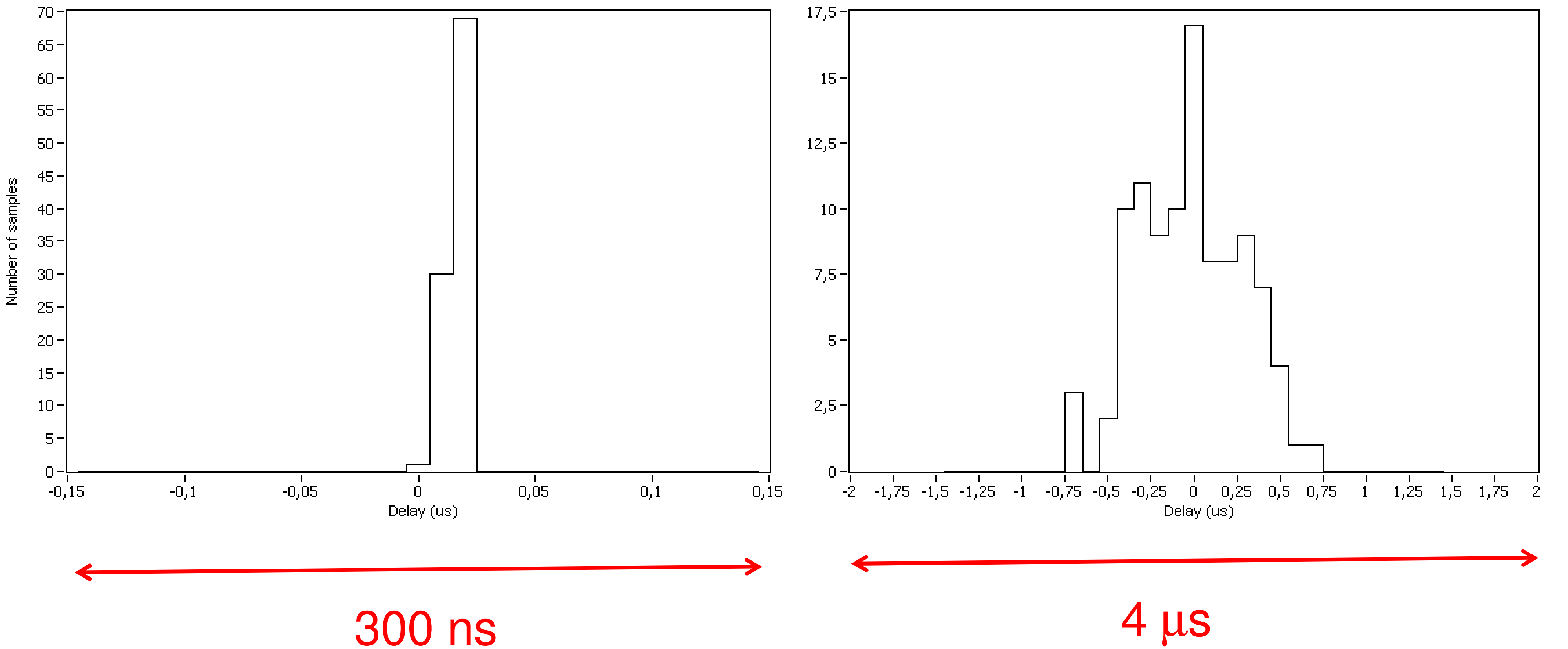
FOFB Time synchronization

Setup for the simultaneous sampling test. The chassis are connected through the same EtherCAT network.



FOFB Time synchronization

For two cRIO chassis in the same network the total synchronization error is smaller than 2 micro seconds.



Delay histograms for acquisitions from one module (left) and from different chassis (right)

Reliability

- No serious faults were detected during the bench tests. We just realize that operating near the Scan Engine speed limit can cause some strange behavior of variables reading/writing over the EtherCAT networks;

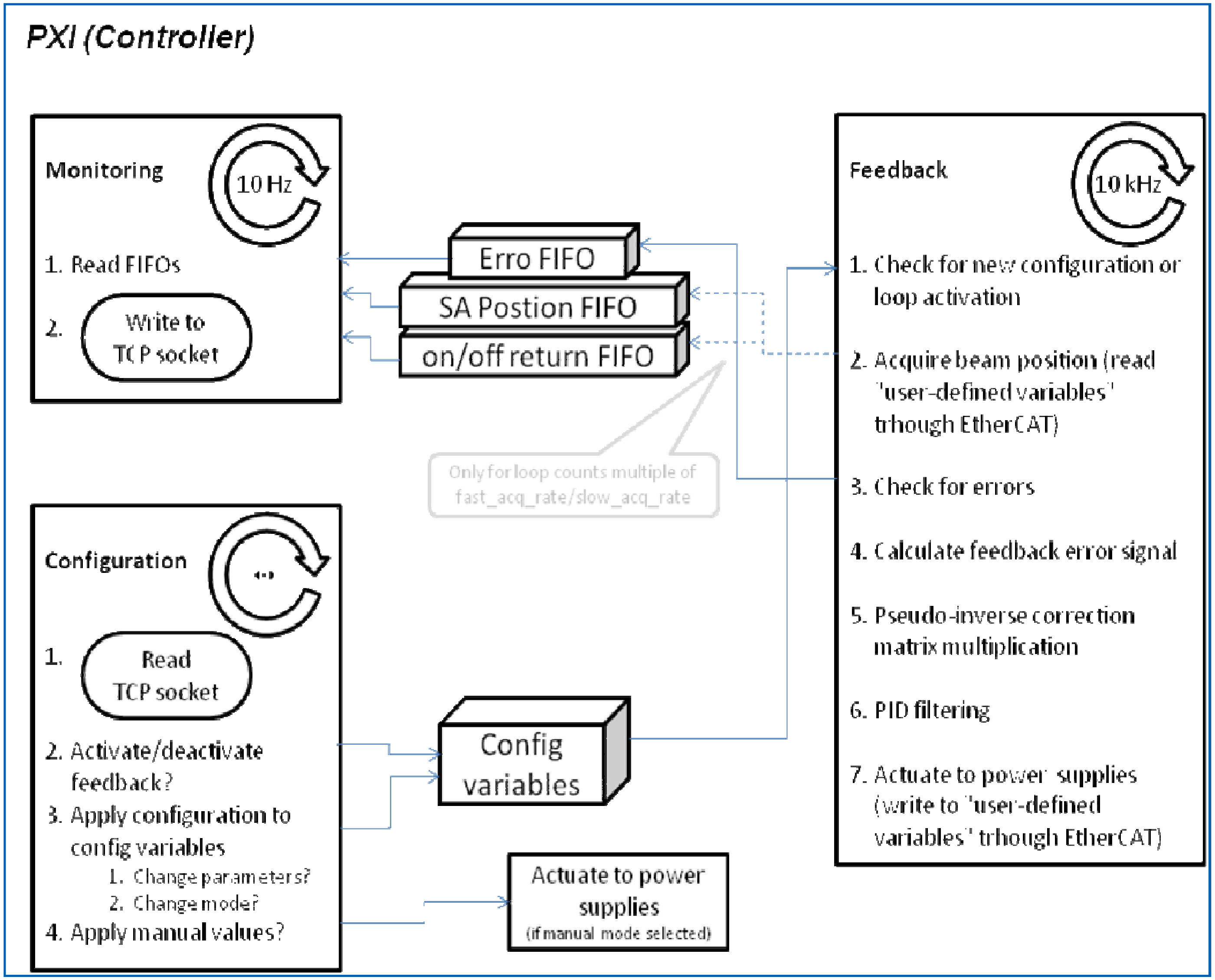
- Few LabVIEW crashes occurred during the tests with beam when, running in debugging mode, large amount of data were exchanged between the front panel (remote interface) and the controller. We still do not know if this is just a matter of computational resource or an internal error in LabVIEW;

•So far, no problem that could limit the system performance or reliability was found.

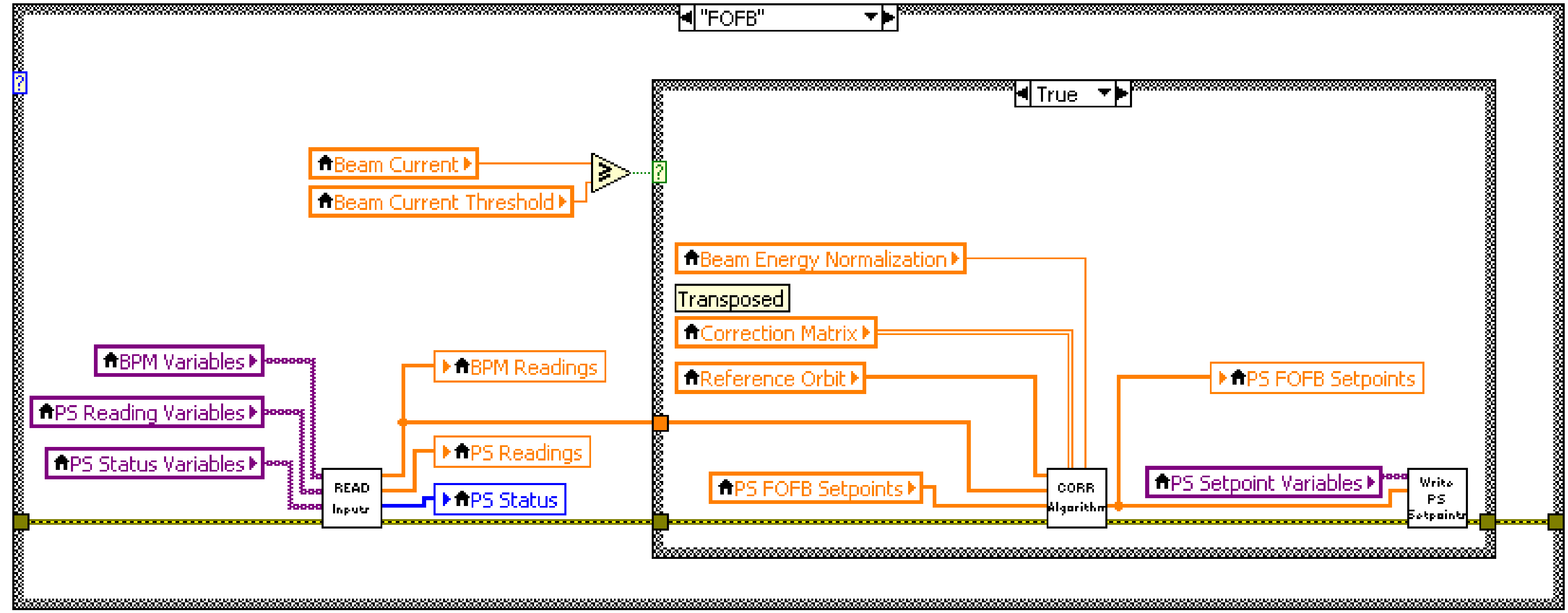
SOFTWARE

Example of software architecture *(Controller)*

Several loops with different priorities run simultaneously in the controller. The 3 main loops are described below.

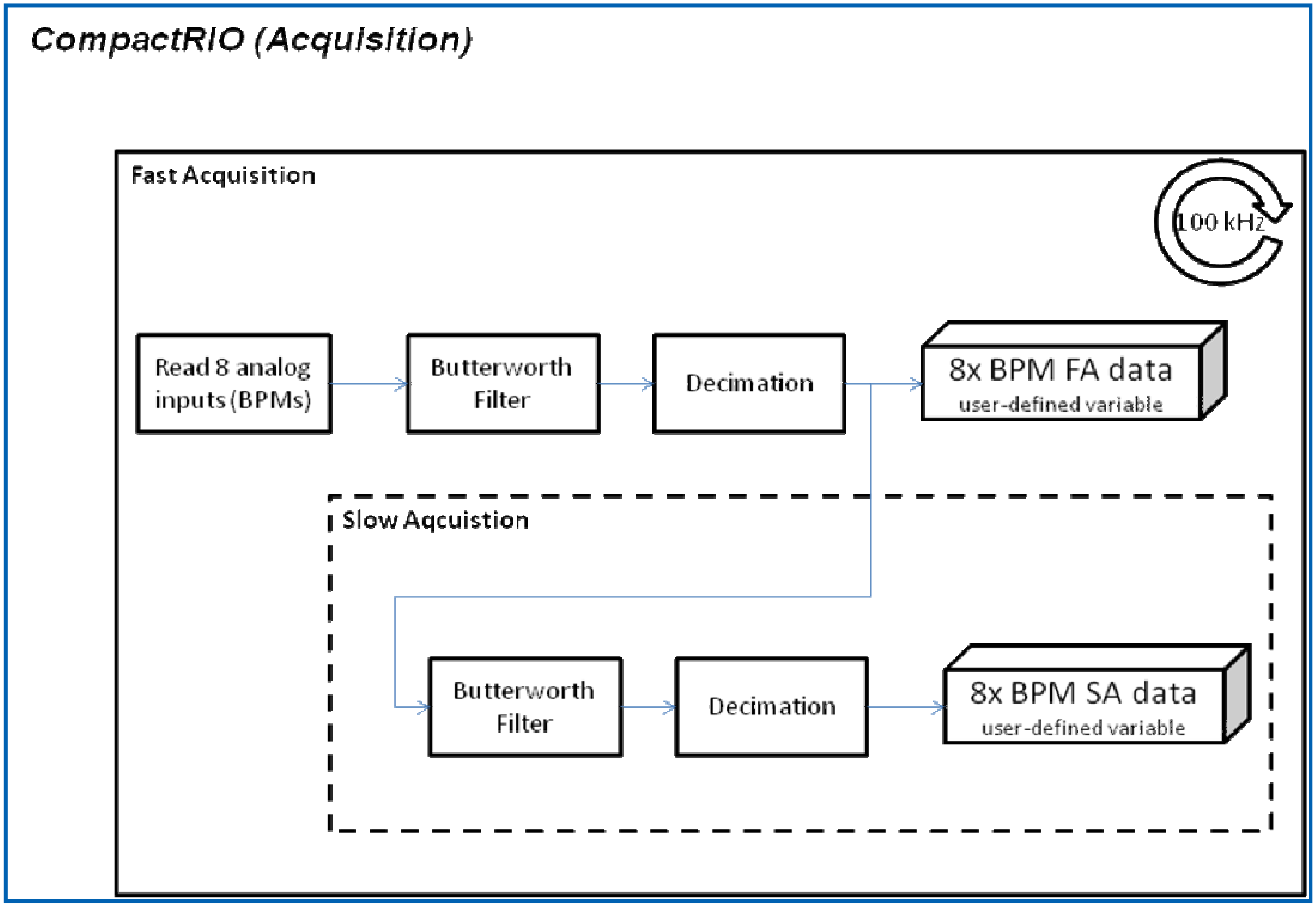


Example of software architecture *(Controller)*



Example of software architecture
(Fast acquisition of position data)

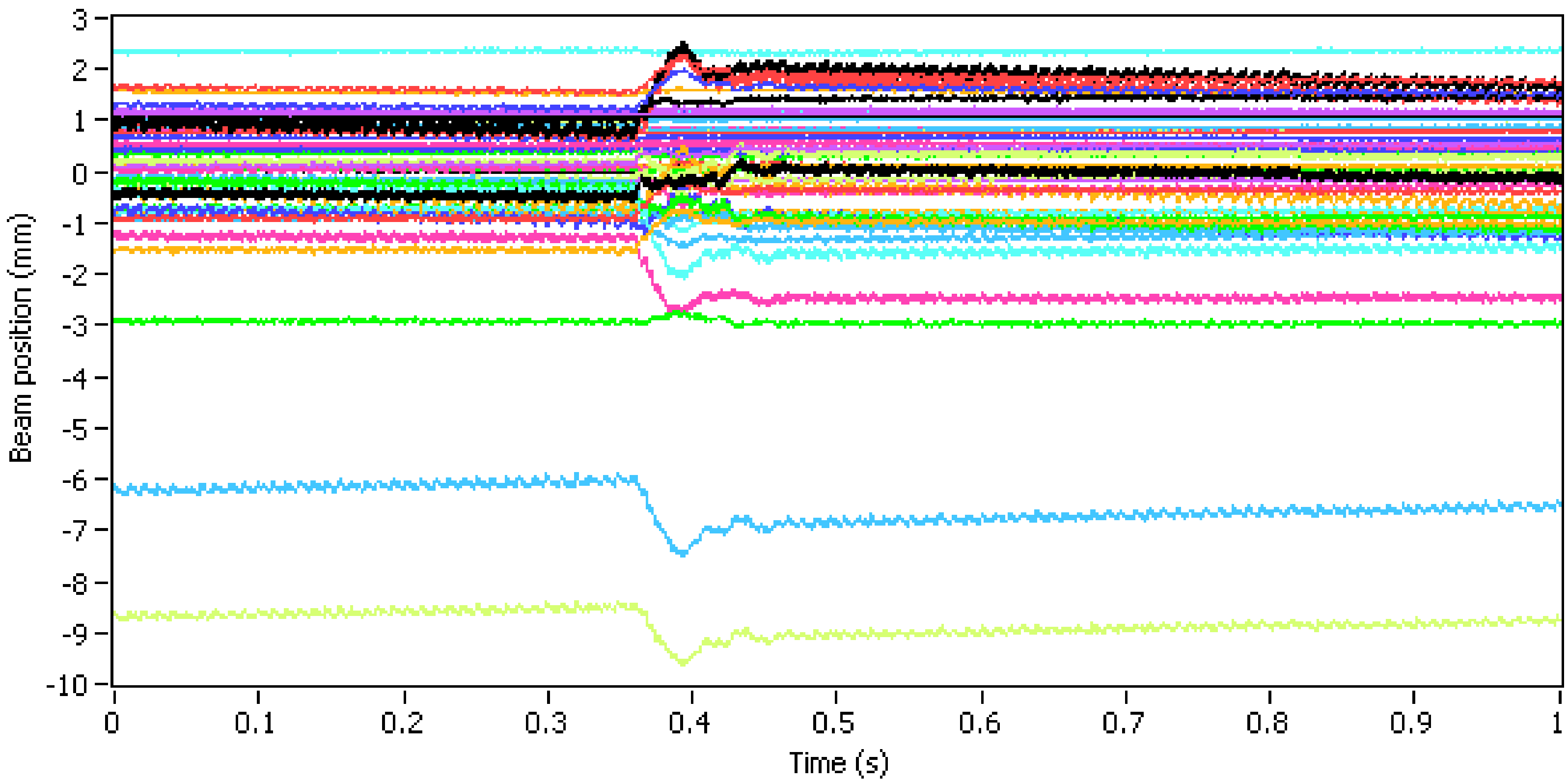
The 100 kS/s data are filtered and decimated before sending to the controller trough the EtherCAT network



FIRST RESULTS WITH BEAM

New orbit correction system performance

Example of fast acquisition (3k samples/second) during energy ramp. The current system would provide only 3 position values for this time frame (1 second).



New orbit correction system performance

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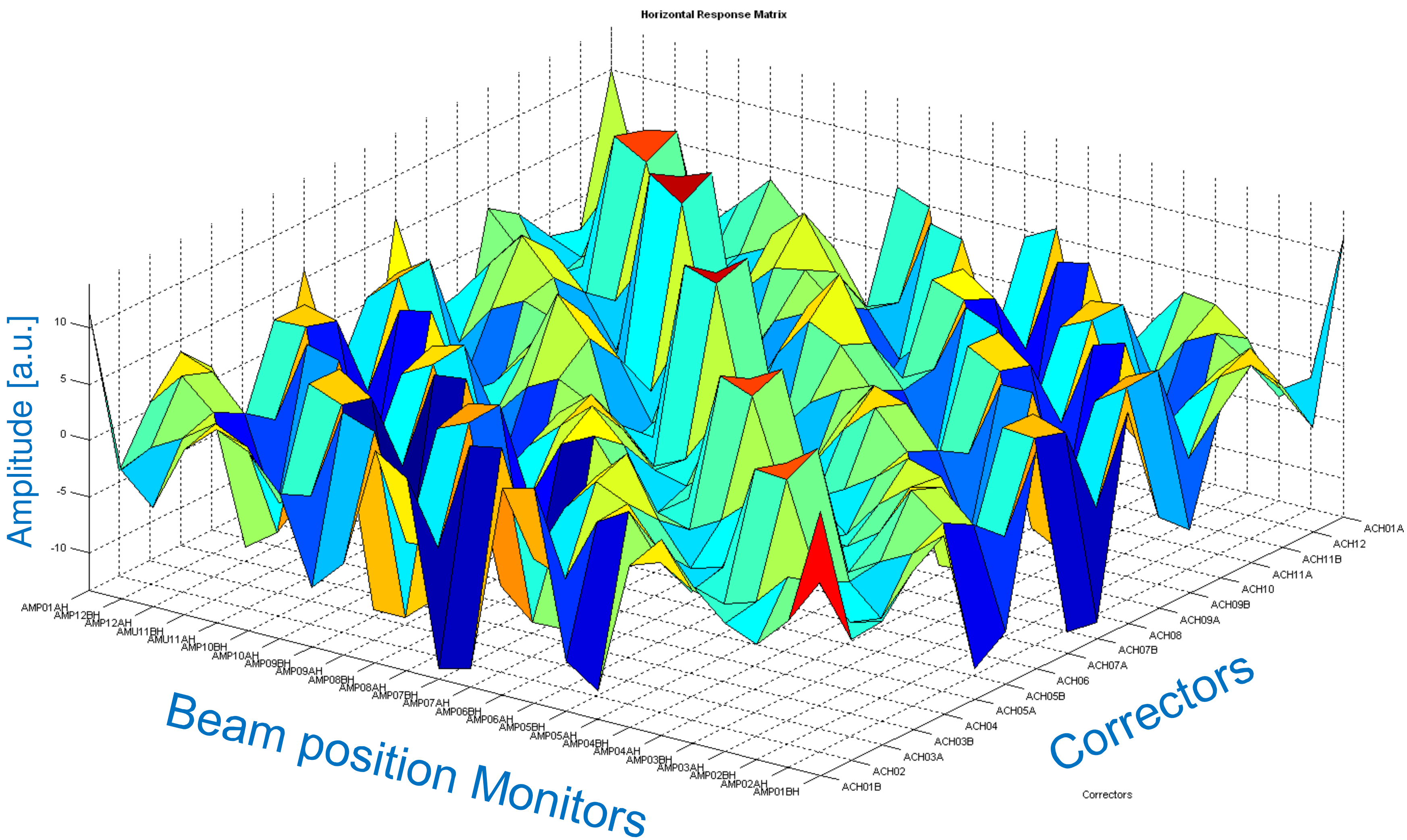
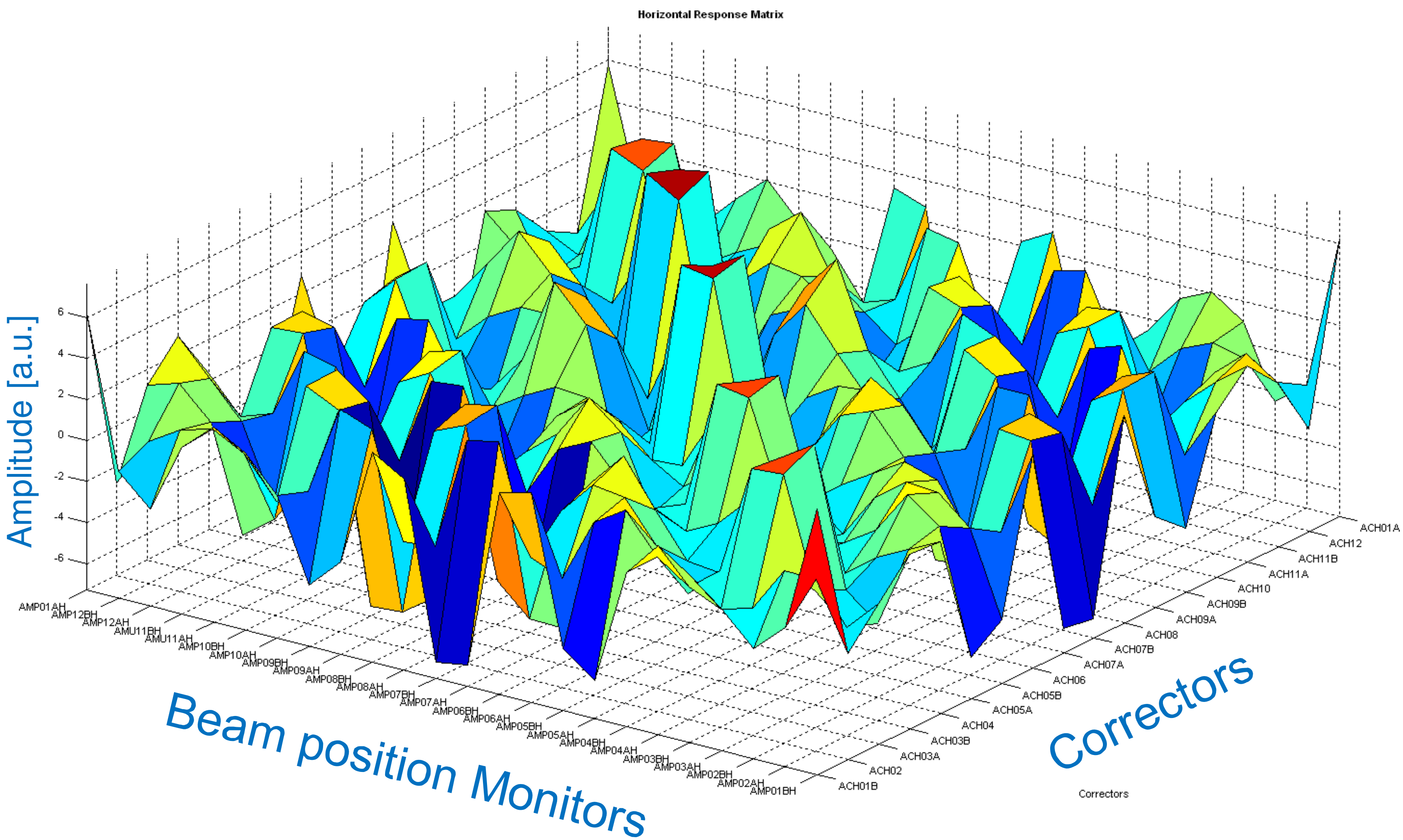
Comparison between response matrix measurements:
result obtained with the current orbit feedback system



New orbit correction system performance

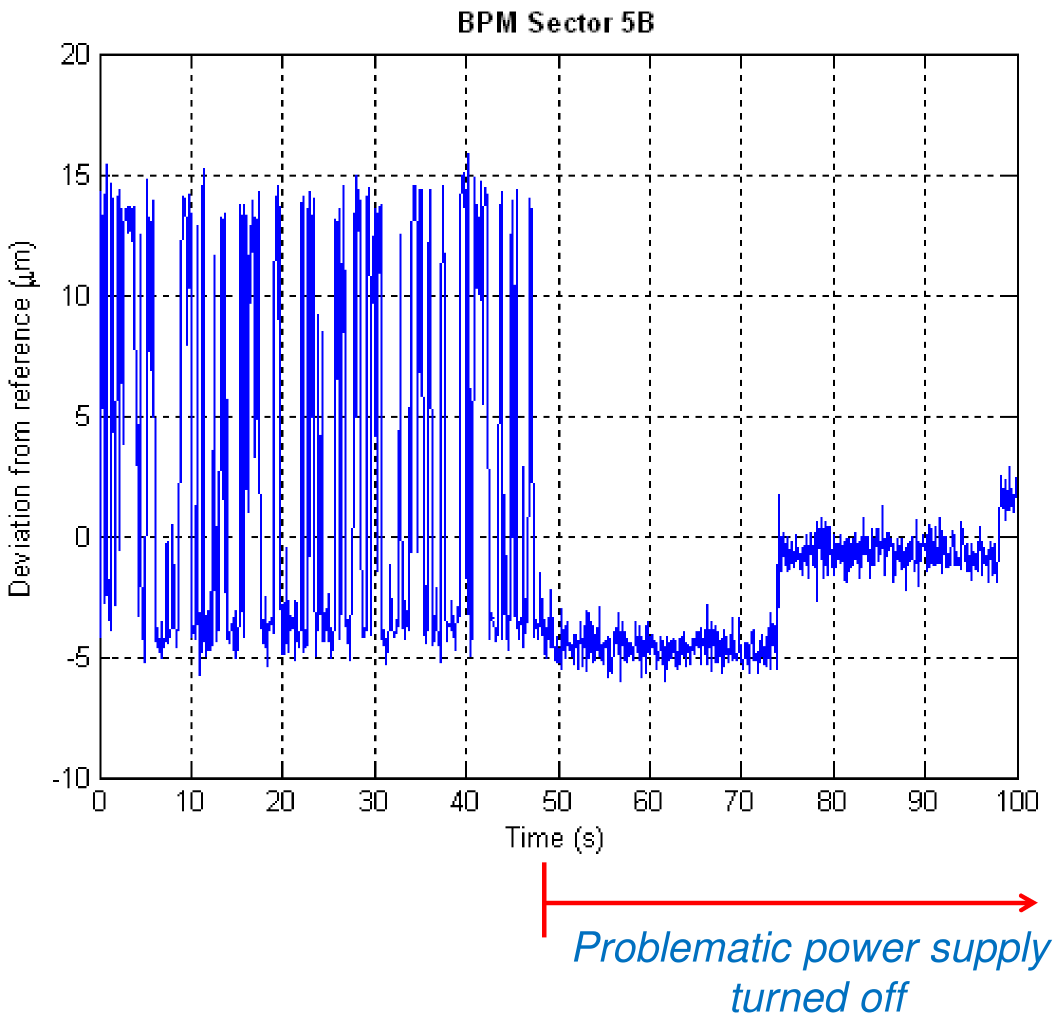
Comparison between response matrix measurements:
Result obtained with the <u>new fast orbit feedback system</u>



New orbit correction system performance

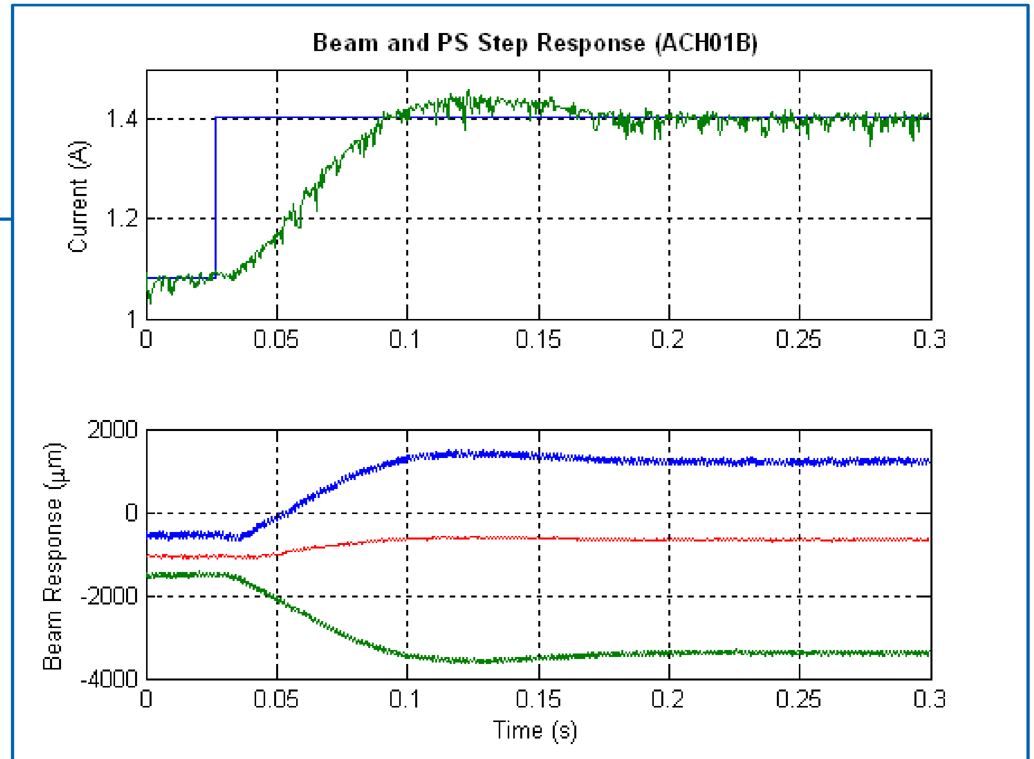
Example of problem detected by the fast continuous acquisition

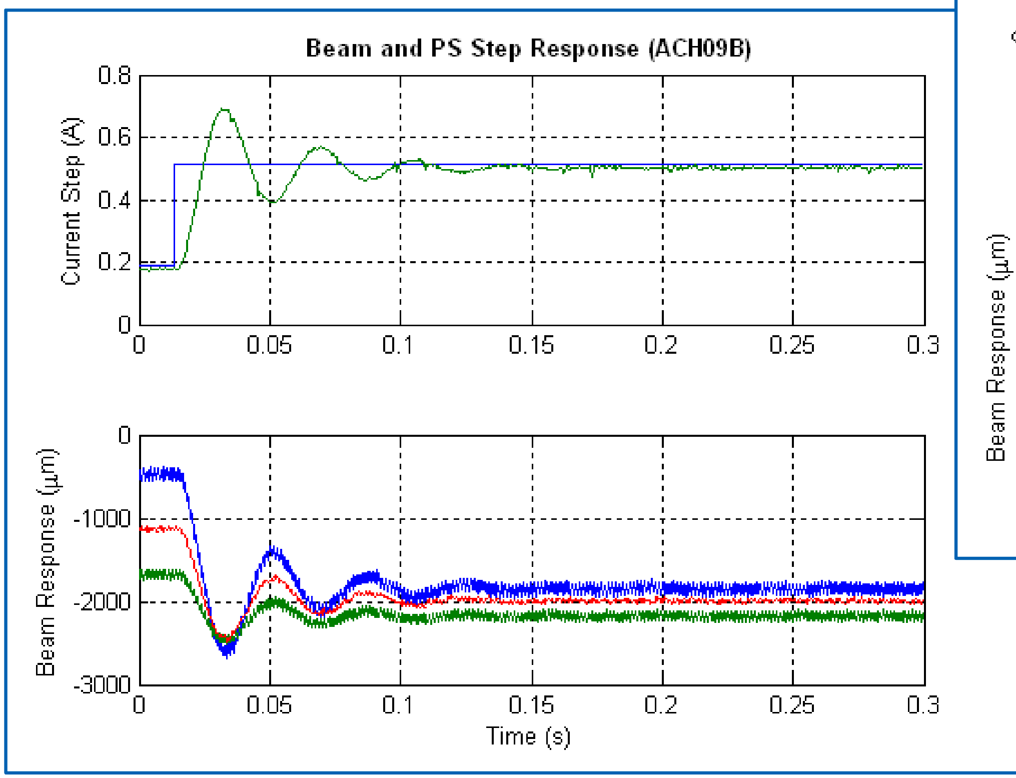
(the system in operation filters out the fast phenomena and did not see the problem)



New orbit correction system performance

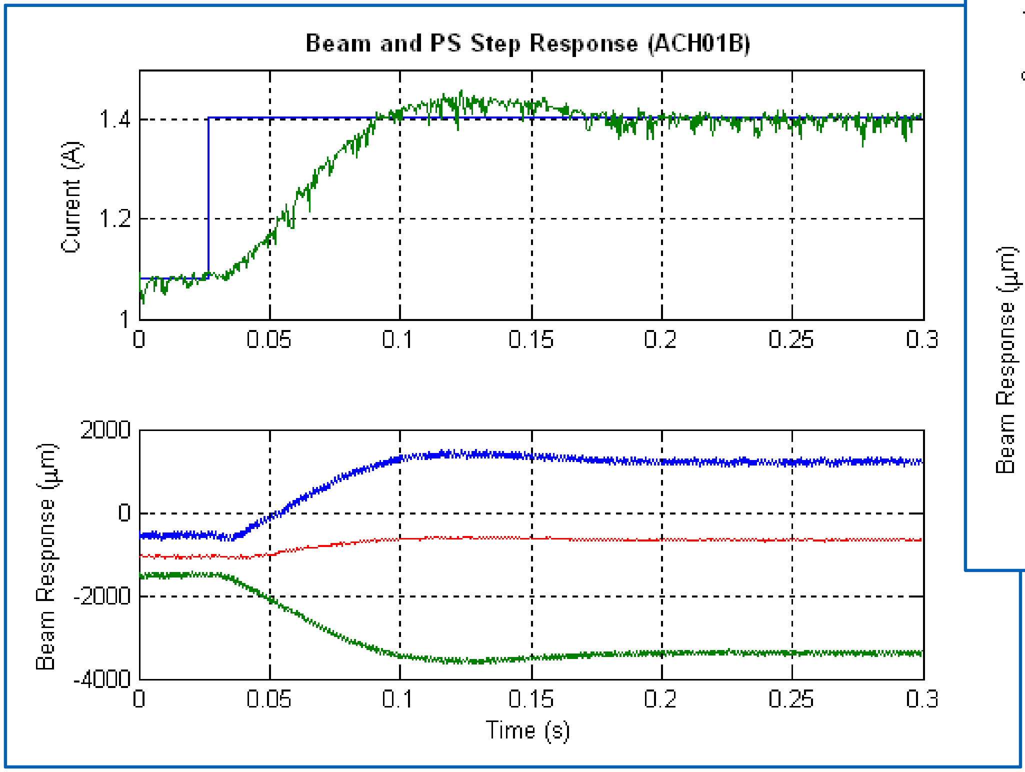
Fast acquisition showing the disturbing effect of some slow and untuned power supplies to the beam position

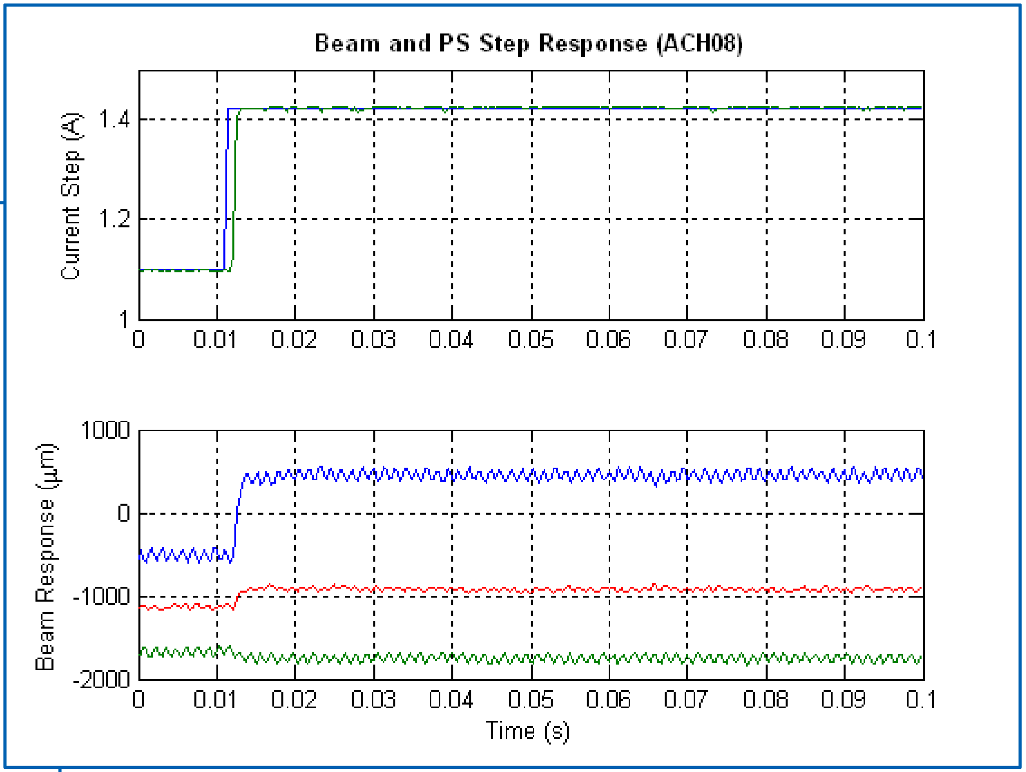




New orbit correction system performance

Fast acquisition showing the difference between a slow and fast power supply





New orbit correction system: future steps

Besides response matrix and fast acquisition experiments, we closed the feedback loop and tested the orbit correction algorithm. Currently we are limited to ~ 10 corrections per second due to the power supplies “asymmetries”. In the near future we intend to:

- Optimize the pre-filtering parameters (FPGA acquisition at NI 9215)

- Verify the performance of the system running at full speed (5 kHz?)

- Improve the graphical interface of the system and implement tools for beam diagnostics (this will allow the definitive replacement of the old system by the new one!)

- Push the limits of the feedback controller testing more shophisticated algorithms for orbit correction taking in account the dynamics and limitations of the power supplies

FINAL REMARKS

•Software developments in LabVIEW proved to be simple and relatively not time-consuming. 1,5 engineer worked during 7 months on the project. In this period they took LabVIEW courses, designed the system, performed a proof of concept, finished the physical installation and started the commissioning;

•The major software tasks (fast orbit feedback loop, feedback configuration and process variables monitoring) as well as FPGA pre- and post-processing (oversampling and filtered acquisition for inputs and PID control for outputs) were quickly implemented with a robust architecture;

•The simultaneity of acquisitions, within ~ 1 μs between adjacent EtherCAT slaves, is perfectly acceptable for the fast orbit feedback application;

•The system represents an important achievement in beam control and monitoring for the LNLS instrumentation team.