SOLEIL LLRF & Control Activities

Rajesh Sreedharan, M. Diop, R. Lopes, P. Marchand, F. Ribeiro

Content

- General SOLEIL RF system
- Our present LLRF
- Digital LLRF prototype
- ThomX LLRF
- LUCRECE/LUNEX5 LLRF
- RF phase/amplitude measurement system
- Home made SSA control hardware system
- Digital bunch by bunch transverse feedback upgrade

RF system of the storage ring

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❖ STORAGE RING

- 580 kW (500 mA) & 4 MV @ 352 MHz
- 2 cryomodules, each containing a pair of single-cell s.c. cavities
- Each cavity powered by a 180 kW solid state amplifier (SSA)
- Both CM supplied with LHe (4.5 K) from a single cryo-plant

SOLEIL SYNCHROTRON

Storage Ring LLRF

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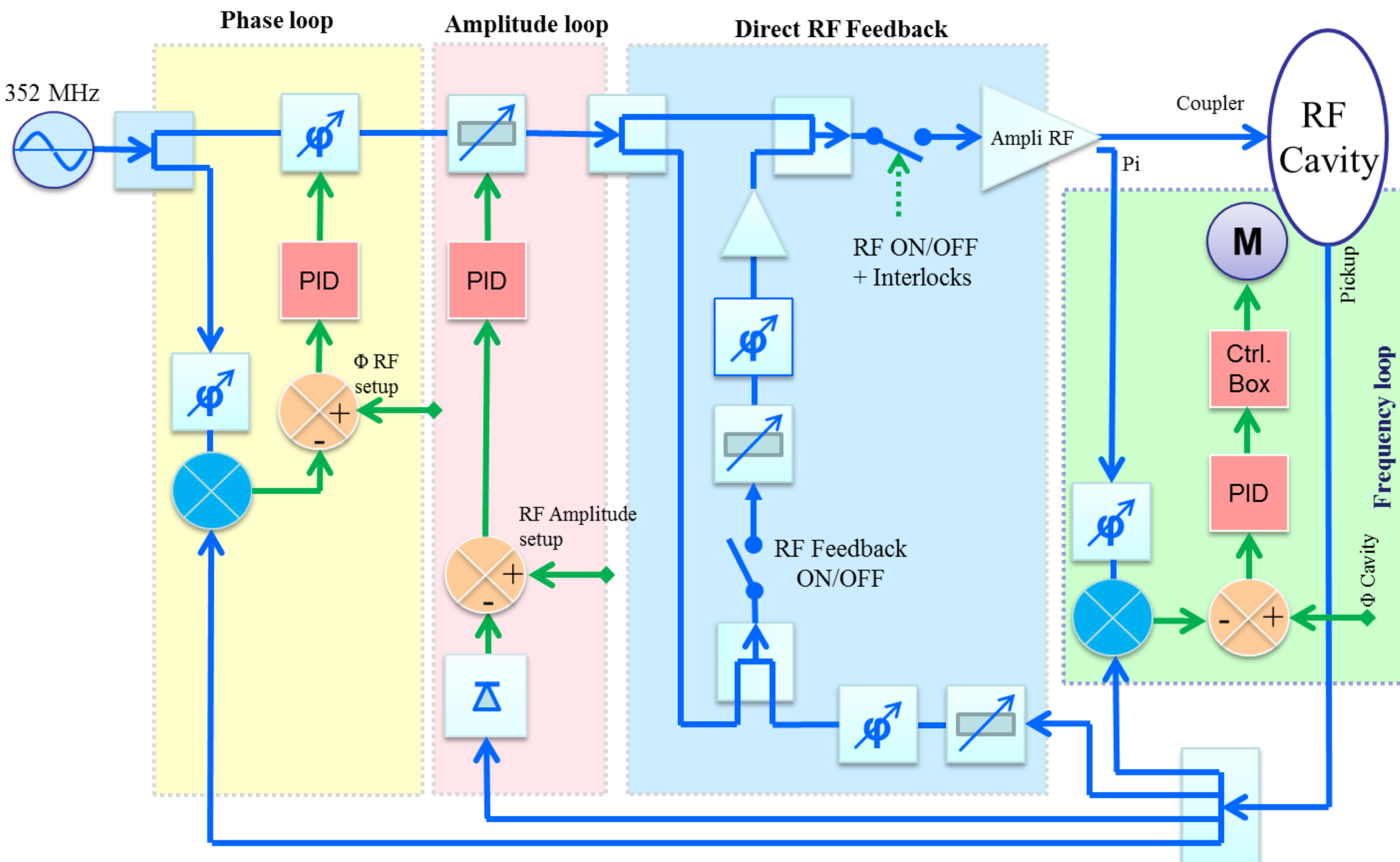

The direct RF feedback is necessary for the Robinson stability at the high beam current.

Performances:
Amplitude : 0,1%
Phase : 0,025°

Storage Ring digital LLRF prototype

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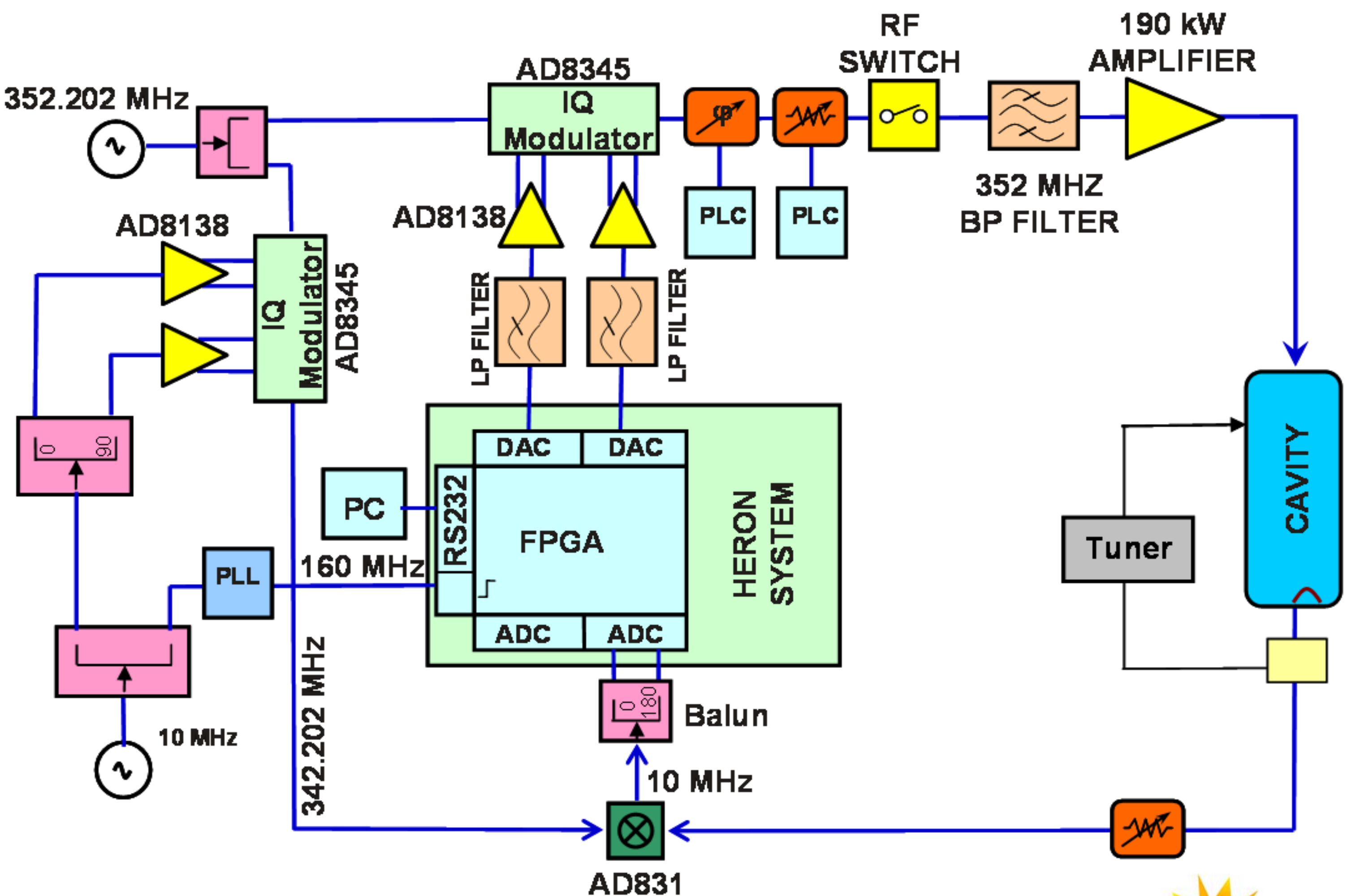
Phase 2 : fast digital (FPGA based) phase and amplitude loops, under development in collaboration with CEA



FPGA architecture

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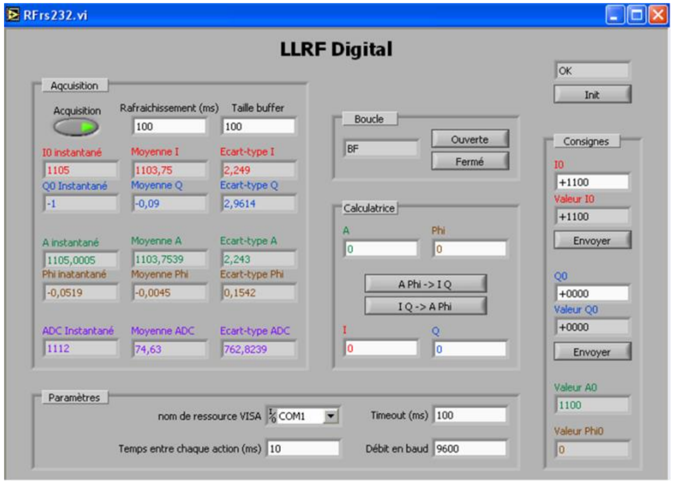
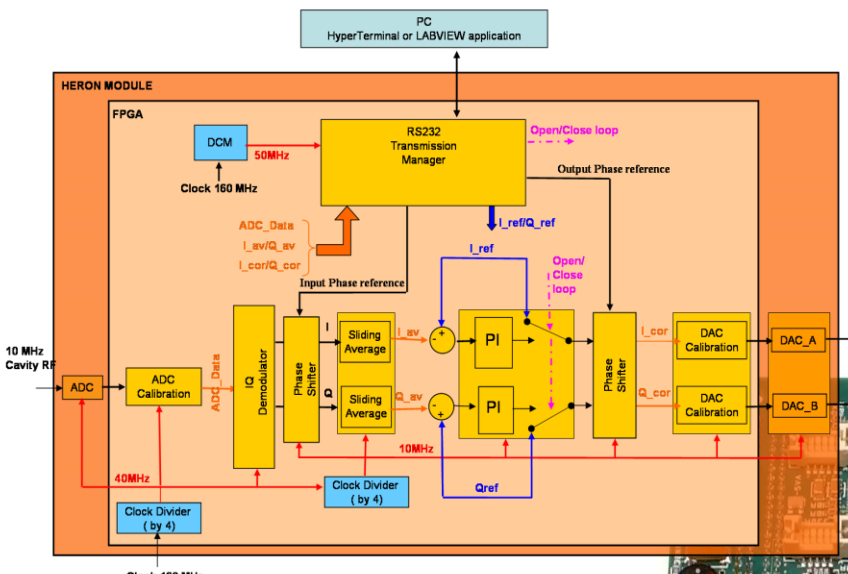
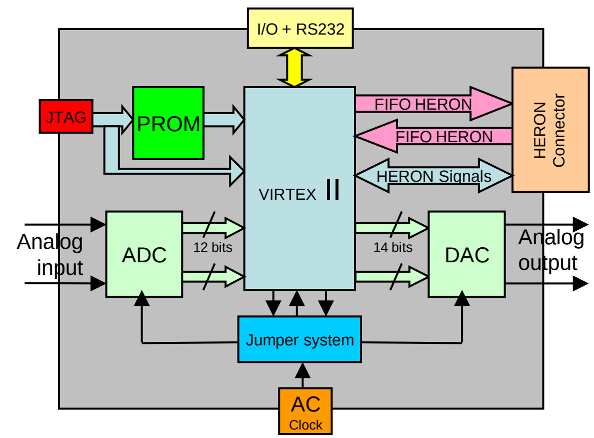


With 300mA beam current stored
Amplitude error: 0.2%
Phase error: 0.15°

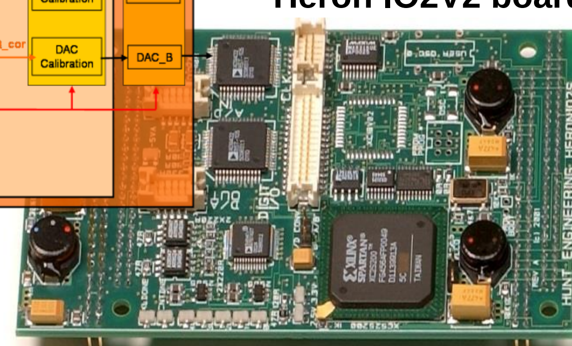
Good agreement between calculations from model and measurements



Module Architecture



Heron IO2V2 board



Contribution to ThomX

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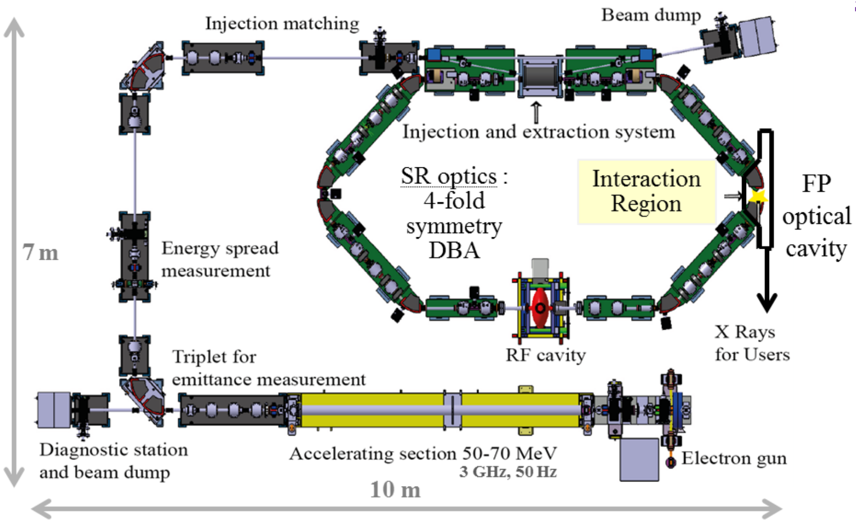
Compact source of hard X-rays (40 - 90 keV), generated by Compton Back Scattering (CBS), which is under construction in Orsay - France



Injection of a single e⁻ bunch (20 mA) at 50 Hz repetition rate, which collides at each turn with a laser pulse inside an optical cavity → X rays (10^{11}-10^{13} /s) from CBS ($\omega_{dif} \sim 4\ \gamma^2\ \omega_{laser}$)

Applications

- **Medical sciences (imaging + therapy)**
- **Cultural heritage sciences (Louvre Museum, for instance)**

→ Compactness

Work supported by the EQUIPEX program from the Research Ministry, Région Ile de France, CNRS-IN2P3 and University of Paris-Sud

Contributors: LAL-Orsay CNRS-IN2P3, SOLEIL, CELIA Bordeaux, ESRF, C2RMF-CNRS, UDIL-CNRS, INSERM Grenoble, Thales TED, Institute Neel Grenoble

Project start : 2012

The SOLEIL RF group is in charge of :

- **the LINAC injector (50 - 70 MeV, 3 GHz, 50 Hz)**
- **the SR RF system**
- **the Transverse feedback system**

SOLEIL SYNCHROTRON

ThomX RF control

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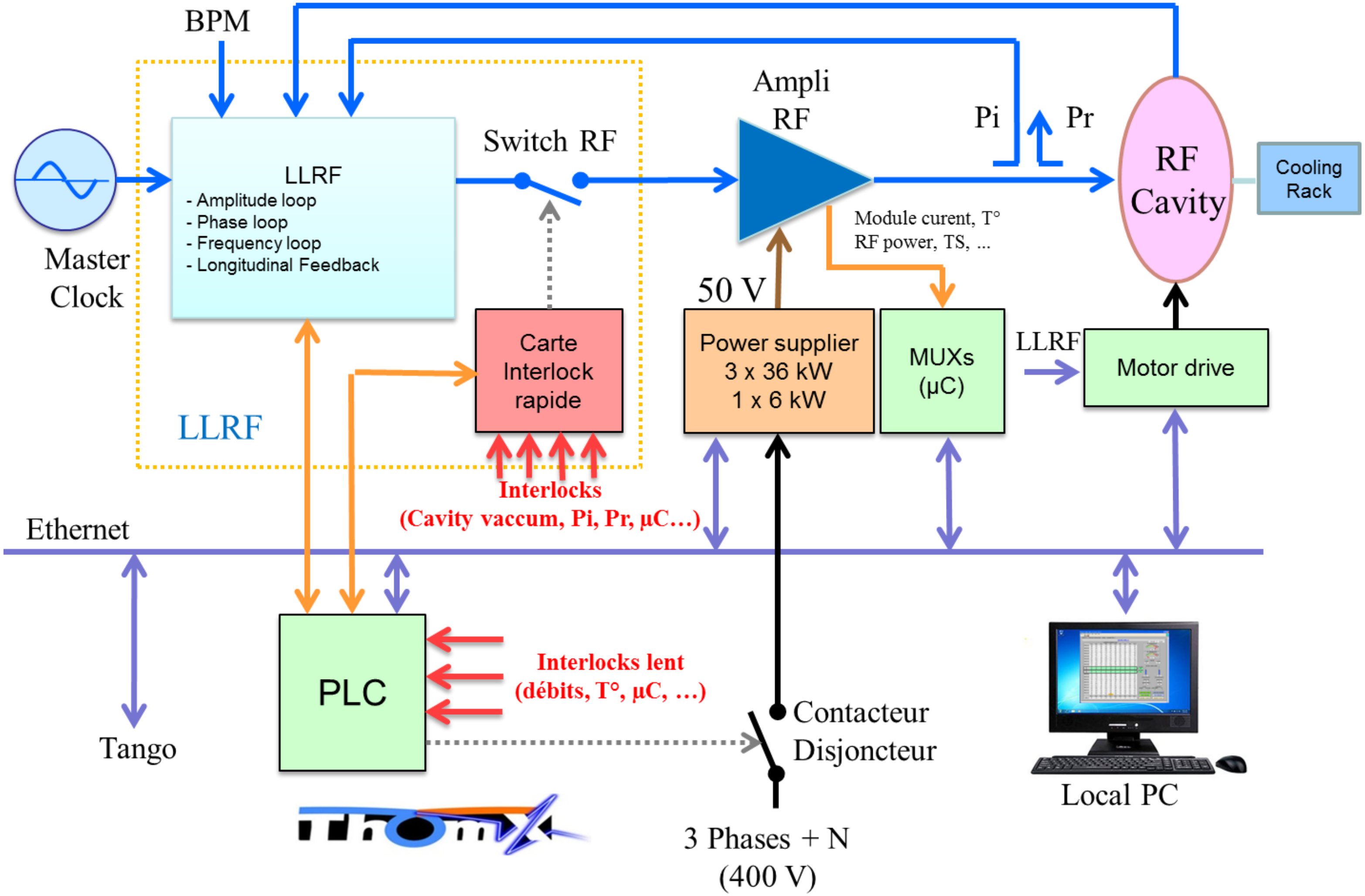

ThomX longitudinal feedback

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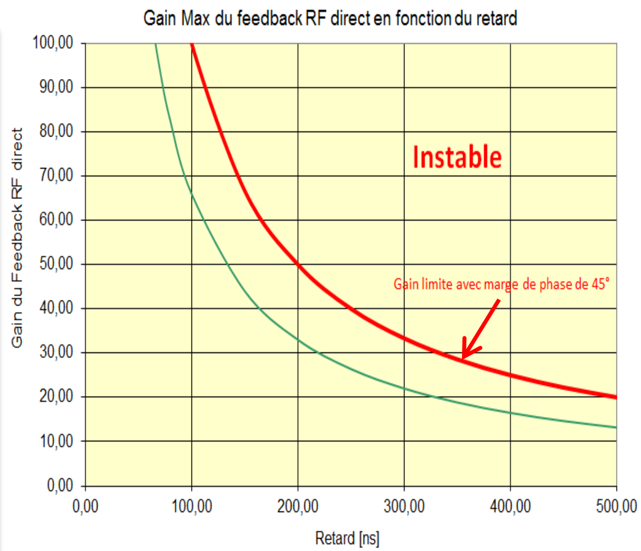
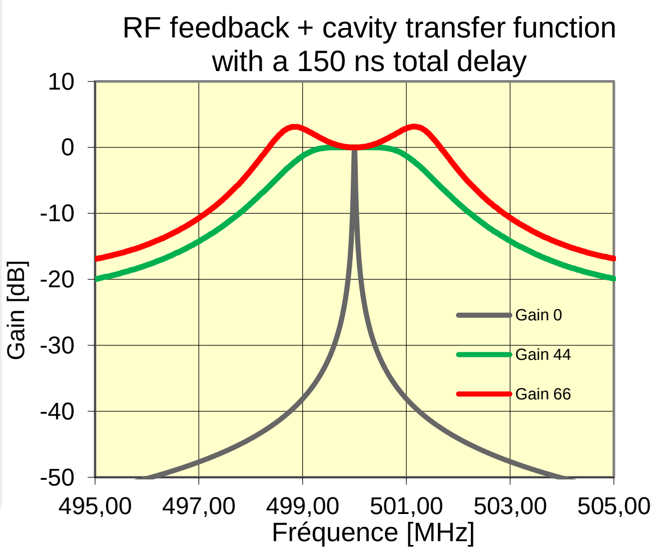




ThomX synchrotron frequency is high (~ 500 kHz)

➢ *Need to increase the cavity bandwidth (~25 kHz) by a factor ~ 50 in order to use it as a longitudinal kicker*

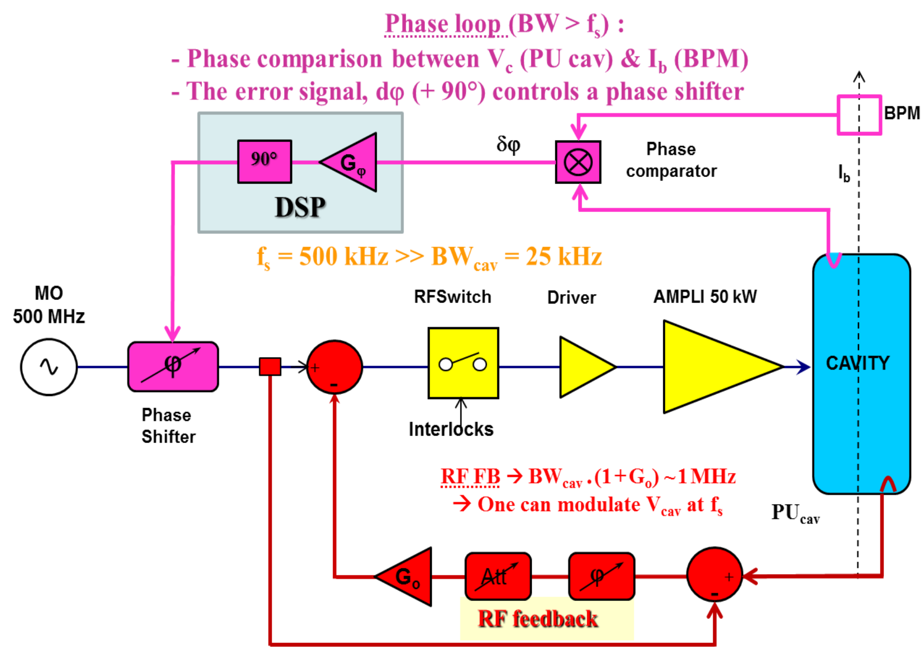
→ ***High gain RF feedback + Fast phase loop***

Limited by loop delay

→ Analog feedback

→ Short cables with good permittivity

LFB = direct RF FB + Phase loop



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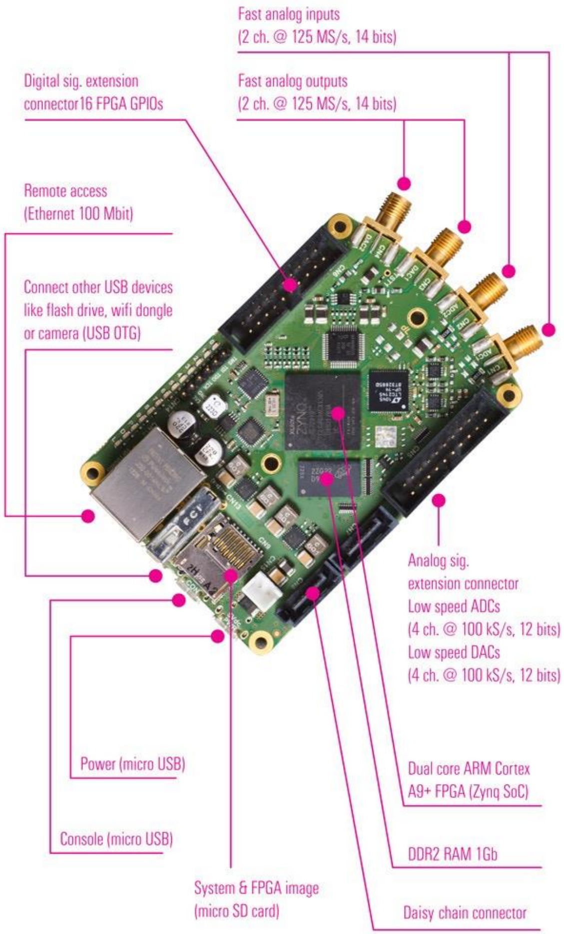
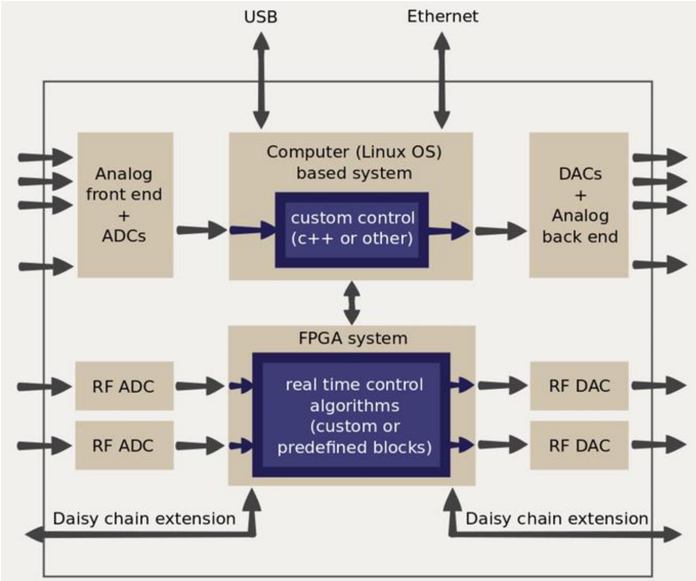
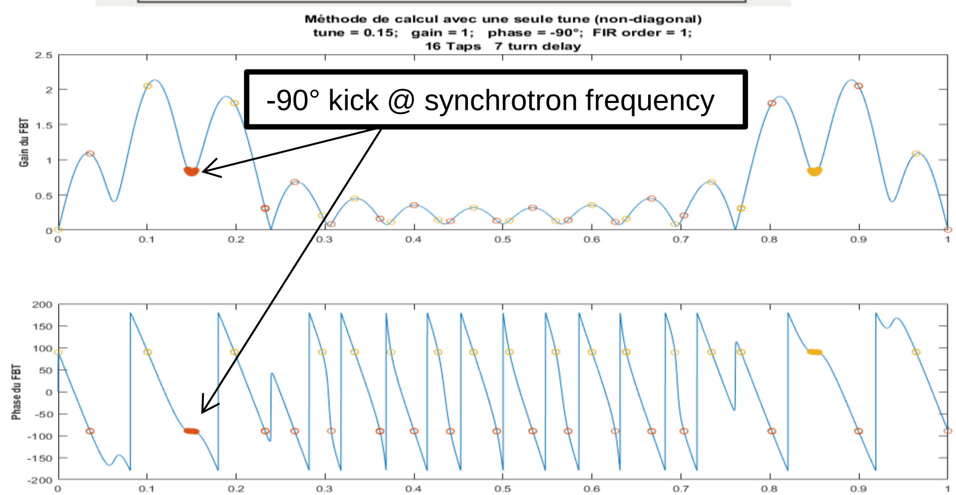


Red Pitaya board

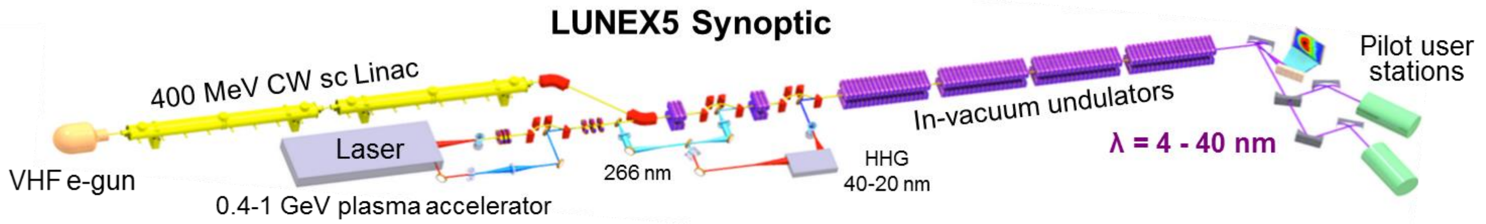




DSP to synchronize the RF on the beam phase.

Contribution to LUNEX5

Content



Phase 1 : based on a 400 MeV CW sc Linac → explore advanced FEL techniques and applications
Phase 2 : laser wakefield (or plasma) accelerator will be assessed in view of FEL applications

➢ **LUCRECE : program of R&D about RF technology for CW Linacs, with the aim to LUNEX5**
It is coordinated by SOLEIL, involves the CEA and CNRS labs as well as industrial partners, Thales, Alsyom and SigmaPhi Electronics (SPE) ; partly financed by the Region Ile-de-France

Objective : build an elementary (LUNEX5) RF assembly and test it in CryHoLab at CEA

- **A 1.3 GHz - 20 kW CW SSPA, using GaN transistors** ***[SOLEIL, SPE]***
- **A 1.3 GHz 9-cell sc cavity for CW operation, from the LCLS2 batch** ***[CEA, SOLEIL]***
- **A TTF3 type coupler, upgraded for P > 20 kW CW** ***[CNRS-LAL, Thales, SOLEIL]***
- **A digital LLRF system (10^{-4}, 0.01°), based on FPGA + CPLD + µC** ***[SOLEIL, CNRS-LAL]***
- **Tests of the assembly at 2K and 1.8K in CryHoLab** ***[CEA, SOLEIL]***
- **Cryomodule mechanical studies** ***[CEA, ALSYOM, SOLEIL]***
- **Time schedule : 2015 → 2019**

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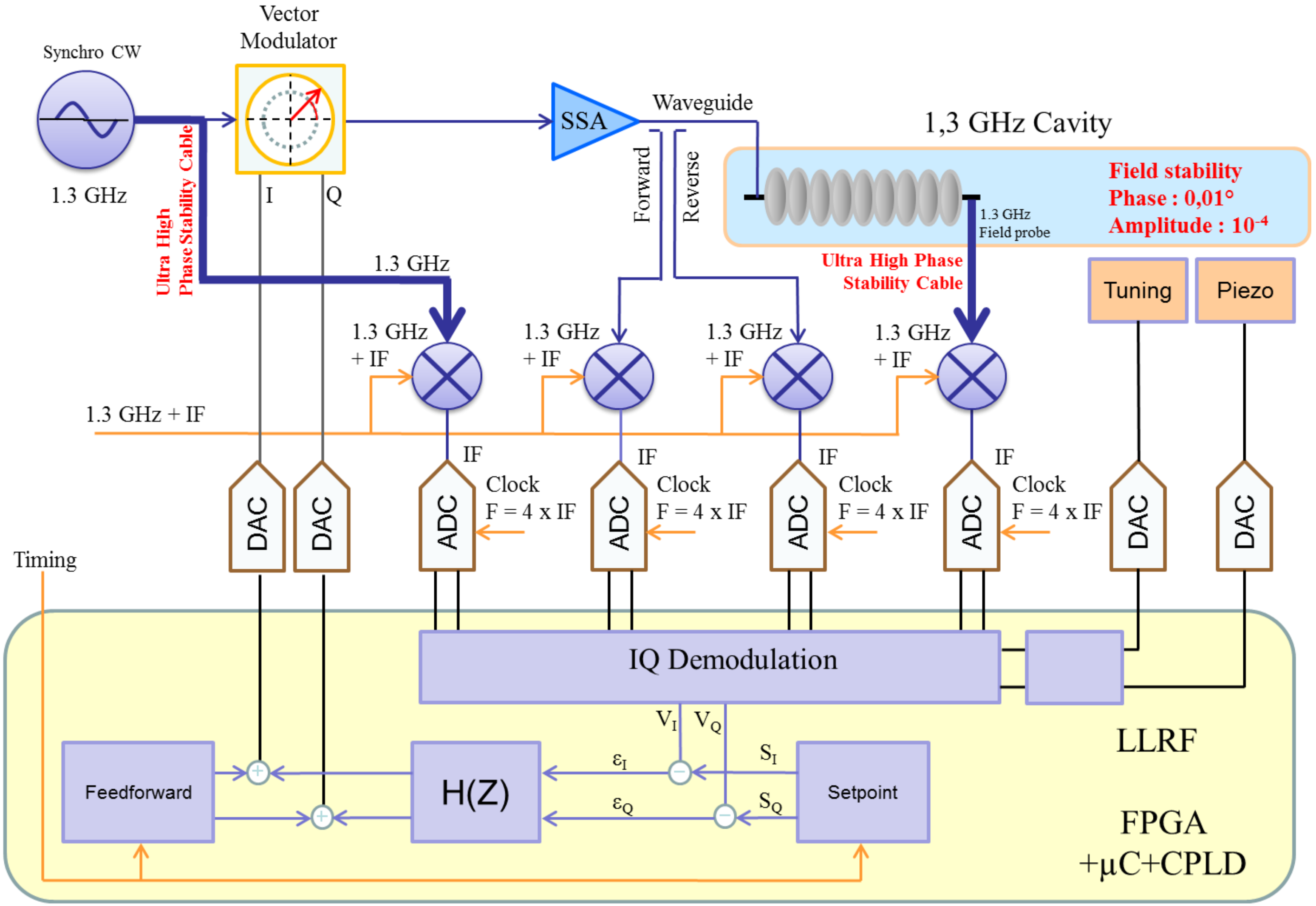

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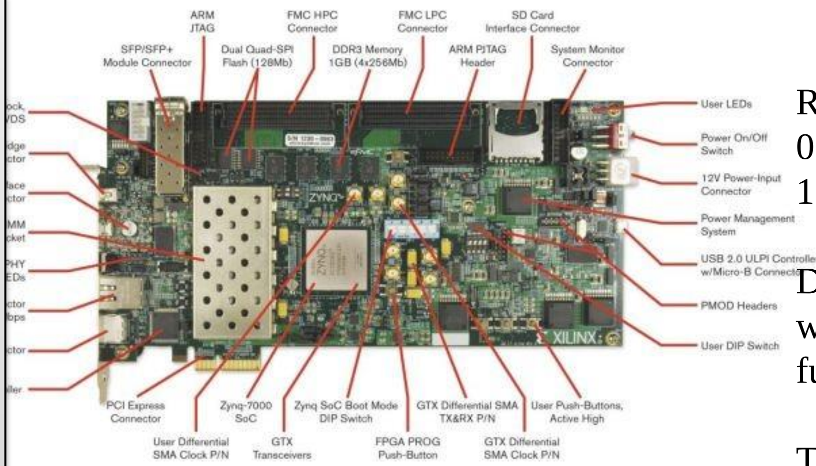
FPGA Xilinx SoC ZC706 (Zynq-7000) board



4 channel ADC FMC board (TECHWAY)

RF cavity field stability requirements are :
0.01 ° in phase and 10^{-4} in amplitude
1 LLRF + 1 SSA per cavity.

Digiatl LLRF based on IQ (or non-IQ) demodulation will give all the flexibility to implement different functionning modes (CW or pulsed).

The main caracteristic of ADCs and DACs are high bit resolution, good ratio signal-to-noise, low jitter and low latency in order to meet the required stability performance.

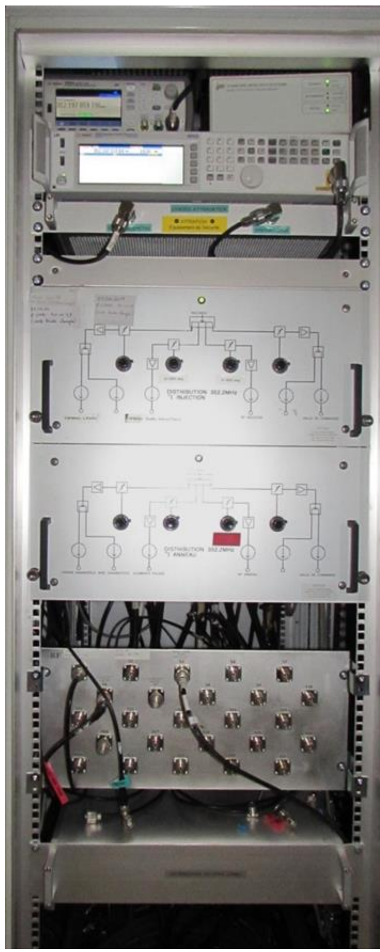
Complete LLRF design in collaboration with LAL (Orsay)

- R&D, components choice
- Components performance test
- Production of the complete system
- Test with the cavity

SOLEIL SYNCHROTRON

Original SOLEIL RF distribution

Content

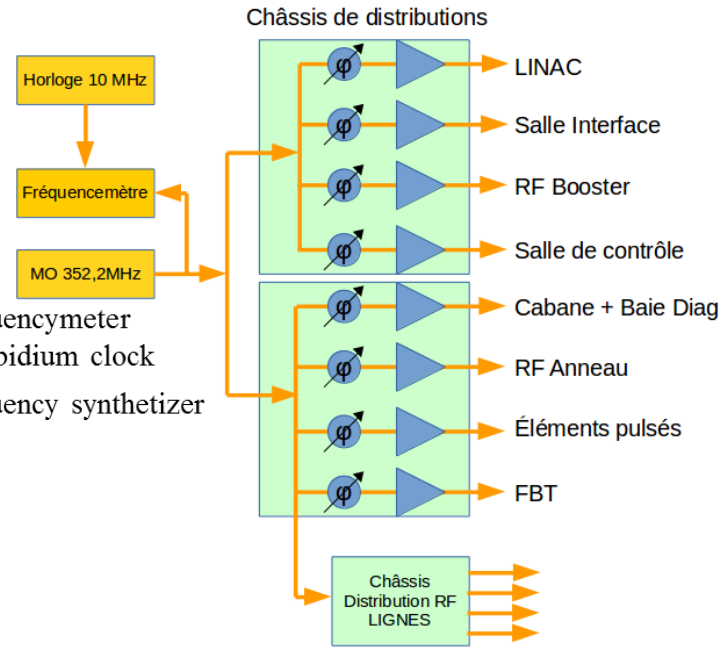


Frequencymeter + Rubidium clock

Frequency synthetizer

Machine RF distribution

RF distribution For users



RF distribution

- LINAC Amplifier failed
- R&S synthetizer screen out of order
- Agilent synthetizer error messages

Evolutions

- synthetizer replacement →R&S to Agilent (better phase noise)
- Frequencymeter added

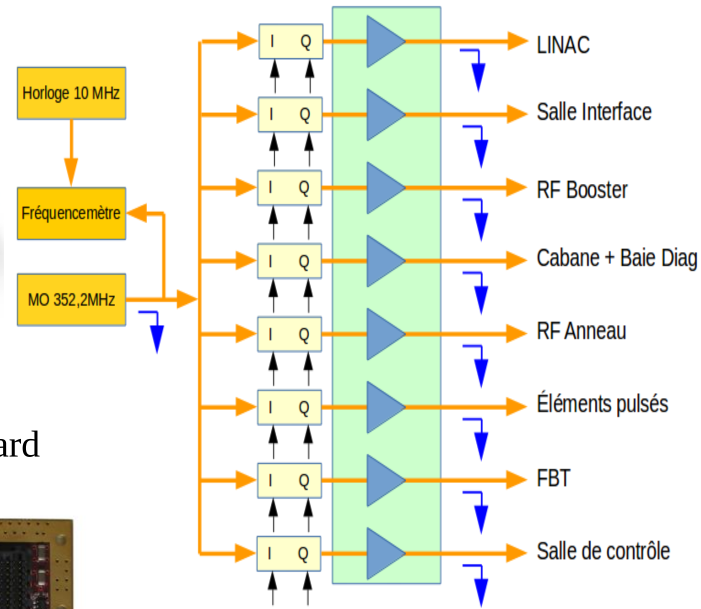
SOLEIL SYNCHROTRON

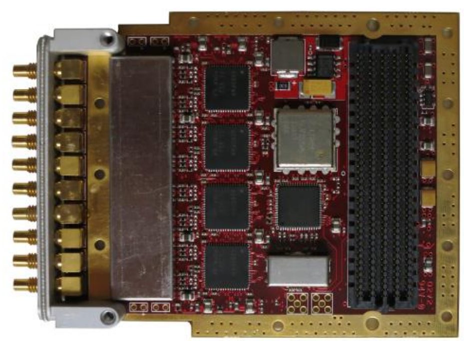
RF distribution evolution

Content

- Amplitude and phase measurement by using a direct non-IQ demodulation technich
- measurements are available on Tango device via Gigabit Ethernet IPBUS protocol
-Plan to implement anolog IQ modulators in order to setup the phase and amplitude of each line

FPGA Xilinx ML605 board





ADC FMC108
14 bits 8 channel up to 250 MHz

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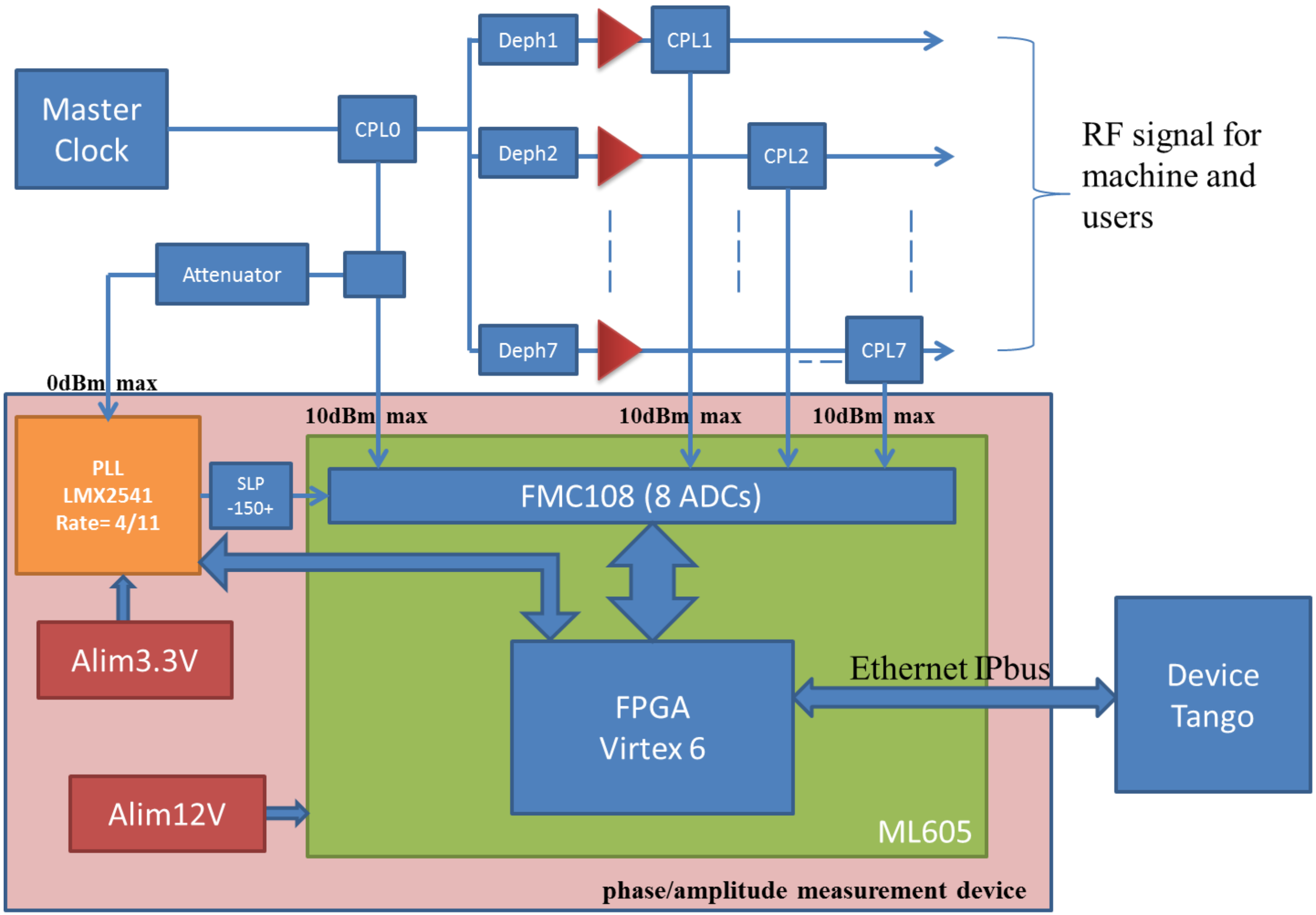
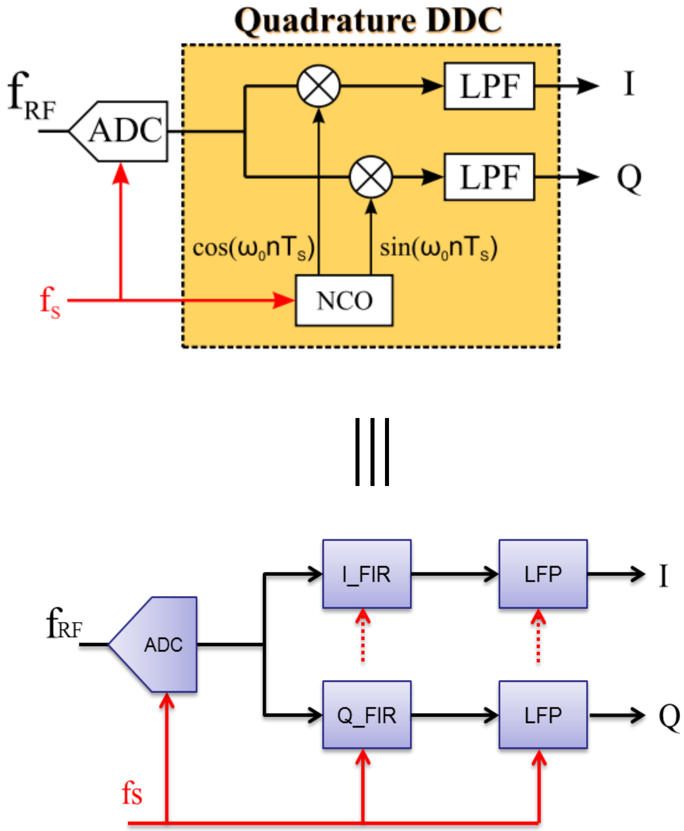


Digital non-IQ demodulation method

Content



$M \cdot f_{RF} = N \cdot fs$ $\quad\quad$ $\Delta\varphi = 2\Pi \cdot N/M$

We choose M=4 and N=11,

$fs = 4/11 * f_{RF} \sim 128$MHz

$$I = 2/M \sum_{i=0}^{M} yi \cdot \cos(i \cdot \Delta\varphi)$$

$$Q = 2/M \sum_{i=0}^{M} yi \cdot \sin(i \cdot \Delta\varphi)$$

Coef_FIR_I(i) $= \cos(i \cdot \Delta\varphi)$

Coef_FIR_Q(i) $= \sin(i \cdot \Delta\varphi)$

By down-sampling a RF signal, we can calculate precisely I and Q.
But you need few RF period instead of one with a classical IQ demodulation.

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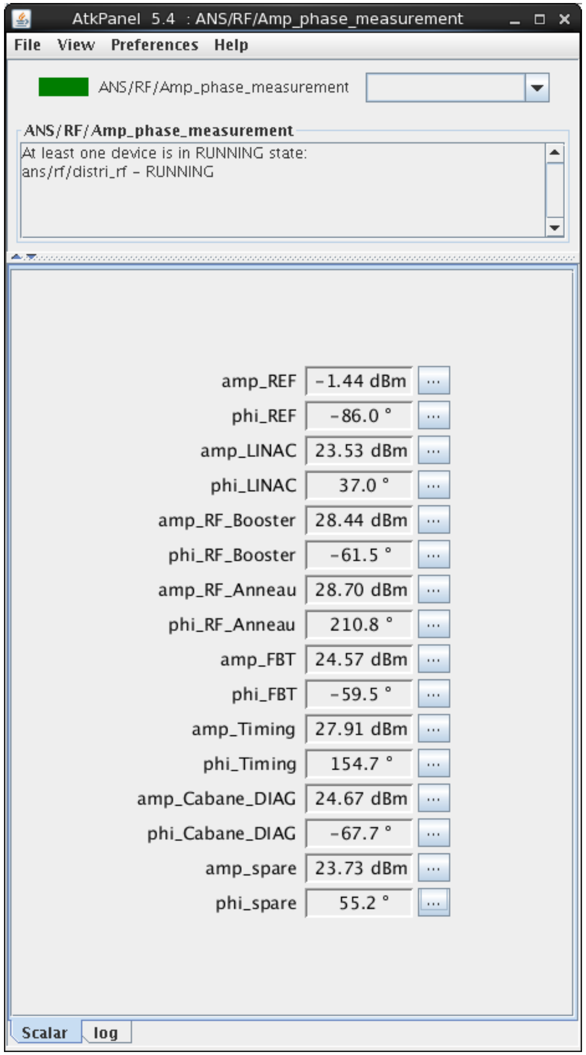

With this technic and with a mean on 128 values, the accuracy of the phase measurement is pretty good.

Rms phase = 0.05°
Rms amplitude = 0.02dBm

The measurement is efficient in a large dynamic range of RF signal level
=> -40dBm to 10dBm.

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New version of the SSPA Control

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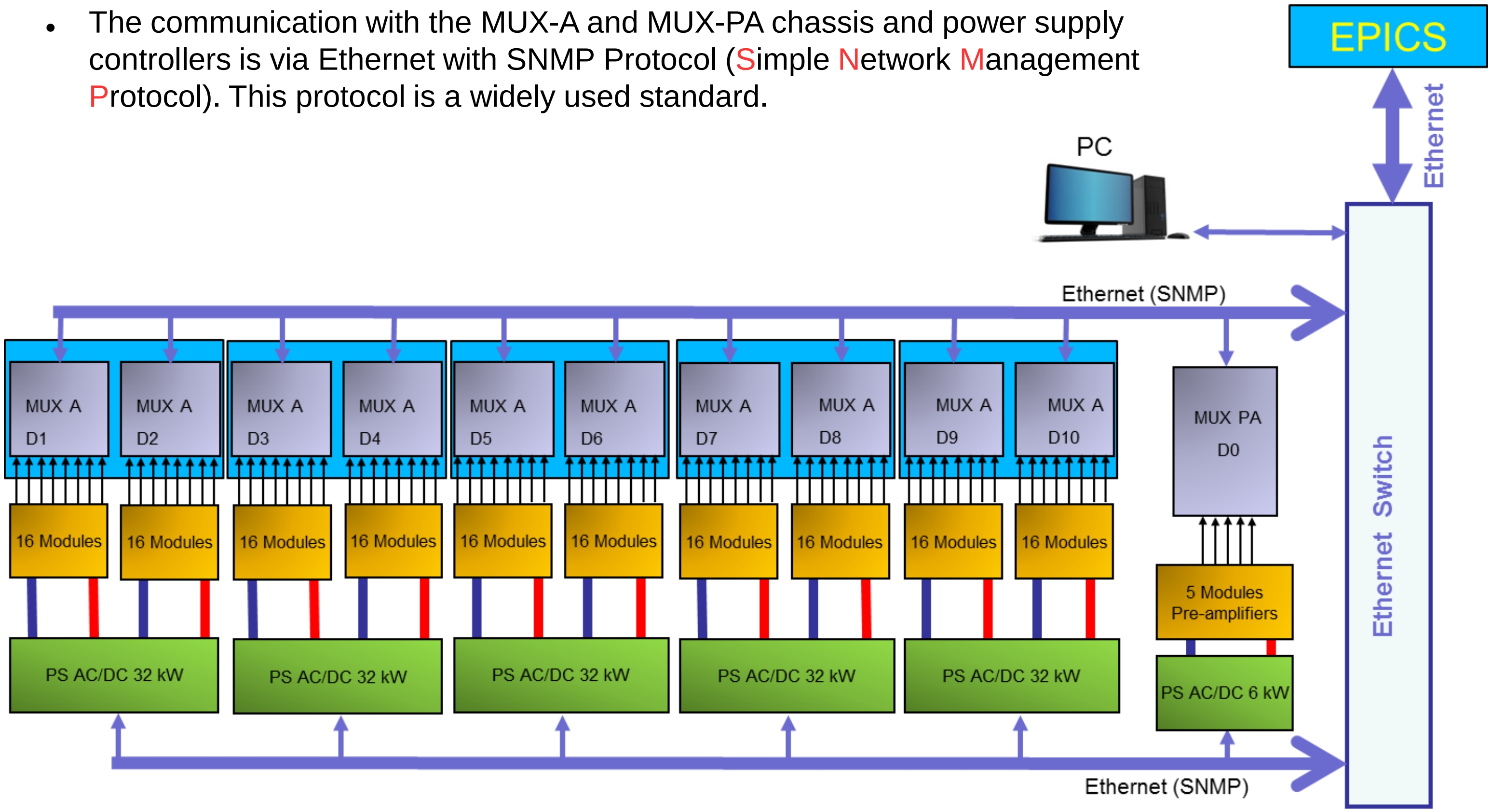
- Supervision of the amplifier is made with MUX chassis and power supply controllers. The MUX chassis is based with micro-controllers and CPLD.
- The communication with the MUX-A and MUX-PA chassis and power supply controllers is via Ethernet with SNMP Protocol (Simple Network Management Protocol). This protocol is a widely used standard.



New version used for SESAME and Thomx SSPA

MUX board architecture

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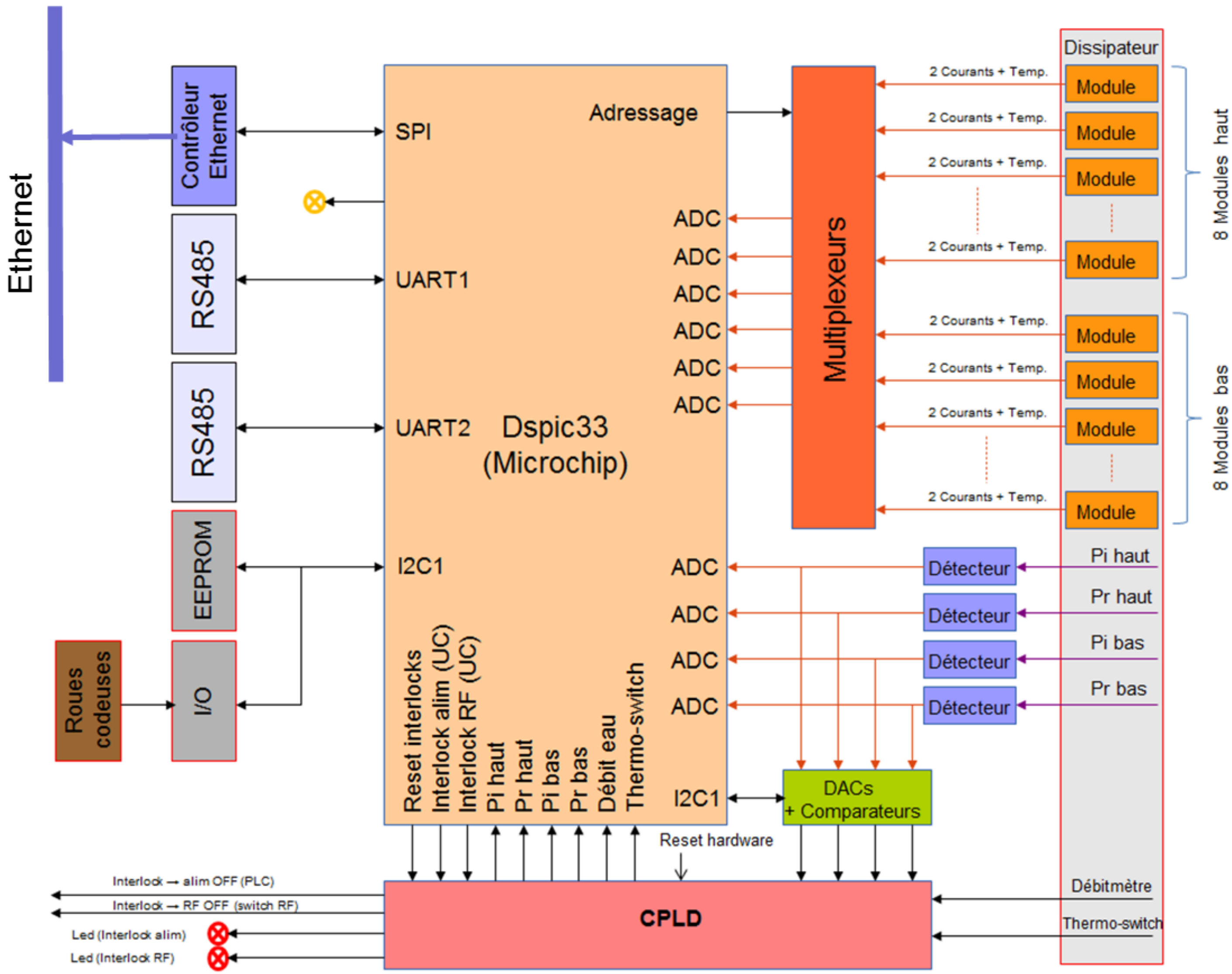

MUX-A & PA

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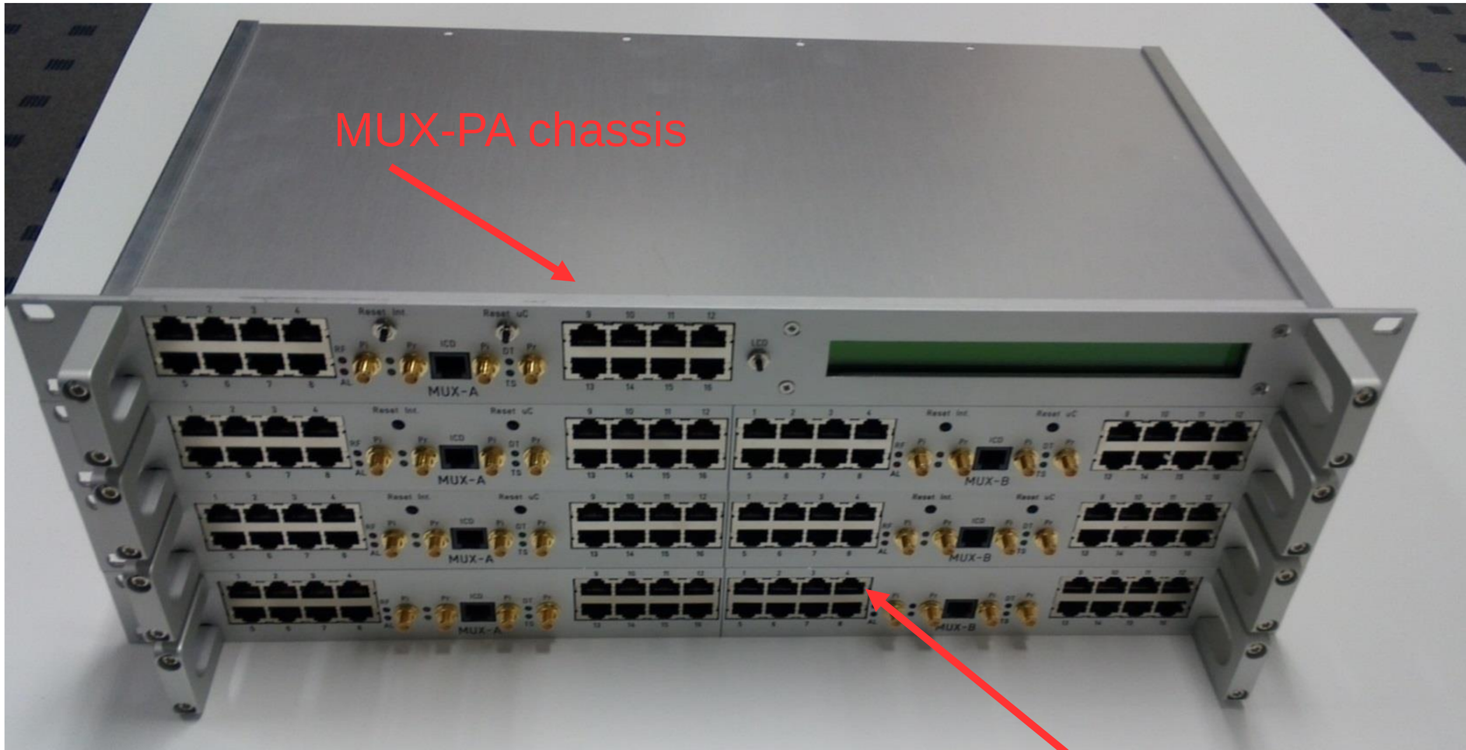


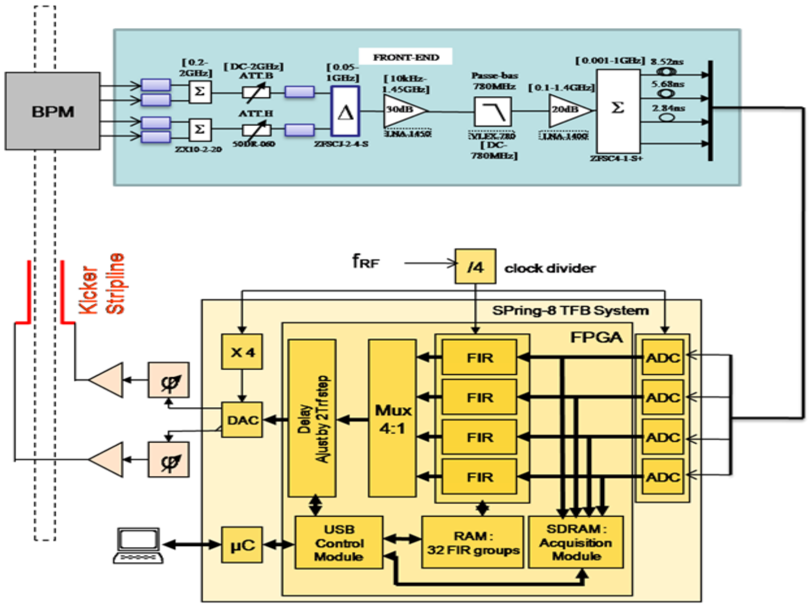
MUX-A chassis

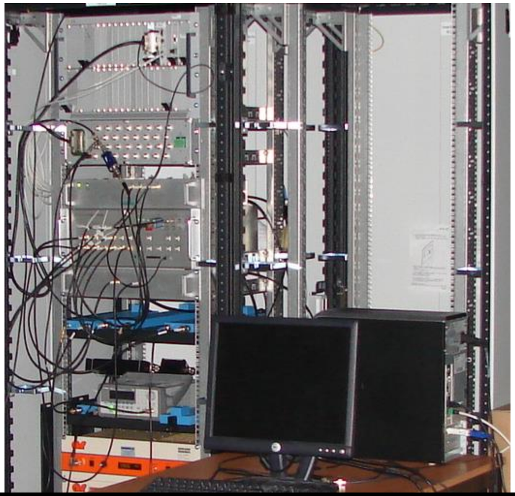
SOLEIL SYNCHROTRON

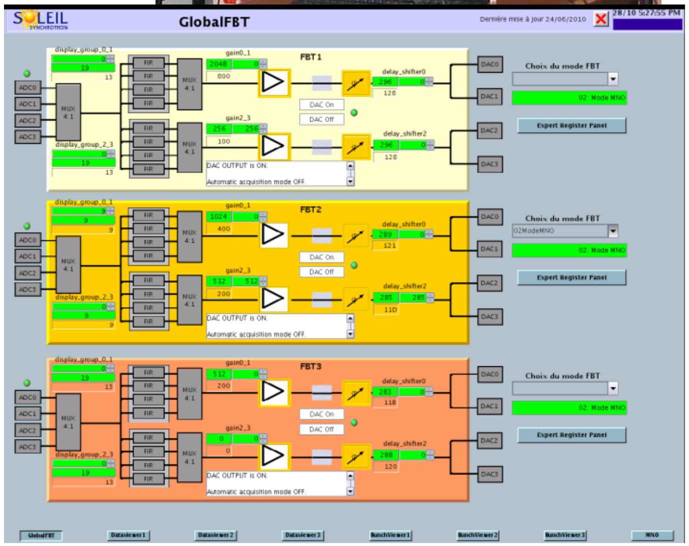
Transverse bunch by bunch feedback operation

Content

Main reasons : resistive wall, Fast Ion, TMCI (Transverse Mode Coupling Instability) in H and V plane







Collaboration with SPring-8

TED made the digital system

Digital feedback system upgrade

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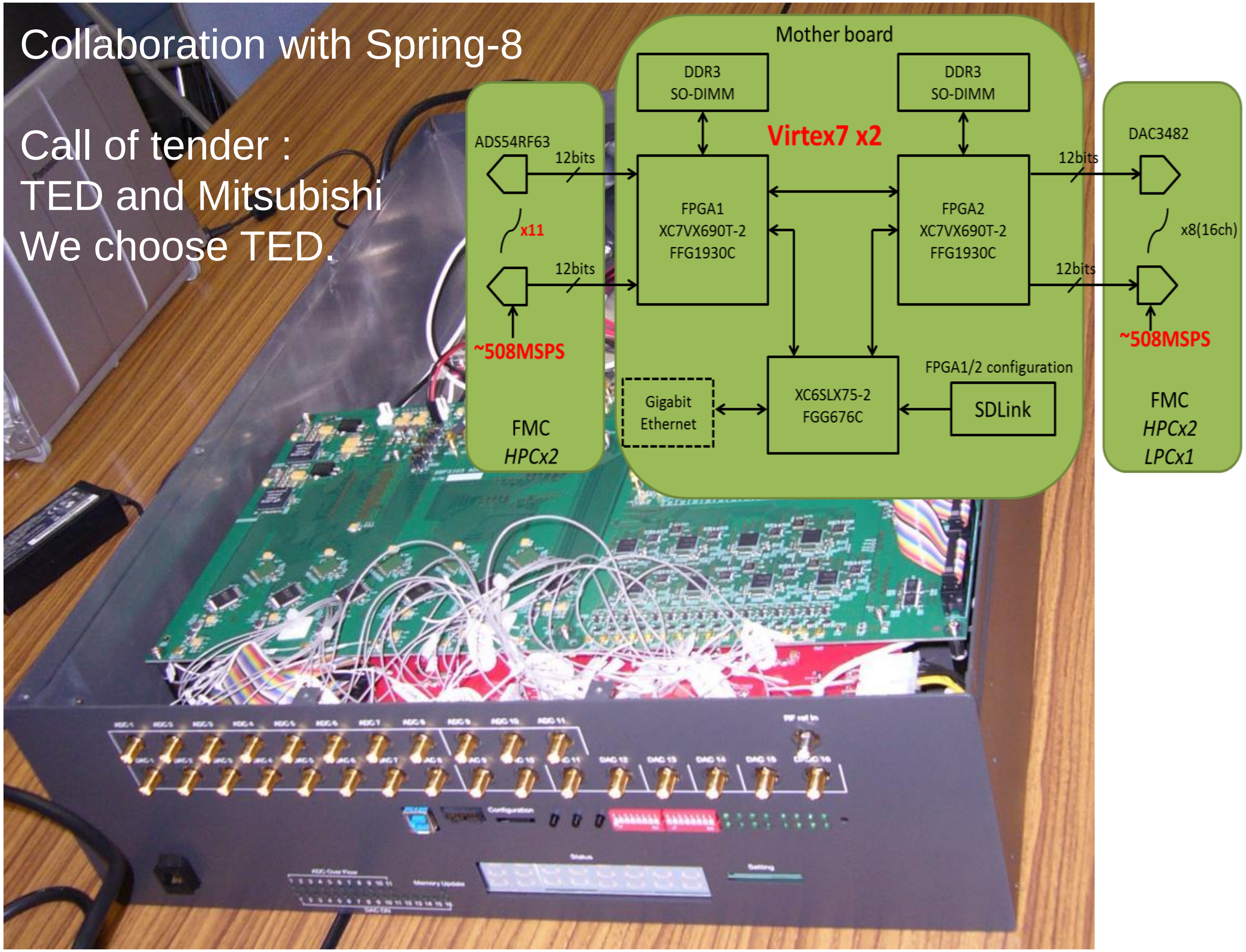


SOLEIL SYNCHROTRON

Digital feedback system upgrade

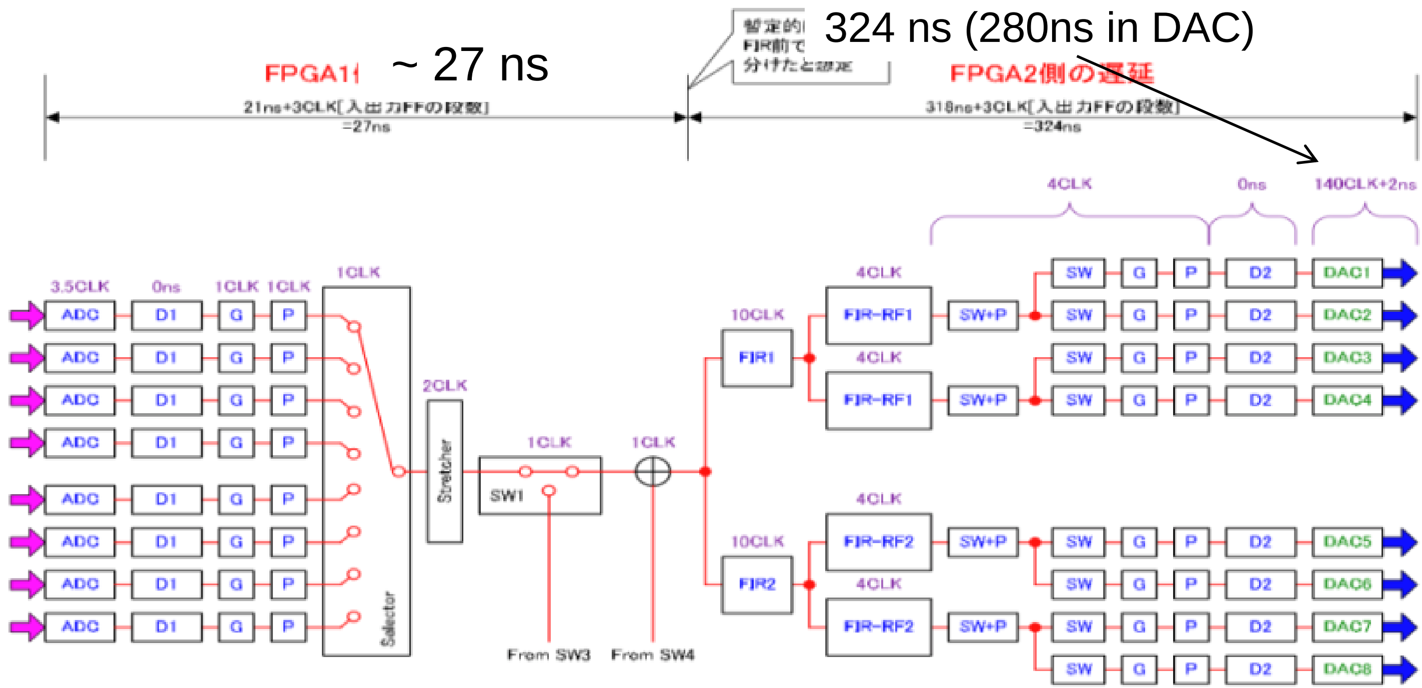
Content

Specifications: ~ 350 ns latency of the feedback processor including FIR filters

First prototype was tested

→But 280 ns in DAC due to integrate FIR that we can't bypass for the moment (not acceptable)

27 ns	**in**	**FPGA 1 (ADC data pre-process, ADC switcher)**
23 ns	**in**	**FPGA2 (FIR filters, DAC drivers)**



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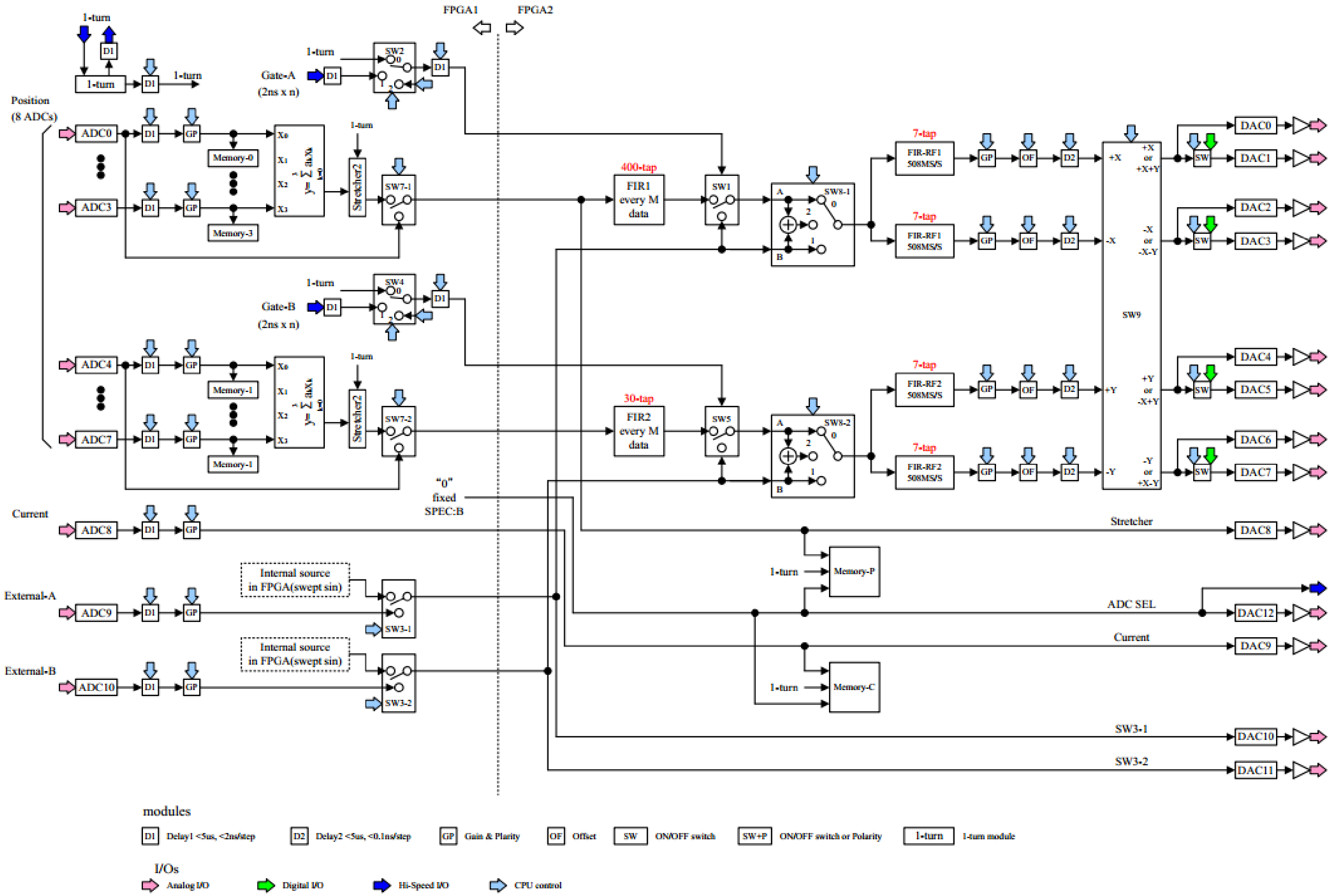


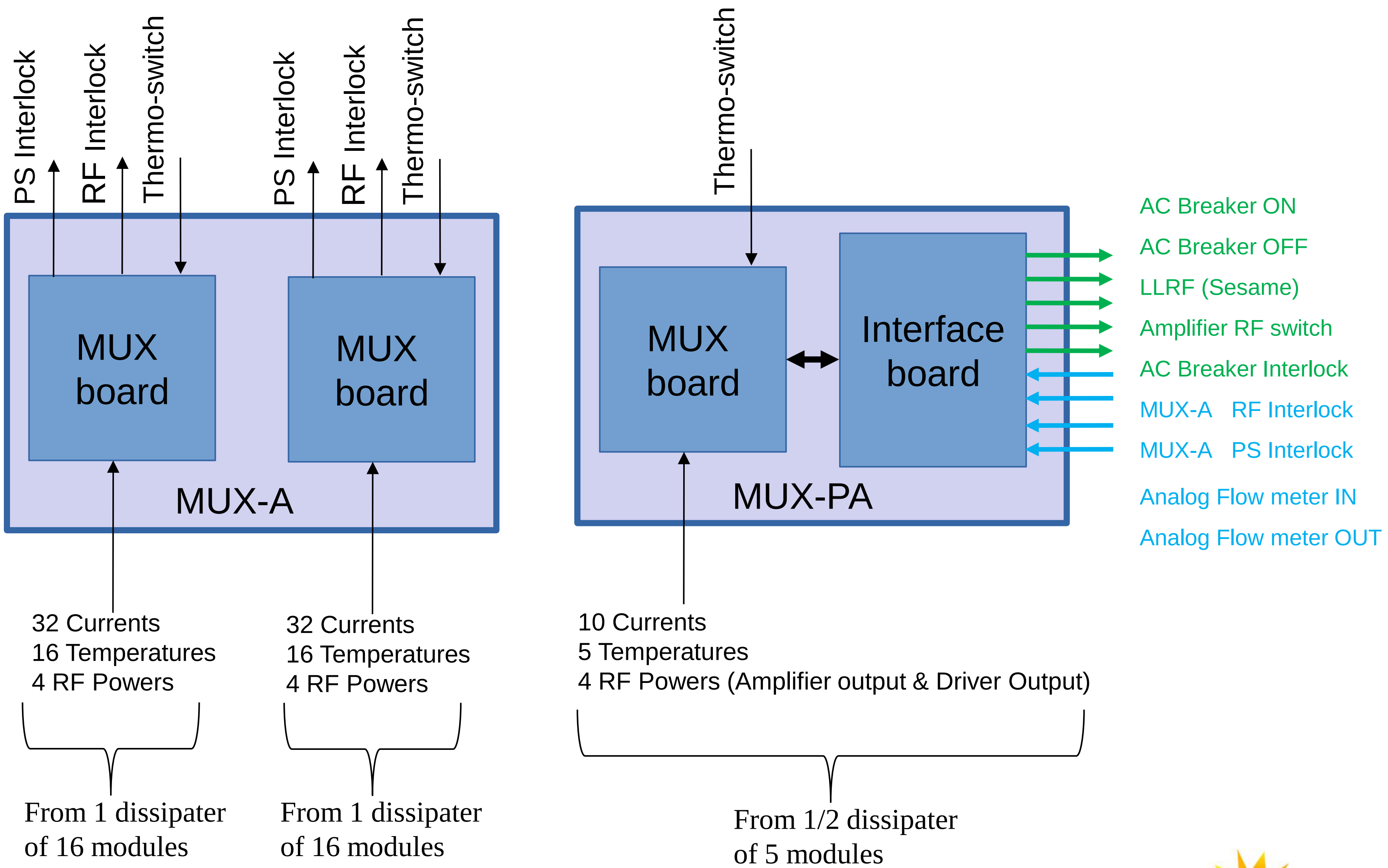
Conclusion

- New developments continue
- Many options to consider for the future
- µTCA-4
- Work to ensure the sustainability of systems and components
- Need to be trained and get some experience with Zynq technology

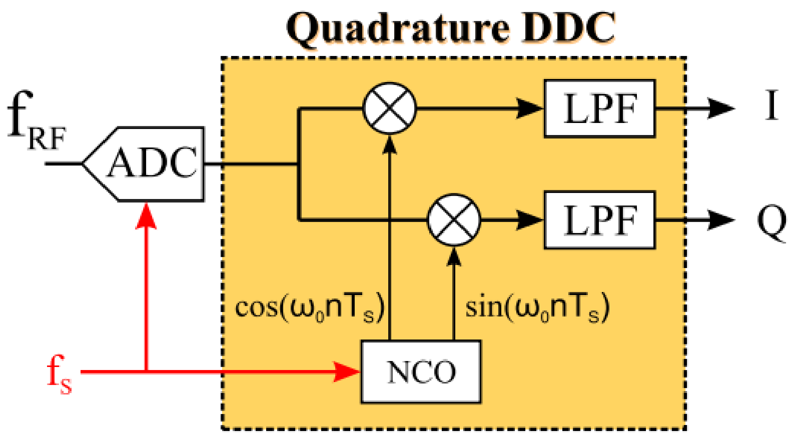
Questions?

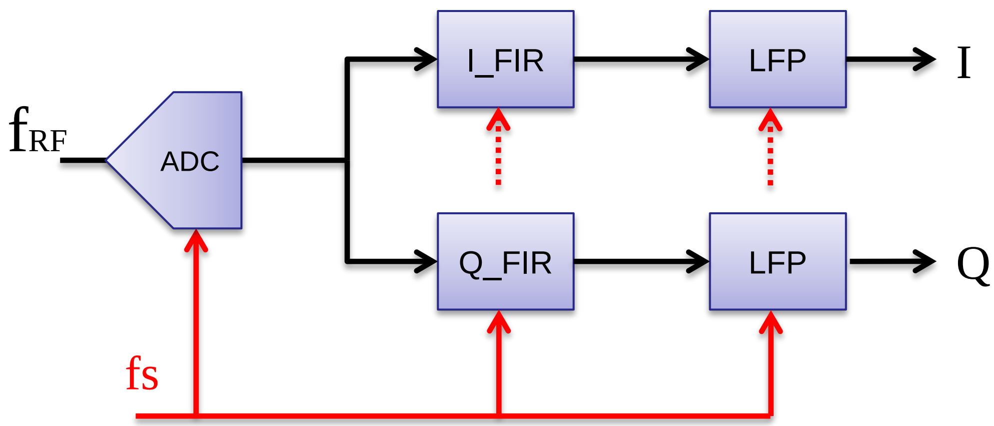
SOLEIL SYNCHROTRON

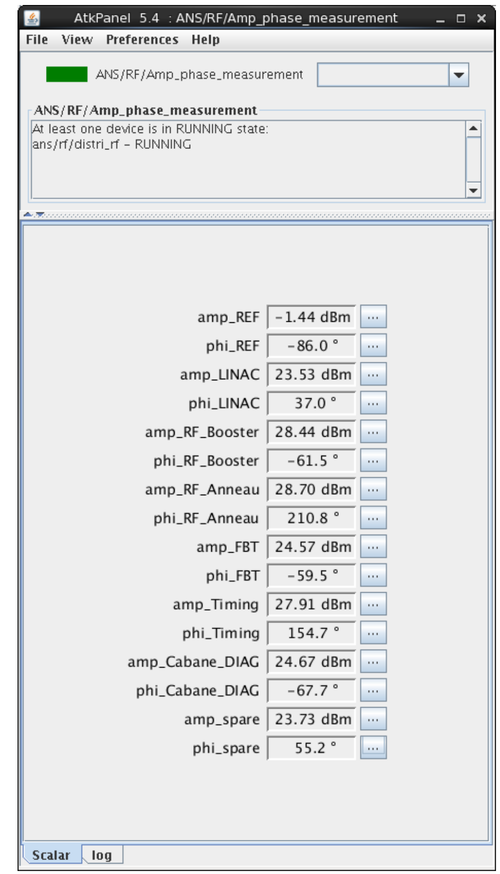
MUX-A & PA architectures



Phase rms (0.05°)

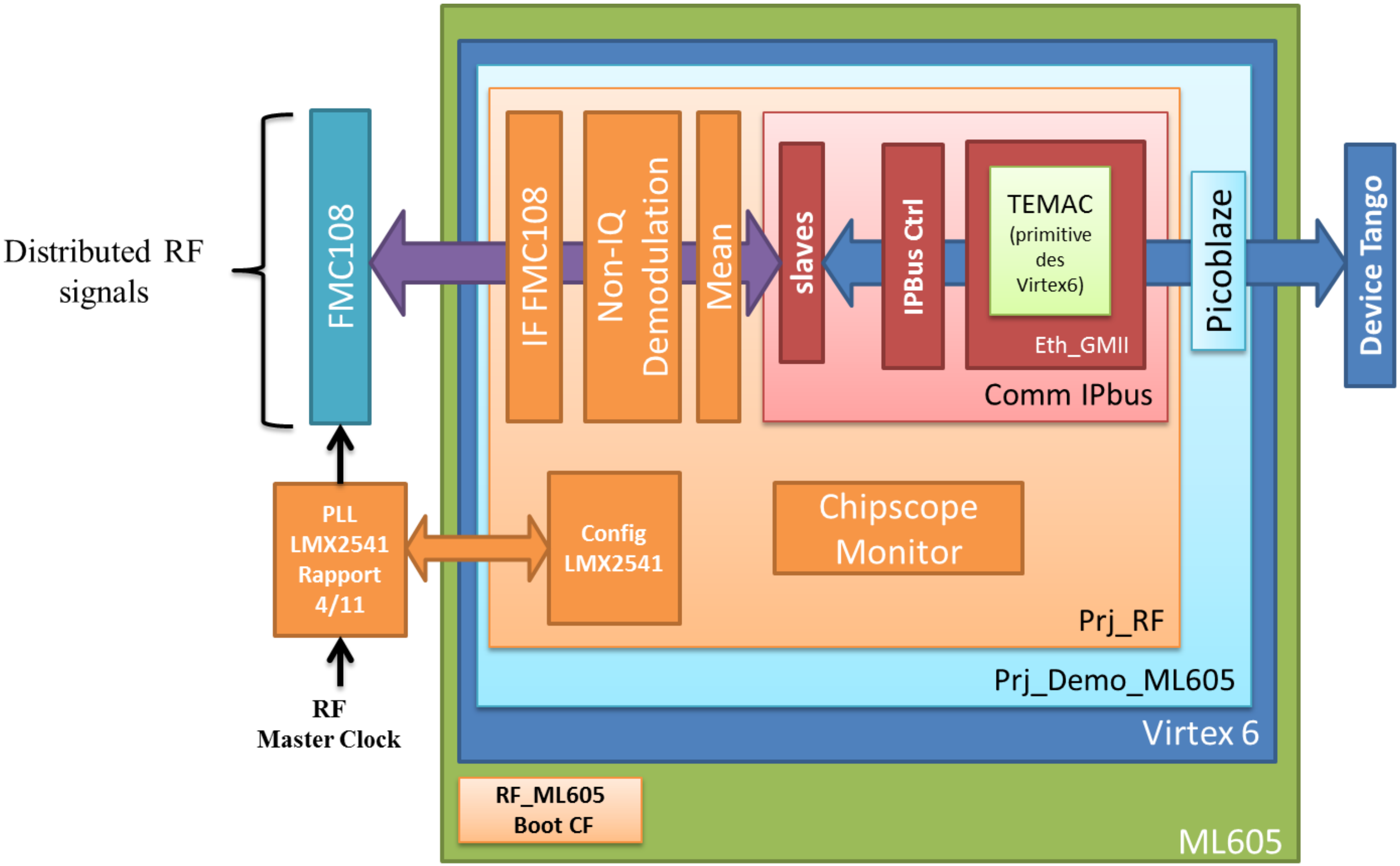






RF distribution evolution

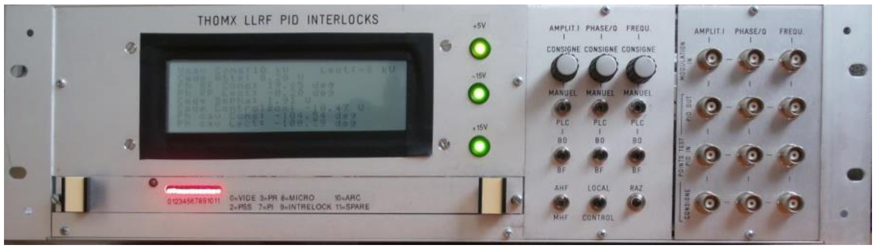
Content



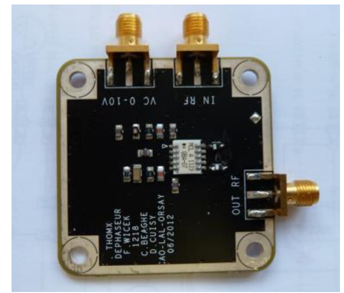
ThomX LLRF equipments

SOLEIL and LAL-CNRS collaboration for the hardware design

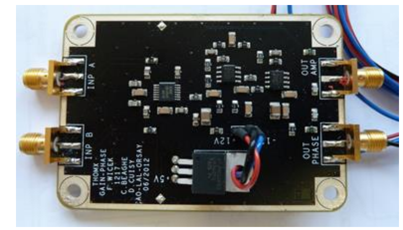
- ✓ **F. Wicek (LAL Orsay** Electric Instrumentation Group leader**)**
- ✓ **M. El Khaldi (LAL Orsay** Accelerator Departement**)**



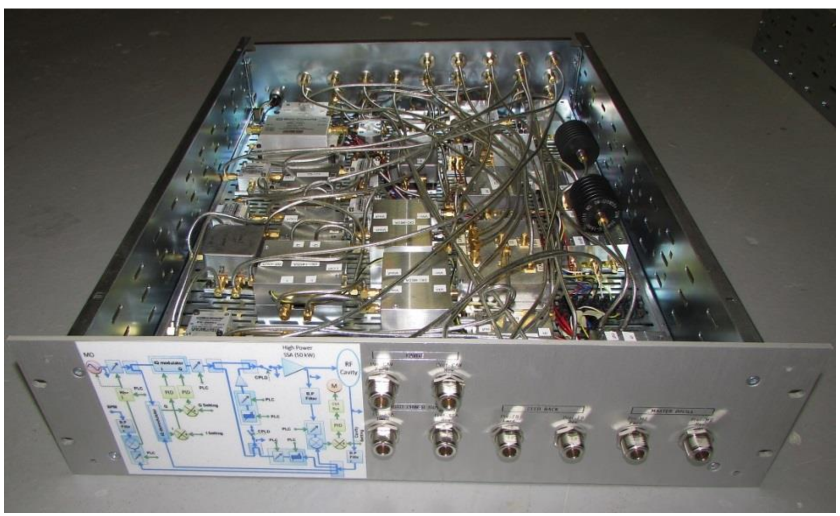
Chassis Interlocks et asservissements



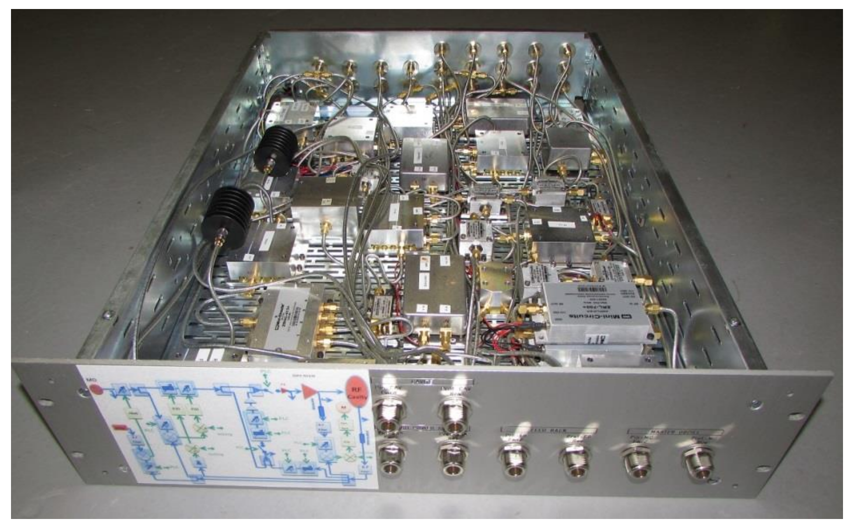
Déphaseur 500MHz



Comparateur de phase



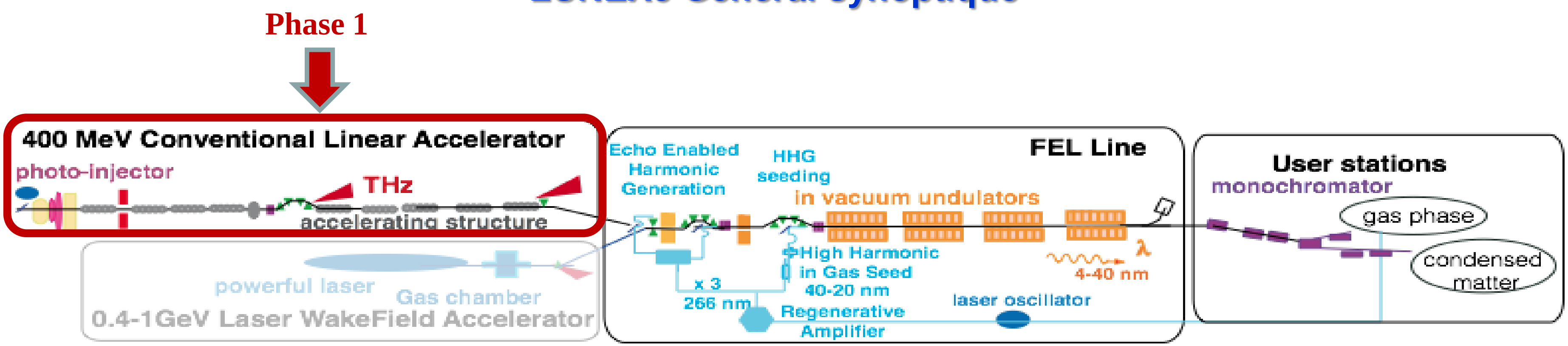
Chassis RF IQ



Chassis RF Amplitude et phase

RF systems for LUNEX5

LUNEX5 General synoptique



- **<u>Phase 1</u>:** Advanced fourth generation (4G+) light sources via the latest free electron laser seeding schemes and electron photon interaction
- <u>Phase 2</u>: Fifth generation (5G) light source => Conventional Linac replaced by a Laser WakeField Accelerator, FEL being viewed as a qualifying LWFA application

- **400 MeV conventional LINAC (phase 1)**
  - *2 x 200 MeV E-XFEL cryomodules of 12 m with CW cavities*
  - *One RF power amplifier for each cavity → 16 x 16 kW @ 1.3 GHz (not the most economical but the best way for achieving the required cavity field stability)*
  - *LLRF system (0.01° in phase and 10^{-4} in amplitude) with its associated synchronization part*

SOLEIL SYNCHROTRON

LUCRECE project

<u>OBJECTIVE</u>: First step in the superconducting LINAC R&D for **LUNEX5**, LUCRECE aims at developping a complete RF elementary cell (cavity, power source, LLRF and control) adapted to **<u>CW operation</u>** to be used for ERLs or fs multi-user FEL at high repetition rate

Detail:

- TESLA type superconducting cavity @ 1.3 GHz with its associated parts (tuners, fundamental power couplers and HOMs, Helium manifold) adapted for CW operation
- 20 kW Solid State Power Amplifier @ 1.3 GHz based on SOLEIL design and with new generation Gallium Nitride transistors (mandatory for high frequency purpose)
- Versatile digital LLRF to ensure different operation modes

Integrated tests (complete cavity, amplifier and LLRF) in CryHoLab at CEA

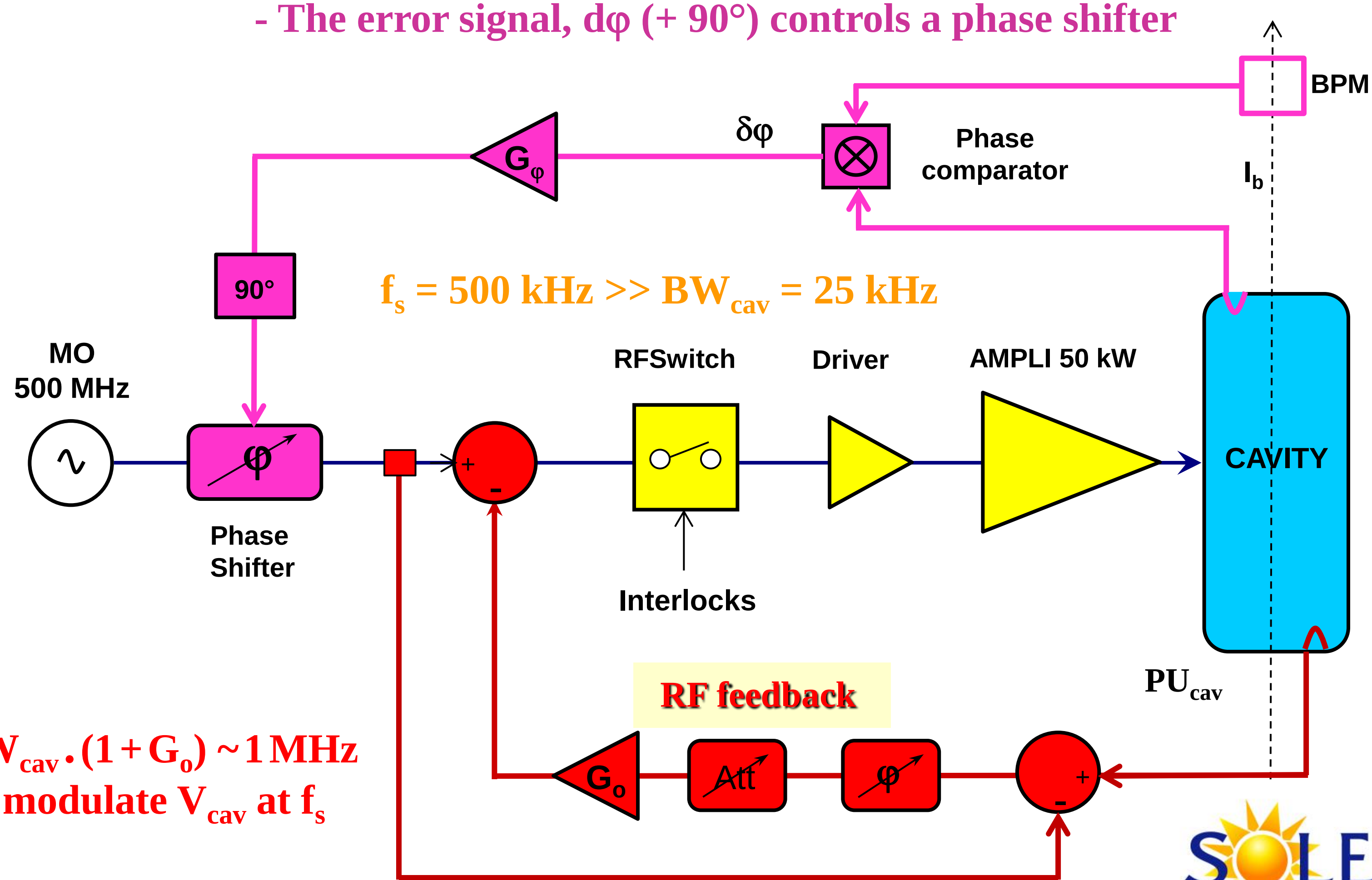
SOLEIL SYNCHROTRON

Back up - ThomX longitudinal feedback (LFB)

LFB = direct RF FB + Phase loop

Phase loop (BW > f_s) :

- Phase comparison between V_c (PU cav) & I_b (BPM)
- The error signal, dφ (+ 90°) controls a phase shifter



RF FB → $BW_{cav}.(1+G_o) \sim 1\,MHz$
→ One can modulate V_{cav} at f_s