SOLEIL RF group activities

- SOLEIL RF systems
- SOLEIL Input Power Coupler (IPC) upgrade
- R&D on Solid State Amplifiers
- R&D on digital feedback system

Rajesh SREEDHARAN
on behalf of the SOLEIL RF-LINAC group

SOLEIL SYNCHROTRON

SOLEIL storage ring main parameters

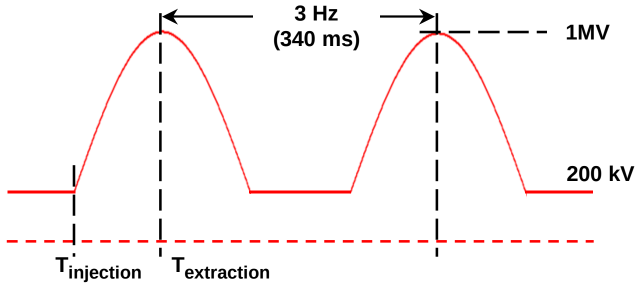
	2 cryomodules
RF frequency (MHz)	352.202
Harmonic number	416
Nominal energy (GeV)	2.75
Energy loss per turn (keV)	1150
Momentum compaction factor	$4.38\ 10^{-4}$
Energy damping parameter, D	$6.88\ 10^{-4}$
Cavity loaded quality factor	10^{5}
R/Q per cavity (Ohm)	45
Beam current (mA)	500
Total cavity voltage (MV)	4 (3)
Synchronous phase (°)	73.6

SOLEIL SYNCHROTRON

SOLEIL RF systems

❖ BOOSTER

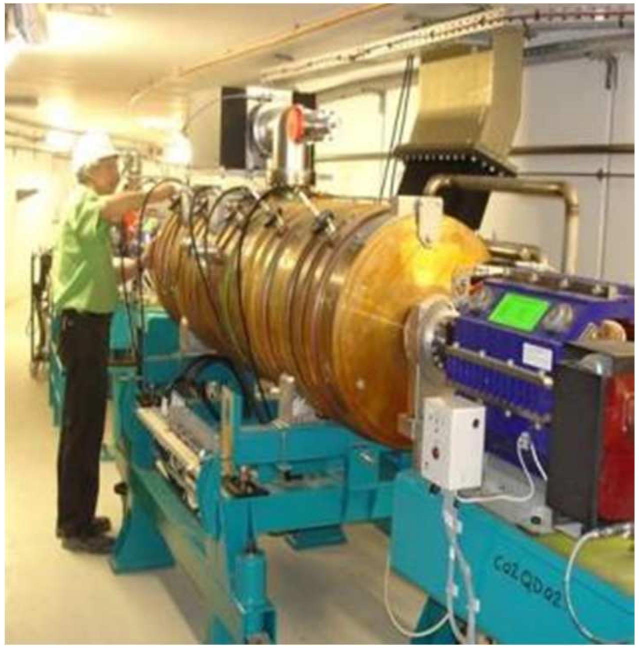
➢ 3 Hz RF ramping



Power balance

- $P_{dissipated}$: 20 kW
- P_{beam} : 5 kW
- P_{total} : 25 kW

35 kW Solid State Amplifier & LLRF



5-cell LEP type cavity

SOLEIL RF systems

❖ 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

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Possible upgrades of our cryogenic system

- **3rd consecutive year without any incidence on the operation due to cryogenic system itself**
- **Pb : few downtimes due to utilities cut off → long restart time**
- **Recovery compressor (identical to the main one) installed since mid 2010, but is operational since 2013→(redundancy and maintenance)**
- **CMs filling procedure has been optimized to reduce the starting time (between 3 and 6 hours)**

- **Consulting on « He liquefier » by G. Gistau, at SOLEIL, 25-28/03/2013**

- **Upgrade of the autonomy →**
  - **Increase of LHe DEWAR capacity**
  - **Increase of GHe storage capacity**
  - **Redundancy on compressor's cooling water (17°C)**

SSA Operation

- ≈ **40000 hours running for A1 and A2 (CM1)**
- ≈ **30000 hours running for A3 and A4 (CM2)**
- Actual module failure rate ~ 2% per year

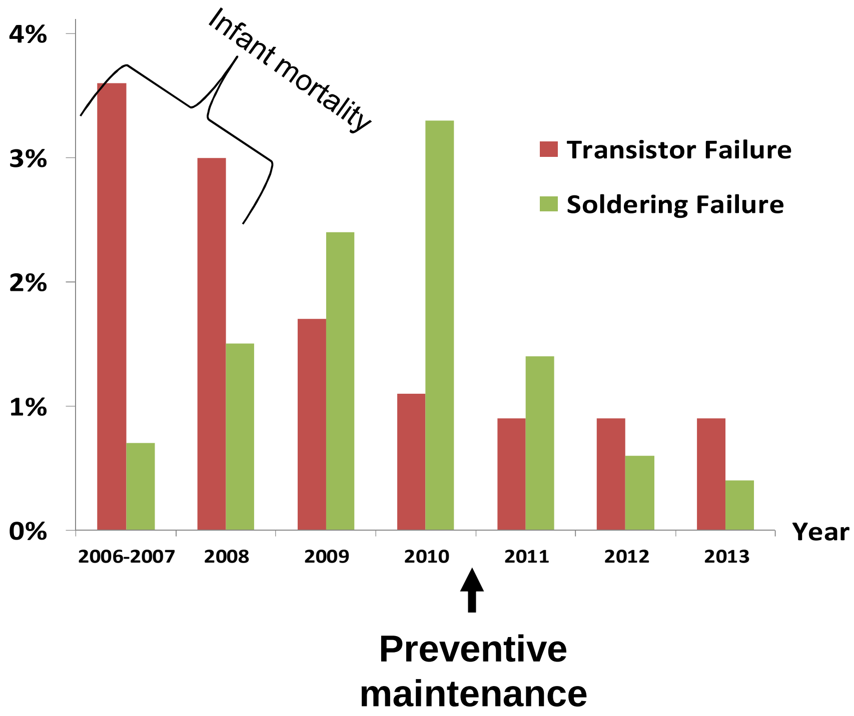
Repair of faulty modules : - transistor substitution (0.6%)
- re-soldering (1.4 %)

None of these failures has impacted the operation (modularity & redundancy)

→ ~100% operational availability (MTBF>1year)

Upgrade

- BLF574XR (NXP) tested and validated in 2011-2012 (~4000 hours)
- 2013: Substitution of LR301 transistor to BLF574XR for only drivers (160 modules for 4 SSAs)
- From 2014: Replacement of all LR301 transistors (1-2 towers per year)



Why SSA upgrade at SOLEIL?

- **Better performance, easier maintenance, cost investment and amortization (within less than 4 years)**
  - More robust transistors
  - Transistor higher power capability => optional operation with 3 amplifiers out of 4 at full beam current (500mA)
  - Lower gain and phase dispersion (+/-0,2dB and +/-5° instead of +/-1,5dB and +/-7,5°) by inserting adjustable component in the input circuit => higher power and efficiency
  - Transistor supply made easier (NXP)
  - Old PCB re-used and only transistors are changed => less than 10% of the amplifier cost
  - 6% increase in module efficiency + less modules (higher G) + lower G and Φ dispersion
=> higher overall efficiency => electrical power savings
=> compensation for upgrade costs within less than 4 years
  - Low failure rate → savings in maintenance cost

At the beginning, we thought about replacing only the damaged modules with new transistors. However the much better performance and cost advantages made us change our strategy for a controlled and planned massive upgrade.

Why SSA upgrade at SOLEIL?

Summary table of previous slide

Parameters	LR301	BLF574XR	Benefits of BLF574XR
P_{nom}	315 W	330 W	more powerful
P_{max}	330 W	450 W	
Gain	13.5	20	less preamplifiers
Efficiency	62 %	68 %	better efficiency
Gain spread	± 0.8 dB	± 0.2 dB	no sorting
Phase spread	± 7.5°	± 2.5°	better combining efficiency
T_{max}	130 ℃	80 ℃	less thermal stress

SOLEIL R&D on SSA

- After 6 years of operation, SSA innovative design has proved itself and demonstrated that it is an **attractive alternative to the vacuum tube amplifiers**, featuring an outstanding reliability and a MTBF > 1 year.

- **Advantages of SOLEIL SSA:** low phase noise, good linearity, high reliability, long life time, easy maintenance, simple spare parts, no HV, no X ray.

- Thanks to the acquired expertise and the arrival of the 6^{th} generation LDMOS, SOLEIL has carried out developments which led to doubling the power of the elementary module (650 W) while improving the performance in terms of gain, linearity, efficiency and thermal stress.

- **New projects:**
  - Now 500 MHz amplifier based on this technology are being built for **ThomX** (50 kW) and **SESAME** (140 kW) projects.
  - *Study for new frequencies:* 1.3 GHz for **LUNEX5** (20kW) and 176 MHz for **MYRRHA** (180 kW)

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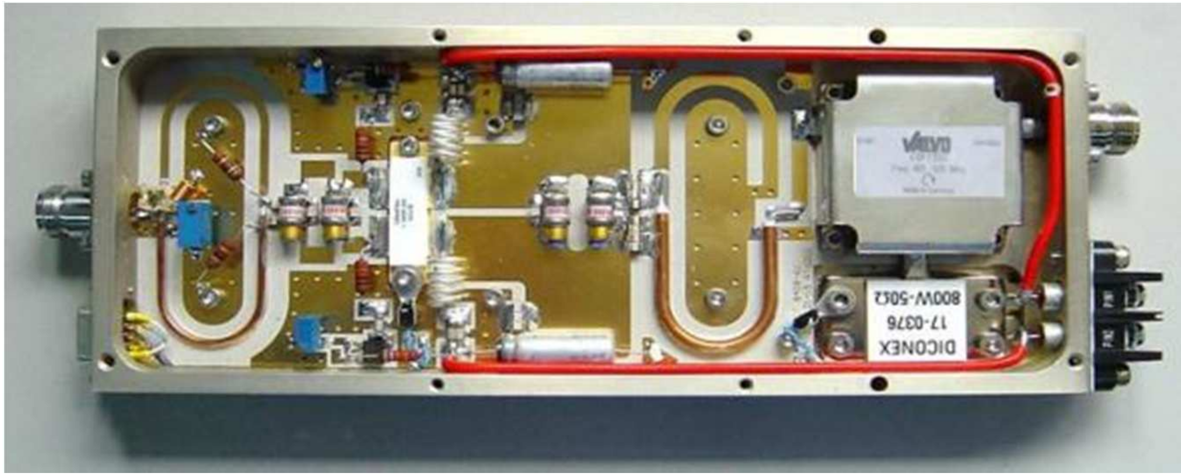
500MHz SSA R&D

6th generation LDMOS → BLF578 : 650 W modules



650W CW - 500 MHz amplifier module

High efficiency (96%) 220 V_ac / 50 V_dc power converters

500MHz SSA R&D

10 kW unit prototype for long term test (> 5000 hours until now)

Efficiency > 55%

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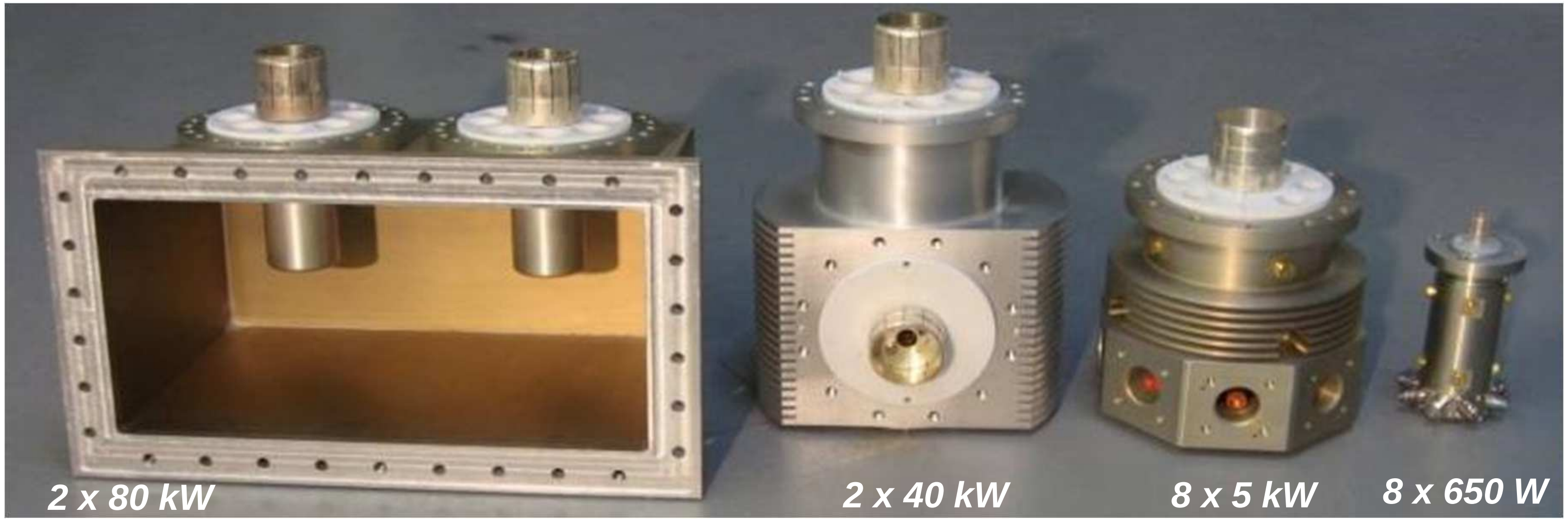
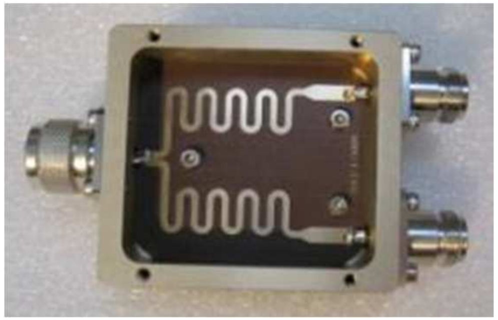
500MHz SSA R&D

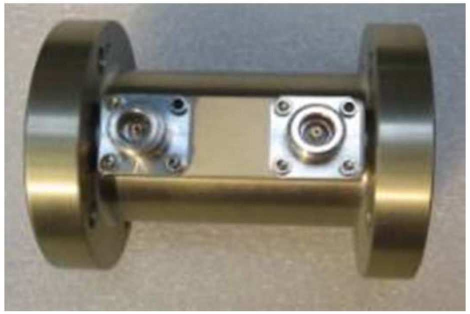
Power combination components





2-way splitter

8-way splitter



P_i - P_r monitoring coupler

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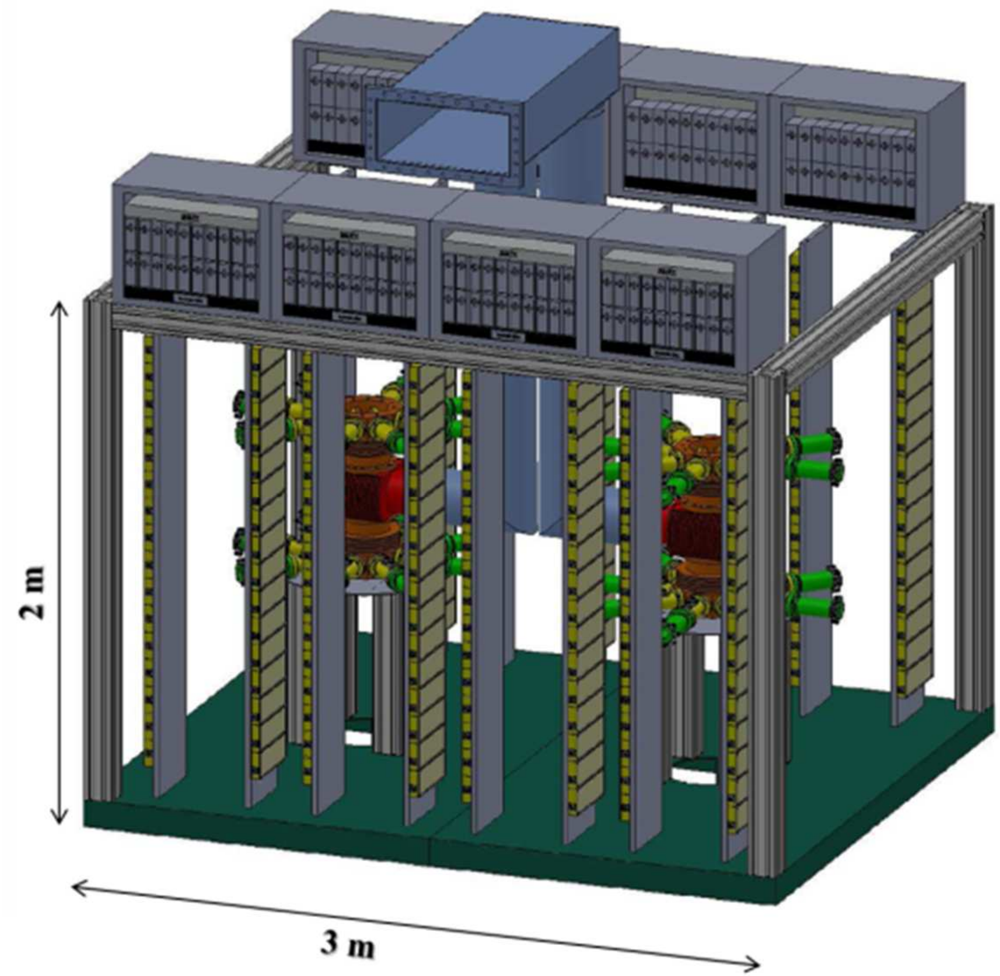
SESAME 500MHz 140kW SSA design



- AC-DC Power Supplies (160 x 2kW modules)
- 1 Waveguide Combiner (WaCCo)
- 2 x 75 kW RF combination
- 64 8-way splitters
- 16 dissipators
- 256 amplifier modules

Alternative for SESAME phase 1:
4 x 80kW SSA (10 dissipators of 16 modules)

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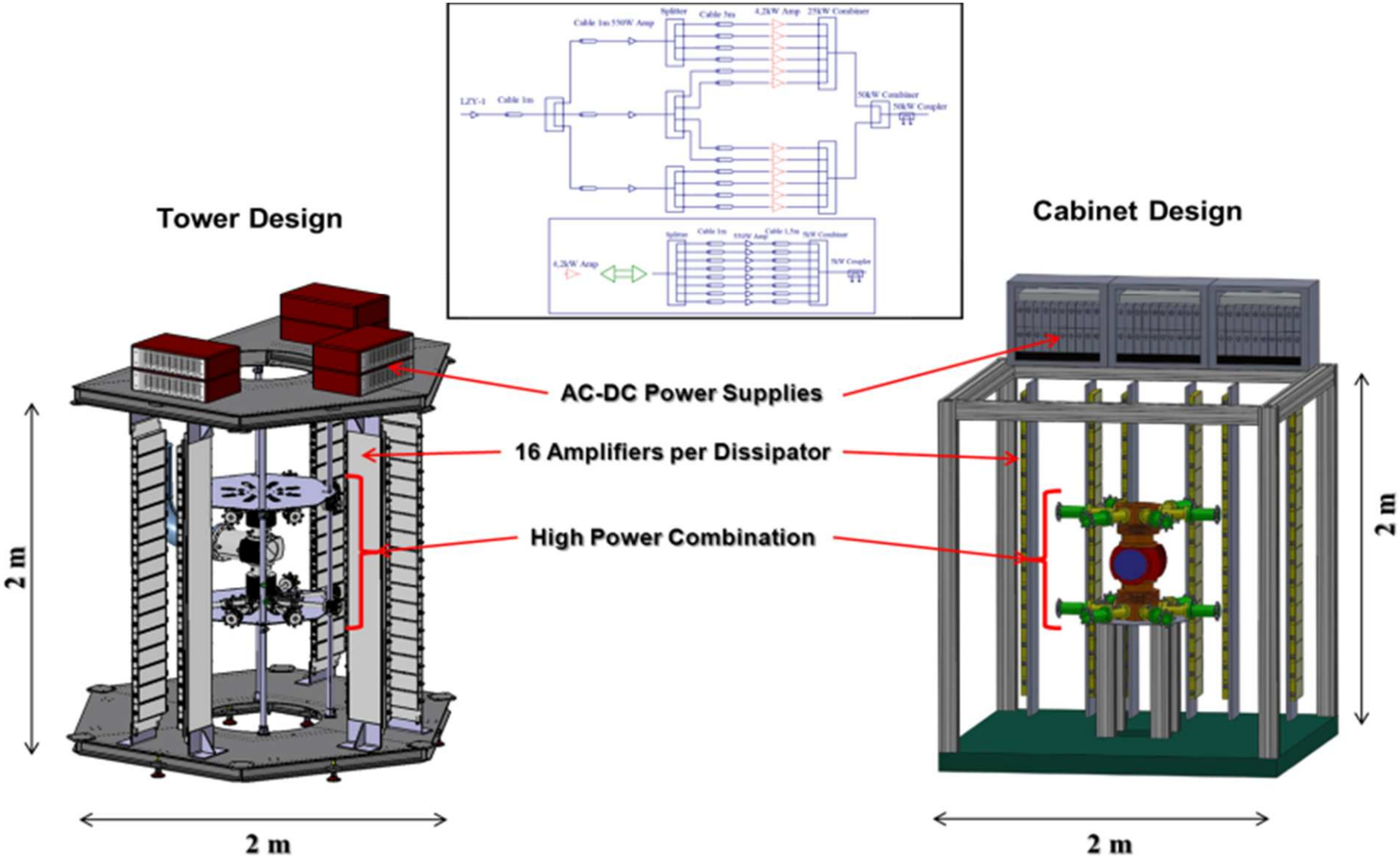
ThomX 500MHz 50kW SSA design

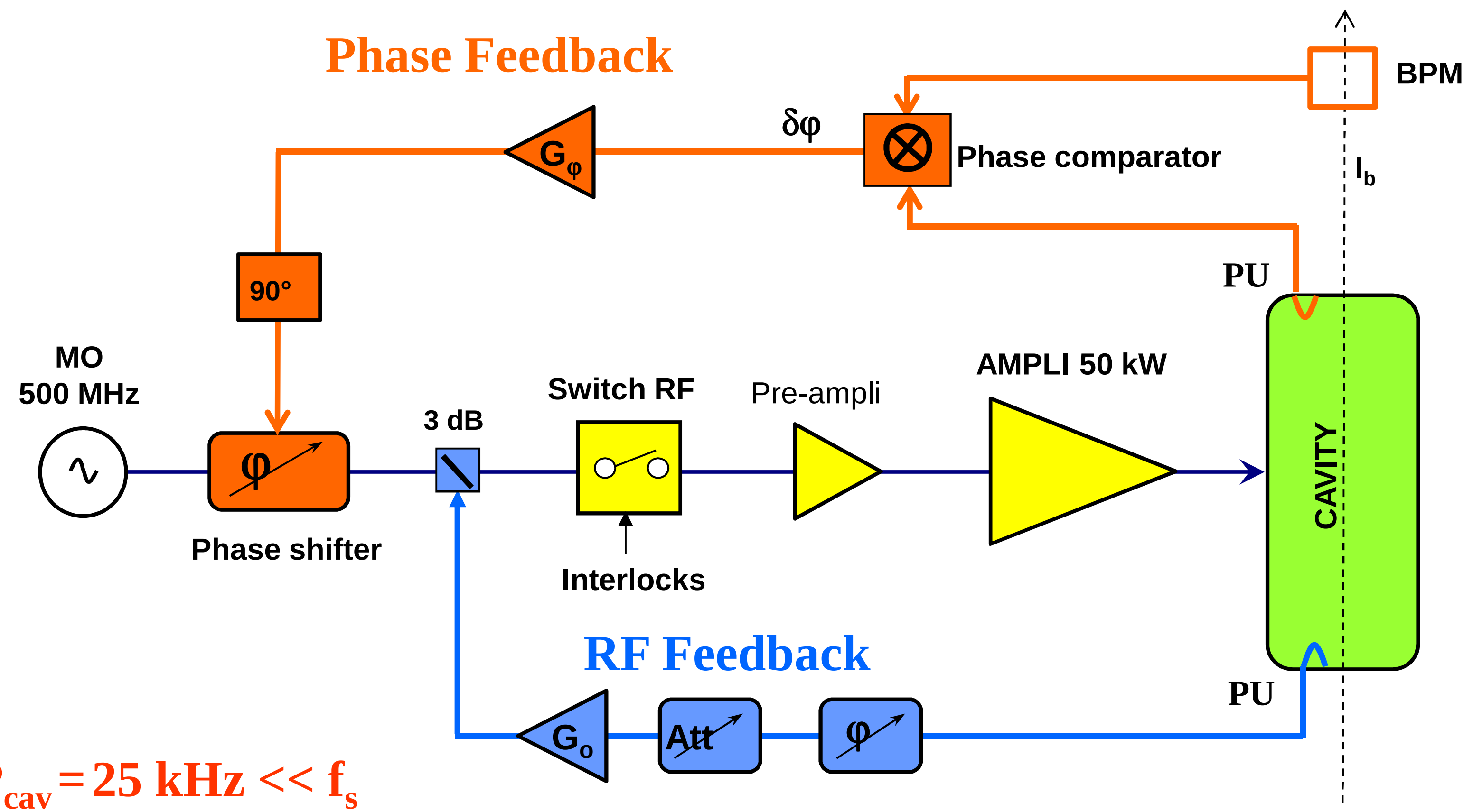


SSA ThomX status:

- All RF components are under manufacturing
- Delivery for beginning of 2014
- Assembly and tests for March 2014

ThomX longitudinal feedback (LFB)

To damp beam phase/energy oscillations @ f_s ~ 400 kHz, due to injections and collective effects → need LFB (t_{rep} ~ 1 µs)



BP_{cav} = 25 kHz << f_s

RF FB → BP_{cav} x (1 + G_o) , G_o limited by the delay δ ← D (dist. ampli - cav)
D ~ 10 m → δ = 150 ns → G_o ~ 50 → BP_{eff} > 1 MHz >> f_s

LFB = Phase FB + RF FB → T_damping ~ 1 µs (simu)

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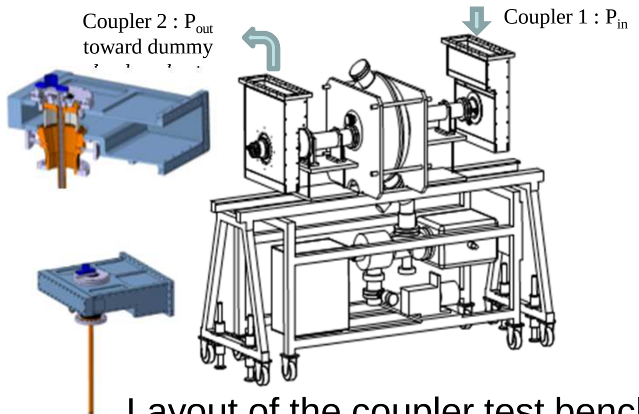
SOLEIL SYNCHROTRON

SOLEIL IPC upgrade

Reasons of the upgrade

- Collaboration agreement between CERN, ESRF and SOLEIL
- At ESRF, ceramic aging problems
- At SOLEIL, suspicion of discharges on the cavity 2 coupler of CM1 above 120kW (once a week when operating with ¾ cavities at 430mA beam current)
- Possibility of storing 500mA using a single CM and combining 2 amplifiers (300kW/cavity)→redundancy

SOLEIL IPC upgrade



Layout of the coupler test bench

- **300kW coupler**: collaboration with CERN and ESRF
  - 1st prototype for ESRF (loop type) tested in Dec 2011
  - 2 couplers for SOLEIL (antenna type) tested at ESRF in February 2013
  - From pulsed to CW mode conditioning up to 300kW (powered by 1MW klystron with circulator)

- IPC substitution on CM 1 planned for summer 2013 in situ→ Cleanness constraints

- 2x180 kW amplifier combination (with 3 ports waveguide combiner with a post for the matching) to provide 150kW for the IPC conditioning from pulsed to CW mode up to 150kW full reflection (75kW Pr/Amp)

Schedule:

- **IPC of cavity 2 (CM1) was succesfully installed, this summer (2013)**
- **IPC of cavity 1 (CM1) will be implemented during the january shutdown (2014)**
- **The next pair is for the summer 2014**

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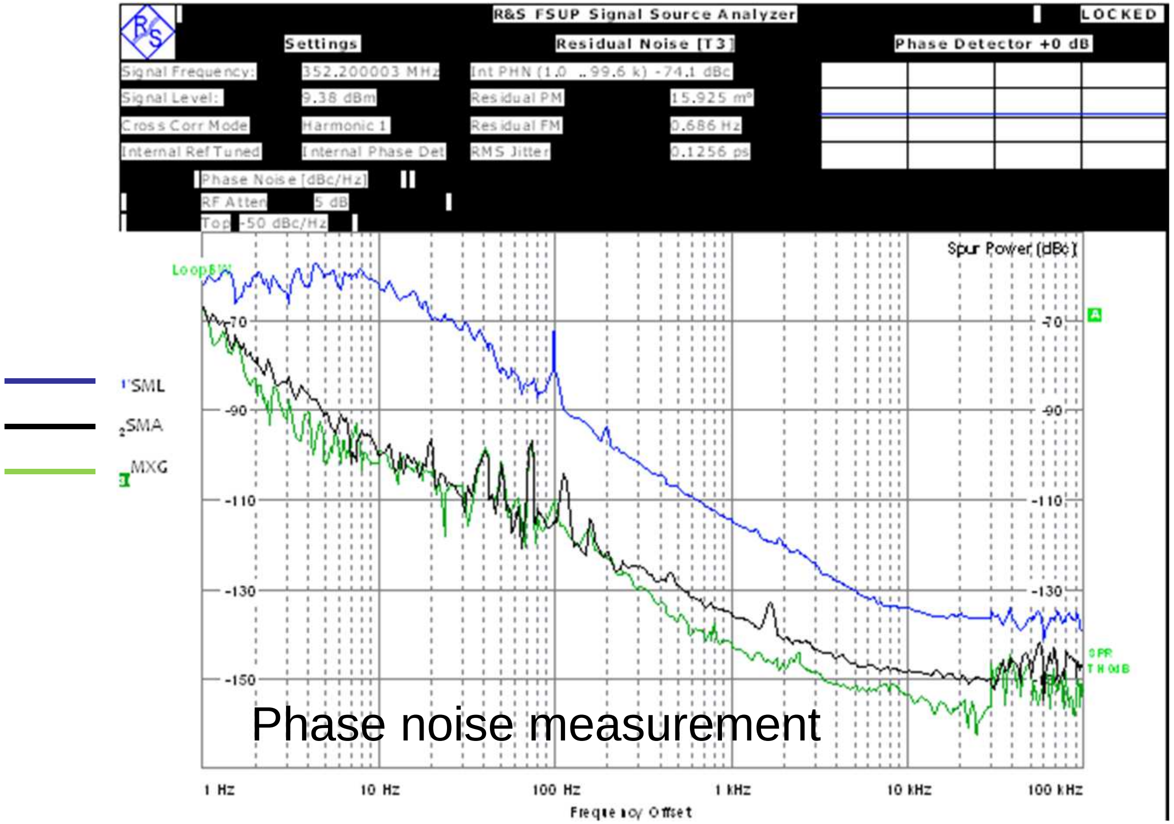
New SOLEIL MO

Expectations	SMA (Rohde & Schwarz)	MXG (Agilent)
SOFB : frequency tune	Yes with the "continuous phase active" option	Yes
HU640 : external analog frequency modulation	Yes, by using Ext Tune input (excursion fixed at +/-30Hz)	Yes, by using Ext Tune input (excursion can be adjusted)
Synchrotron frequency measurement: internal phase modulation	not possible : systematic RF cut off if any action is done on modulation command (big phase transient)	Yes without any incidence on RF



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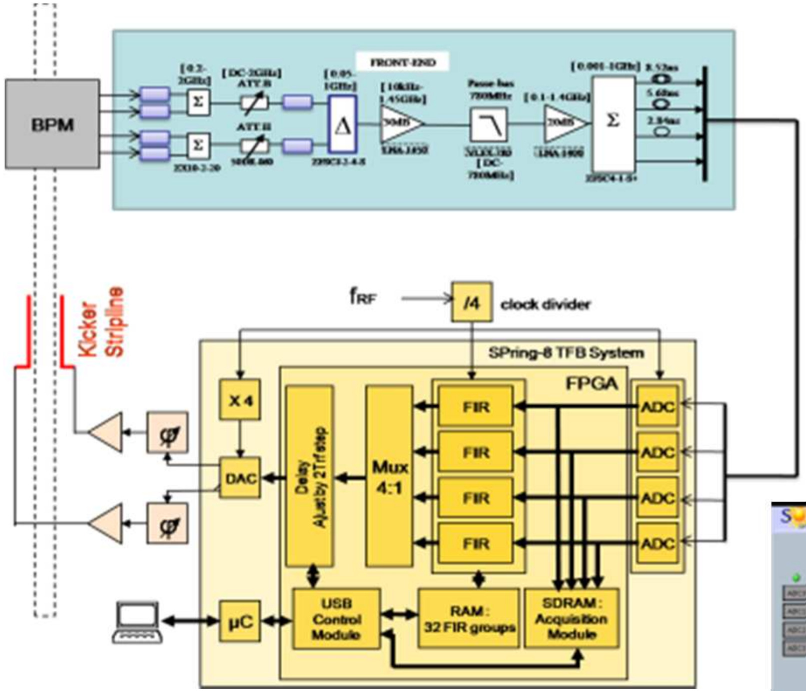
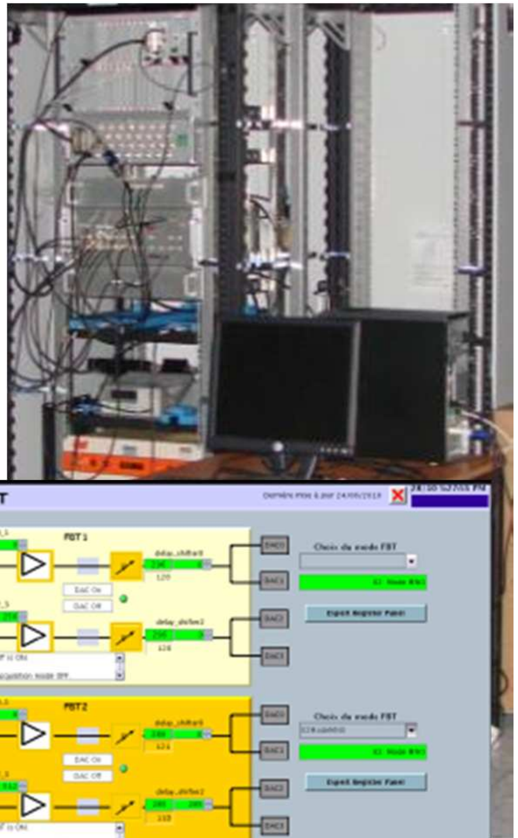
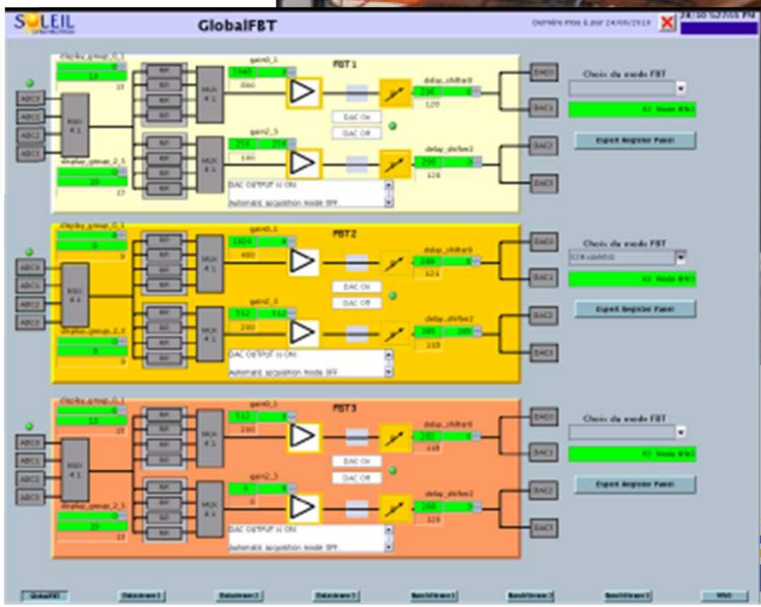
SOLEIL SYNCHROTRON

Transverse bunch by bunch feedback operation

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

SOLEIL SYNCHROTRON

Transverse bunch by bunch feedback operation

◊ Different Modes of Operation and the Digital Filters:

- Purely H, V and the diagonal mode. In the diagonal mode, only the diagonal electrodes of the BPM and the stripline are used. Despite the tune difference of 0.1, the diagonal mode works well at SOLEIL .

- Digital (FIR) filters employed:

Least square fit of the betatron motions, developed by T. Nakamura (EPAC2004):

Fit the betatron motion function in the following form

$$x[k] = A \sin[\, (1+\Delta)\phi_k + \psi] + B$$

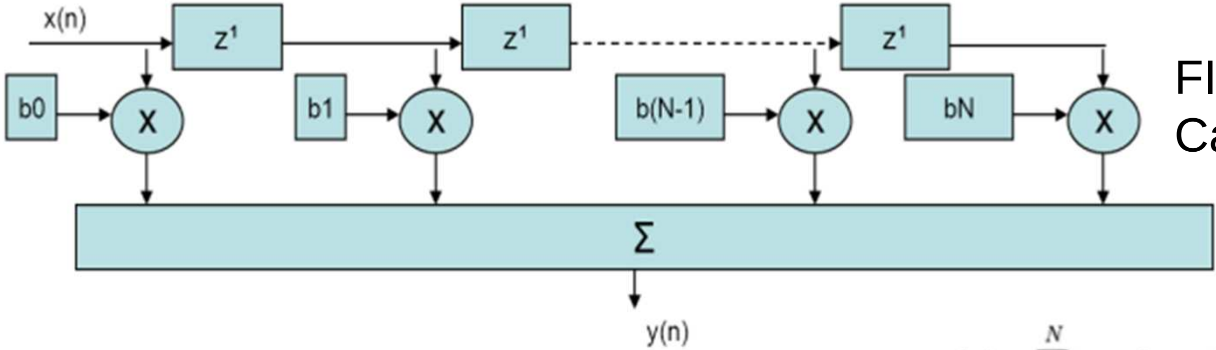
$$\equiv P_0 \cos\phi_k - P_1\, \phi_k \sin\phi_k + Q_0 \sin\phi_k + Q_1\, \phi_k \cos\phi_k + B + \text{higher-order terms}$$

Determine the coefficients P_0, P_1, Q_0, Q_1, B, … via least square fit of

$$F \equiv \sum_{k=0}^{N-1} \left(x_k - x[k]\right)^2,$$

which can be solved by the standard matrix inversion method.

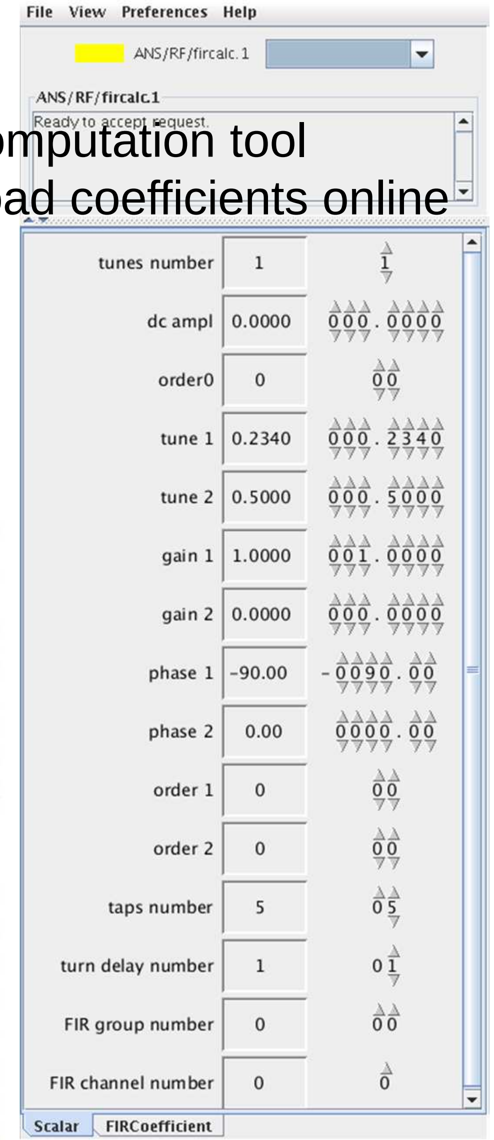
FIR Filter

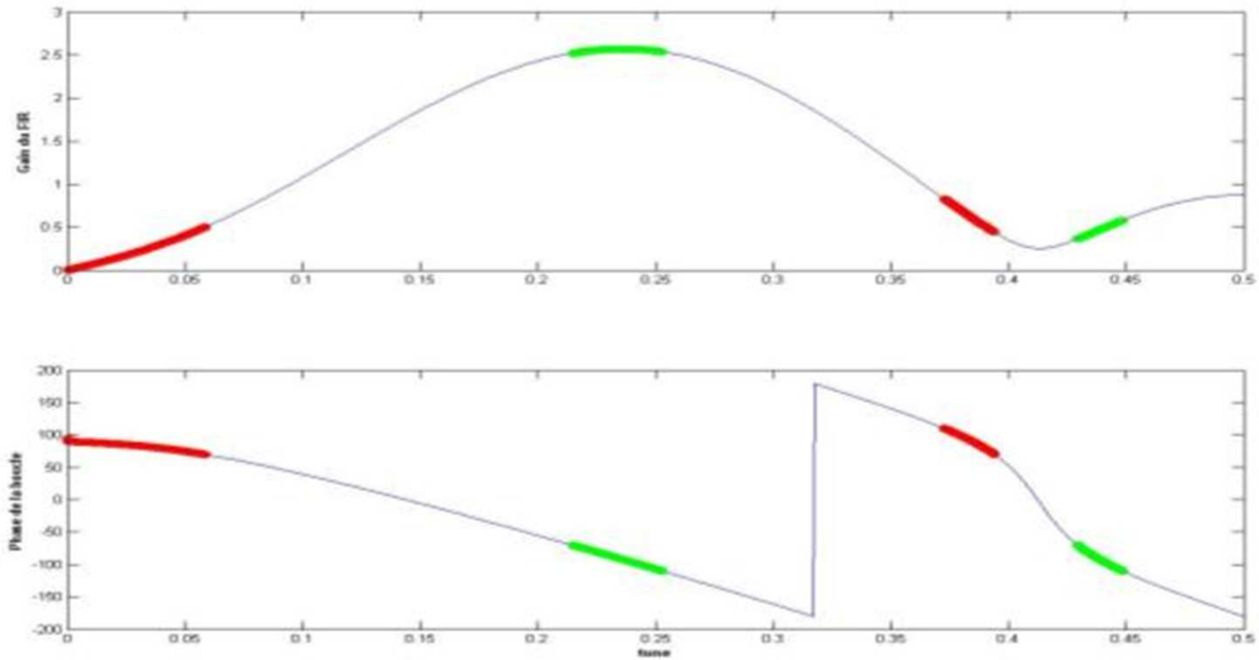


$$y[n] = b_0 \cdot x[n] + b_1 \cdot x[n-1] + b_2 \cdot x[n-2] + ... + b_N \cdot x[n-N]$$

$$y[n] = \sum_{k=0}^{N} b_k \cdot x[n-k]$$

FIR computation tool
Can load coefficients online

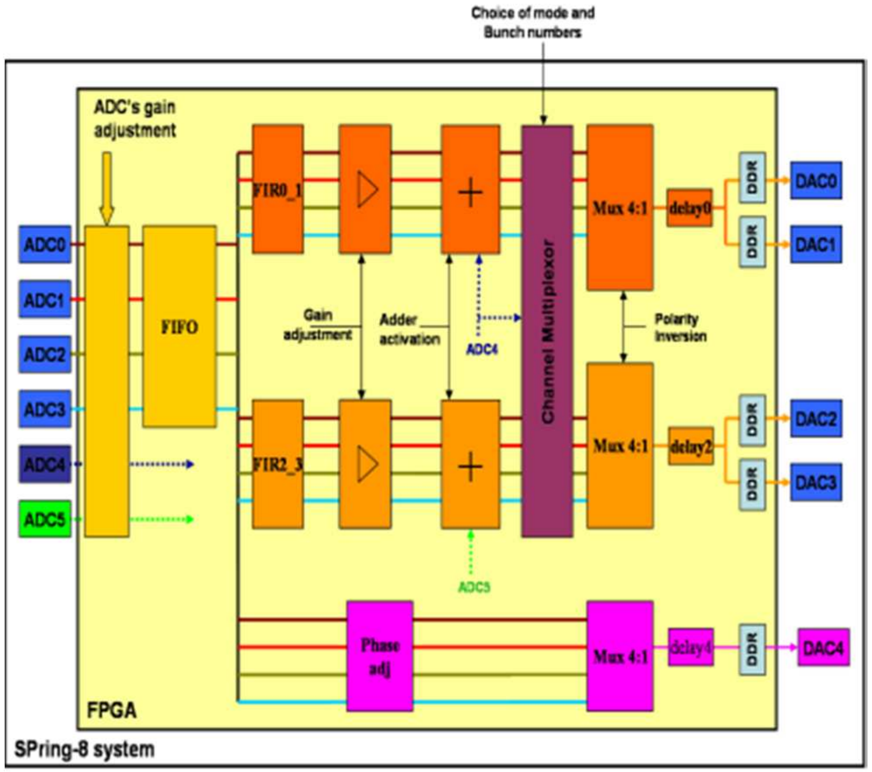


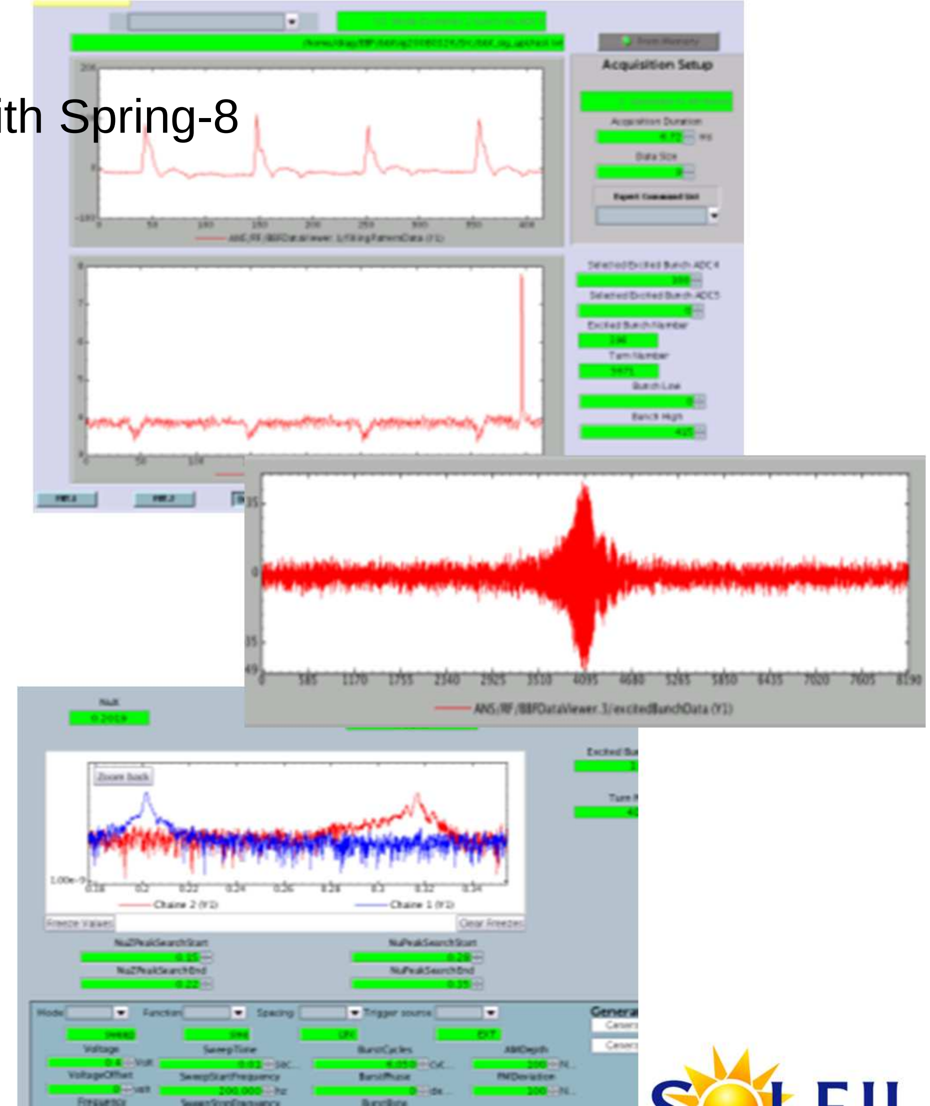


Gain and phase of a 5-tap FIR filter

Some home made development on our SPring-8 based System

This SOLEIL development was shared with Spring-8





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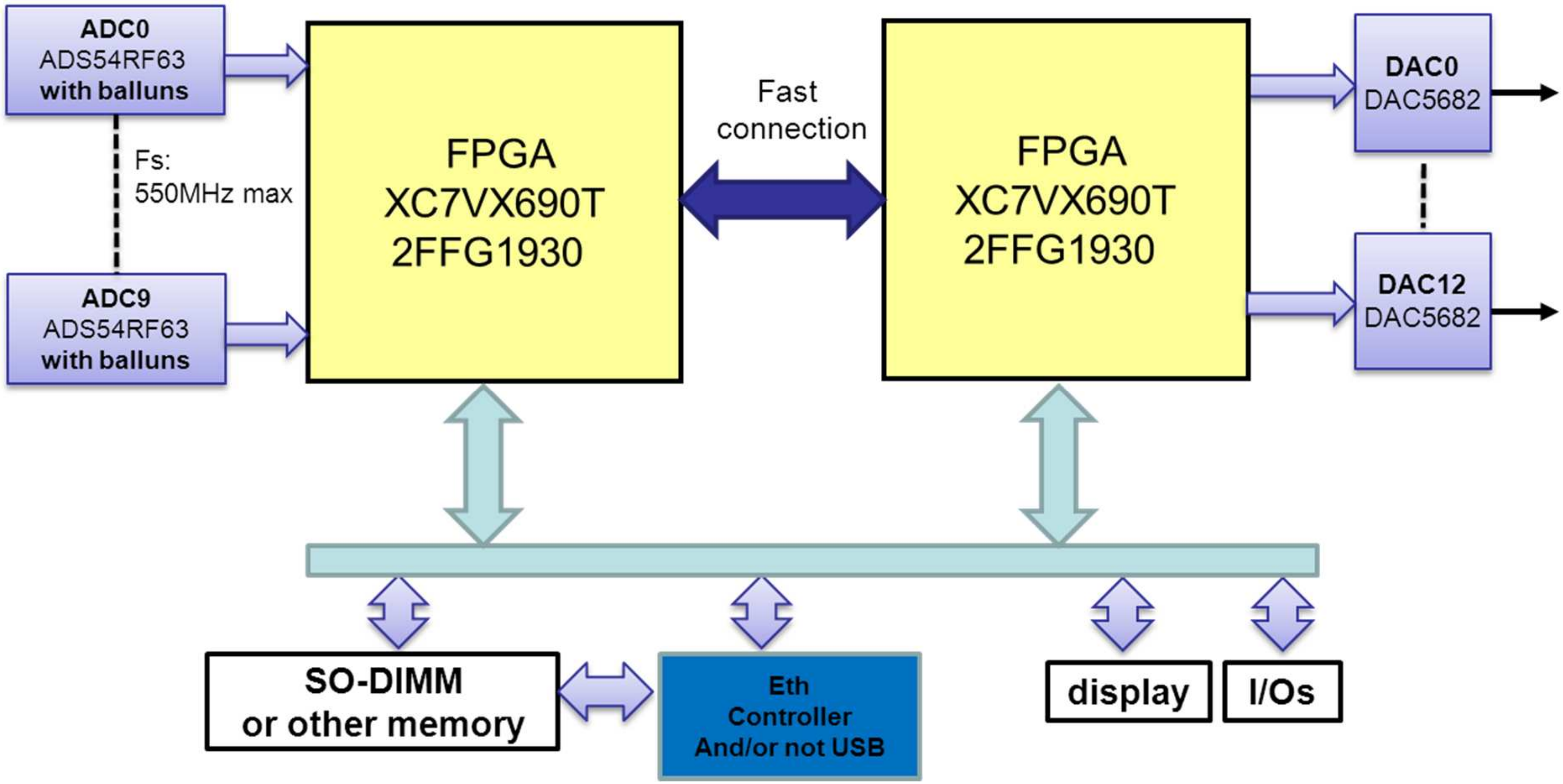
Digital feedback system upgrade

Collaboration with Spring-8

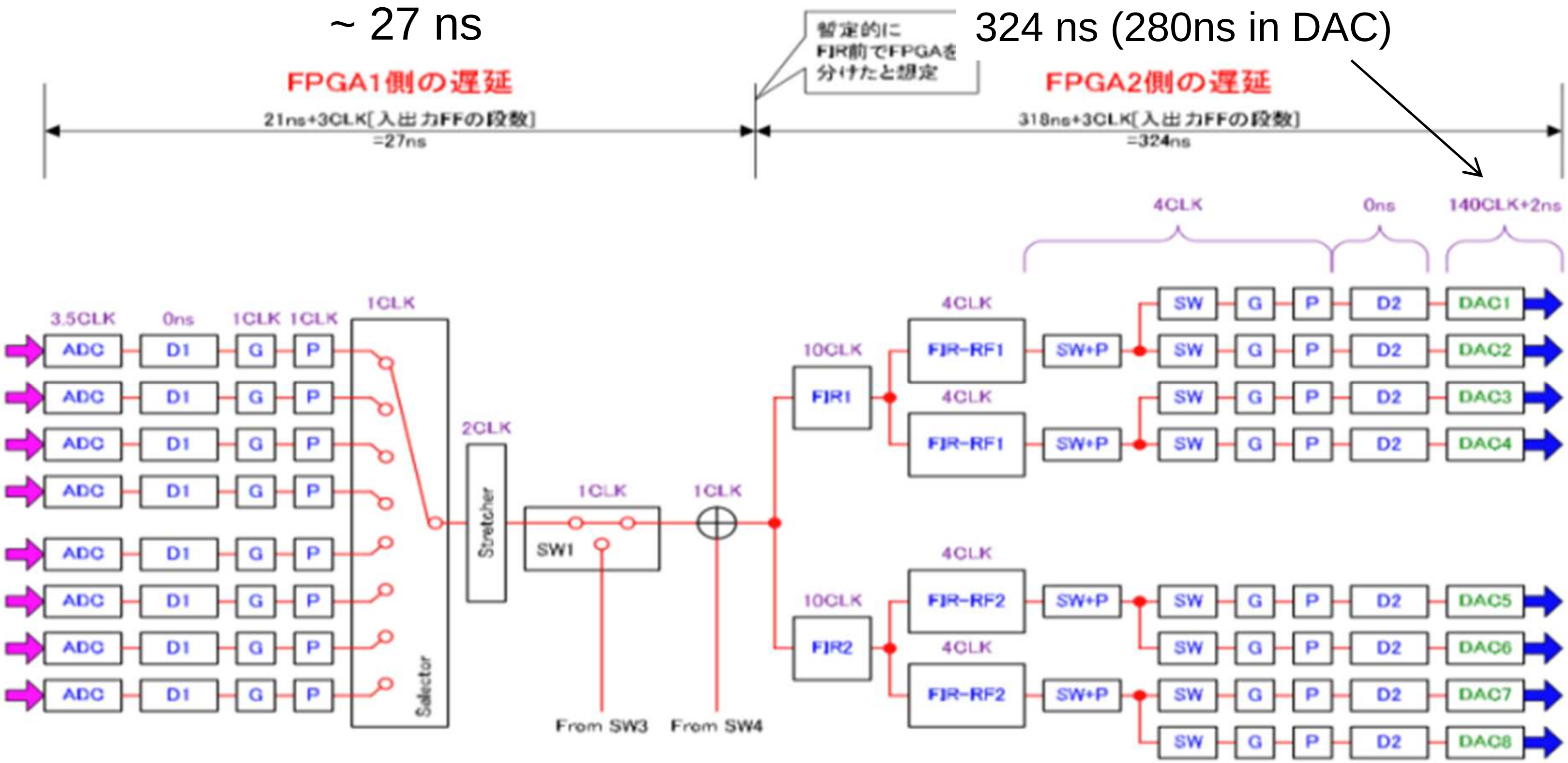
Call of tender : TED and Mitsubishi
We choose TED.



Digital feedback system upgrade

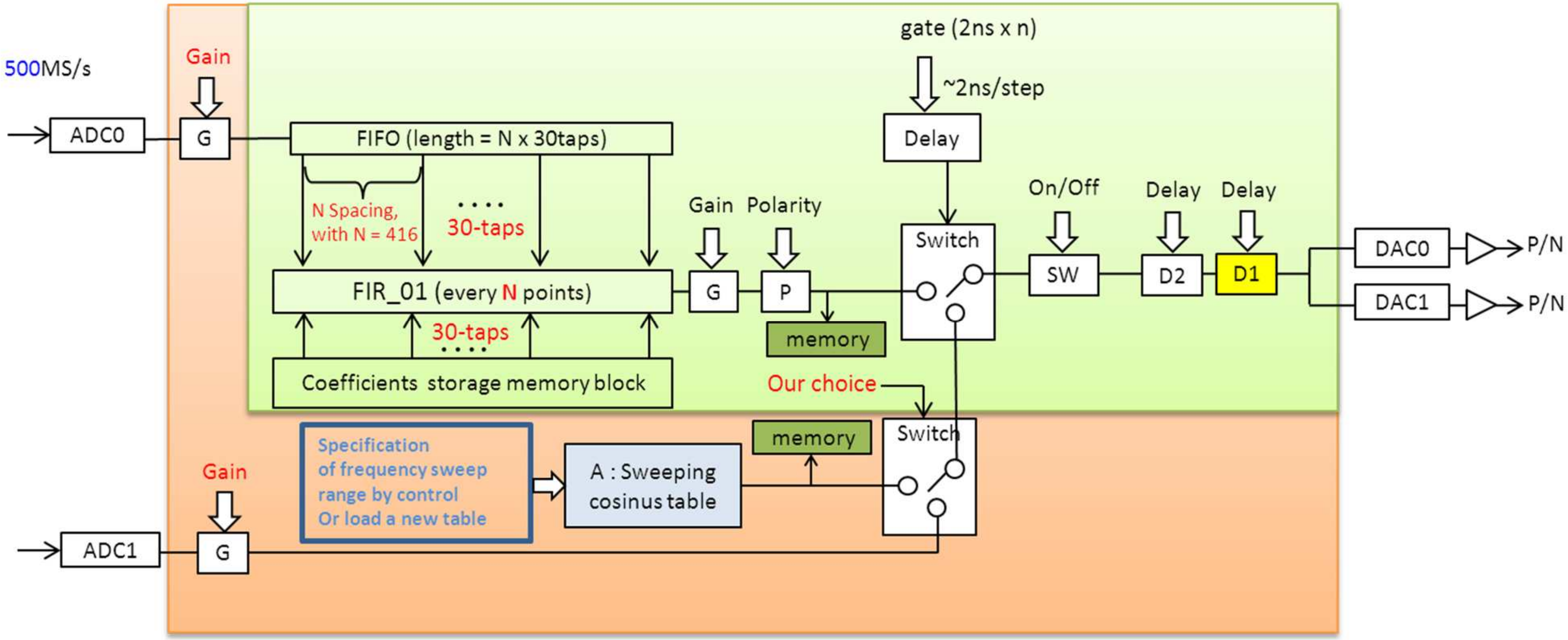
Specifications: ~ 350 ns latency of the feedback processor including FIR filters
First prototype was tested this summer
→But 280 ns in DAC due to integrate FIR that we can't bypass for the moment (not acceptable)

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



Digital feedback system upgrade

Design for SOLEIL and ThomX



- Less complex than SPring-8 design
- More chains with this hardware
- More diagnostics (many extra ADCs)

Digital feedback system upgrade

For SOLEIL

- 2 TFB chains with one hardware with many diagnostics means
- Possibility to make DLLRF (exclusively)
- More diagnostics (many extra ADCs) postmortem

For ThomX

- 2 TFB V & H chains with one hardware with many diagnostics means
- Possibility to make DLLRF (LFB)
- More diagnostics (many extra ADCs) postmortem

SUMMARY

SOLEIL RF group activities

➢**SSA**

- Upgrade of SOLEIL SSA as started (LR301→BLF574XR)
- 500MHz SSAs for ThomX (50kW) and SESAME (80kW) under manufacturing
- R&D for 176MHz, 200MHz, 1.3GHz ()

➢**ThomX project**

- RF system (cavity, SSA, LLRF)
- LFB, TFB
- LINAC injector (Jean-Pierre POLLINA)

➢**Collaboration with SESAME**

- SSA and cavity

➢**TFB**

- Automatic calculation of FIRs coefficients from tune value
- Versatile digital board with new generation components
- Digital system upgrade for SOLEIL and ThomX

➢First 300kW IPC successfully installed, three other ones in 2014

➢Improvement of cryogenic system autonomy under study

➢LUNEX5 project → TDR