# SOLEIL Low level RF system

Existing:

- SOLEIL main parameters
- Booster amplifier
- Booster RF control system
- Booster and storage ring low level RF system

Under development :

- Future digital low level RF of storage ring
- Microphonic measurements
- Direct and digital feedback simulation model
- Transverse feedback under development

R.SREEDHARAN

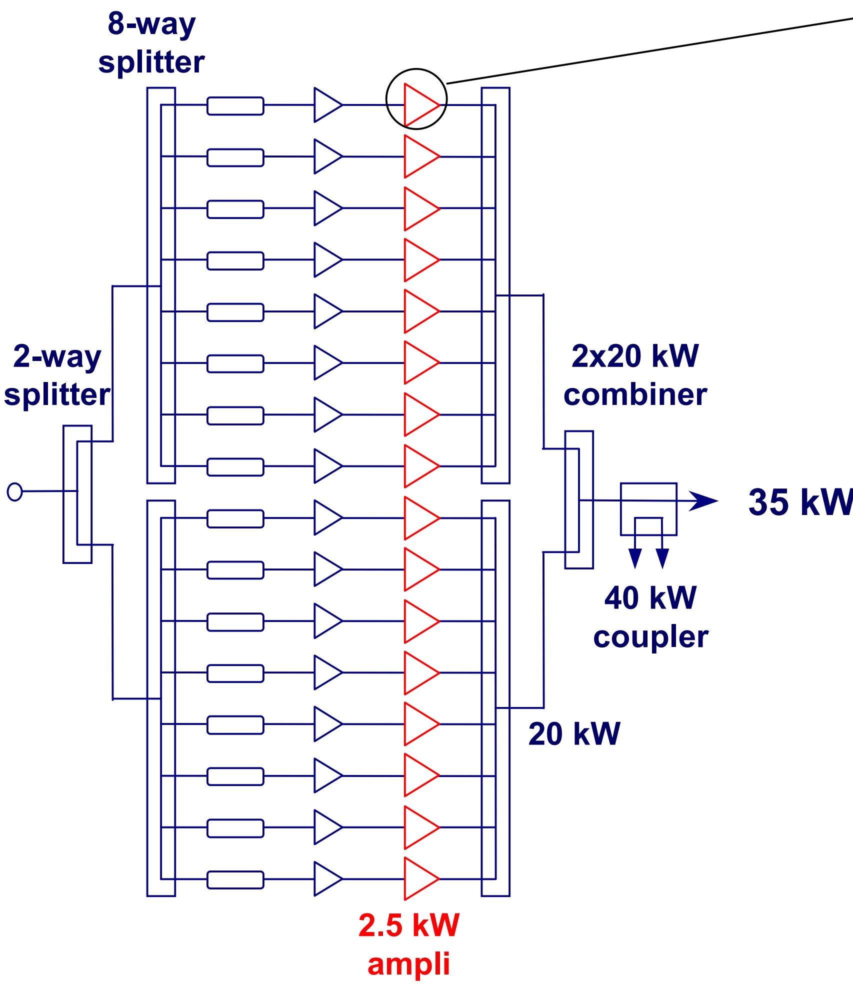
SOLEIL SYNCHROTRON

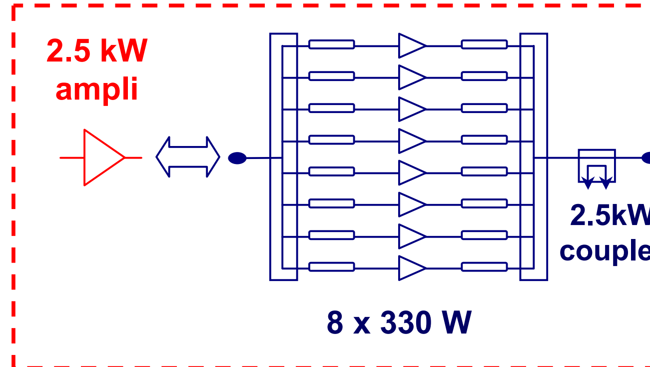
# SOLEIL main parameters

| | 2 (1) cryomodules |
|---|---|
| RF frequency (MHz) | 352.202 |
| Harmonic number | 416 |
| Nominal energy (GeV) | 2.75 |
| Energy loss per turn (keV) | 1050 (950) |
| 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 (300) |
| Total cavity voltage (MV) | 4 (3) |
| Synchronous phase (°) | 73.6 (71.5) |

R.SREEDHARAN

# Booster Amplifier :



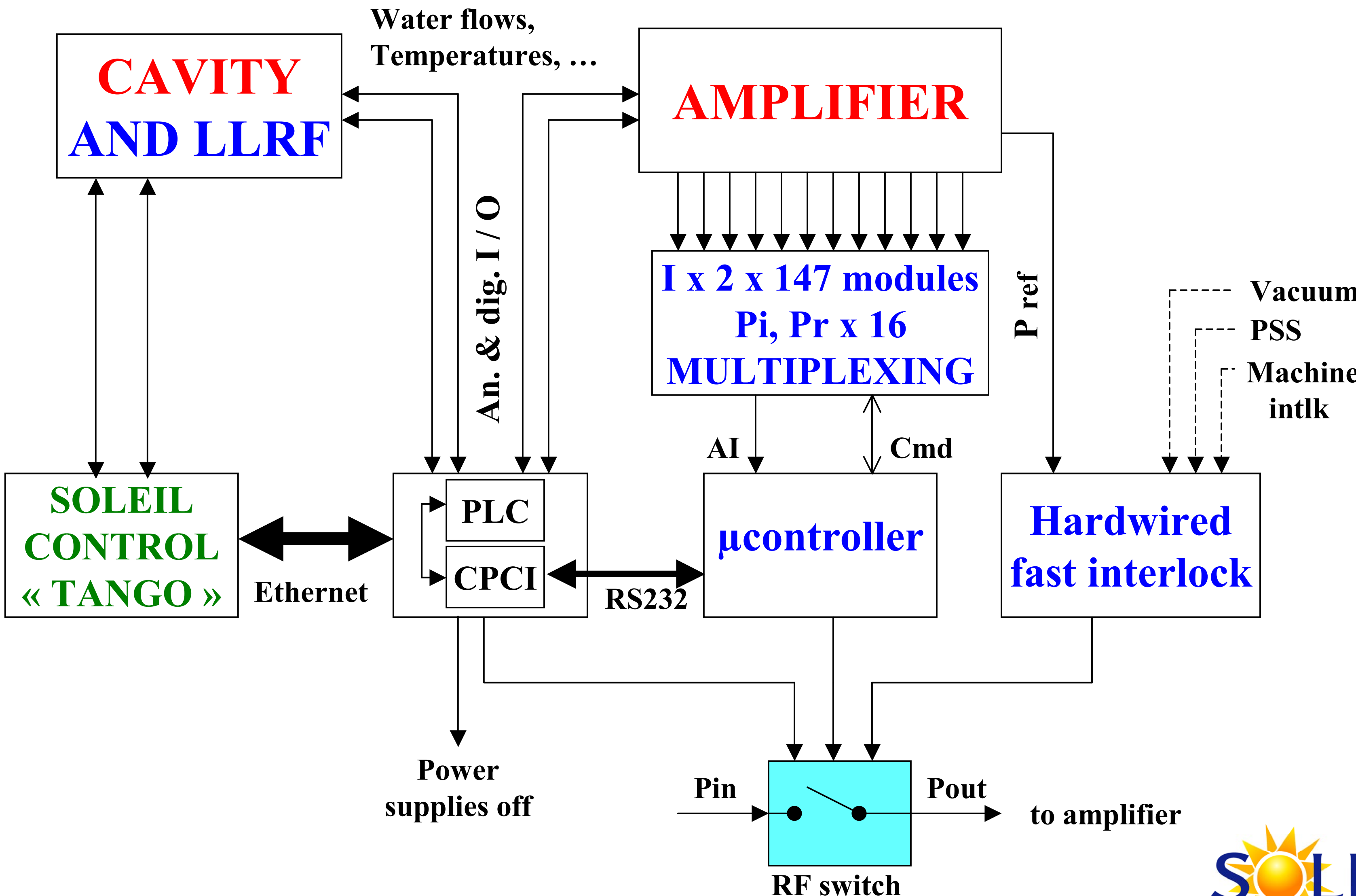




**(18 x 8) + 3 = 147 modules**

R.SREEDHARAN

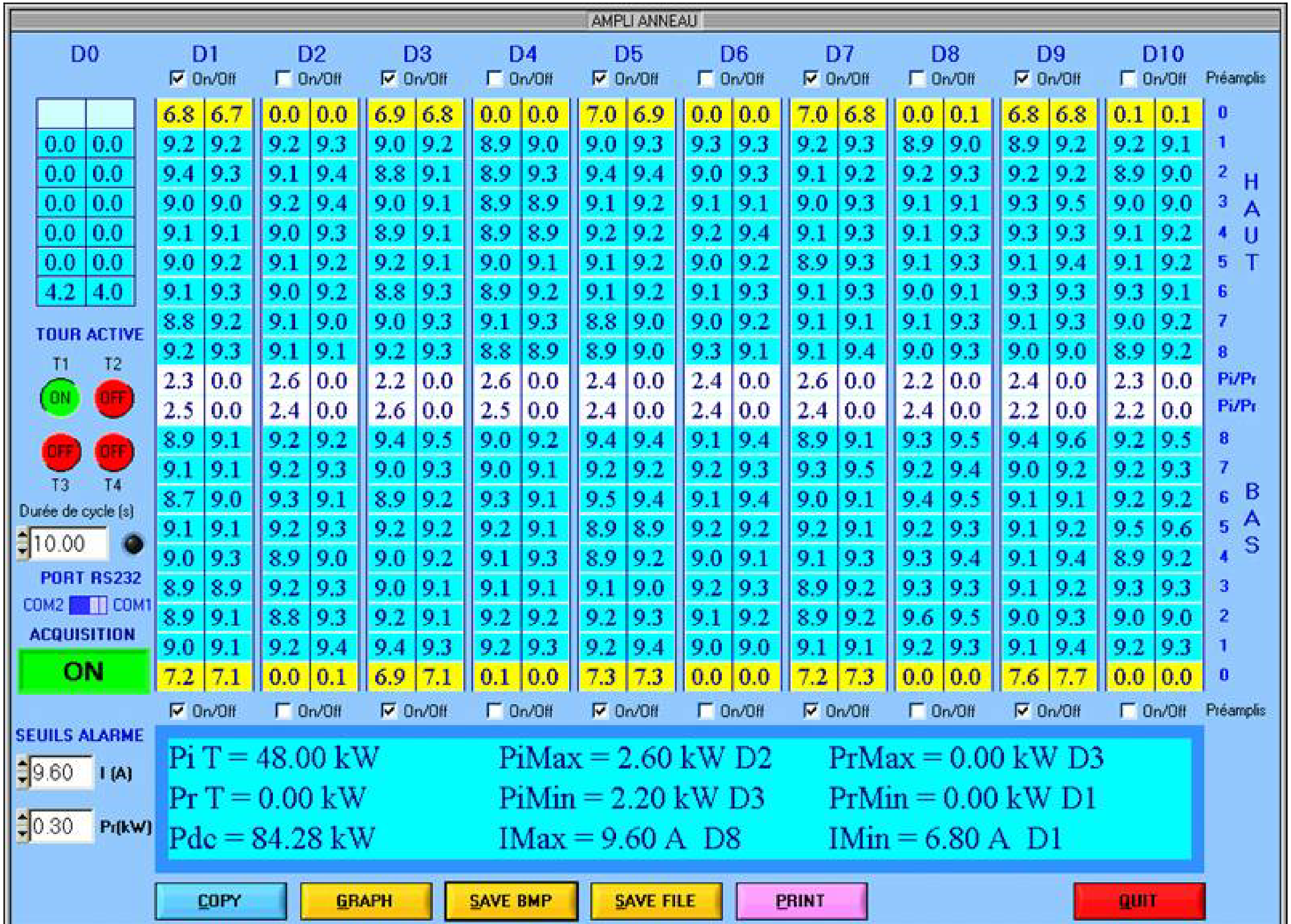
SOLEIL SYNCHROTRON

# Booster RF control system




R.SREEDHARAN

# Amplifier monitoring display




| | D0 | D0 | D1 | D1 | D2 | D2 | D3 | D3 | D4 | D4 | D5 | D5 | D6 | D6 | D7 | D7 | D8 | D8 | D9 | D9 | D10 | D10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 (HAUT) | | | 6.8 | 6.7 | 0.0 | 0.0 | 6.9 | 6.8 | 0.0 | 0.0 | 7.0 | 6.9 | 0.0 | 0.0 | 7.0 | 6.8 | 0.0 | 0.1 | 6.8 | 6.8 | 0.1 | 0.1 |
| 1 | 0.0 | 0.0 | 9.2 | 9.2 | 9.2 | 9.3 | 9.0 | 9.2 | 8.9 | 9.0 | 9.0 | 9.3 | 9.3 | 9.3 | 9.2 | 9.3 | 8.9 | 9.0 | 8.9 | 9.2 | 9.2 | 9.1 |
| 2 | 0.0 | 0.0 | 9.4 | 9.3 | 9.1 | 9.4 | 8.8 | 9.1 | 8.9 | 9.3 | 9.4 | 9.4 | 9.0 | 9.3 | 9.1 | 9.2 | 9.2 | 9.3 | 9.2 | 9.2 | 8.9 | 9.0 |
| 3 | 0.0 | 0.0 | 9.0 | 9.0 | 9.2 | 9.4 | 9.0 | 9.1 | 8.9 | 8.9 | 9.1 | 9.2 | 9.1 | 9.1 | 9.0 | 9.3 | 9.1 | 9.1 | 9.3 | 9.5 | 9.0 | 9.0 |
| 4 | 0.0 | 0.0 | 9.1 | 9.1 | 9.0 | 9.3 | 8.9 | 9.1 | 8.9 | 8.9 | 9.2 | 9.2 | 9.2 | 9.4 | 9.1 | 9.3 | 9.1 | 9.3 | 9.3 | 9.3 | 9.1 | 9.2 |
| 5 | 0.0 | 0.0 | 9.0 | 9.2 | 9.1 | 9.2 | 9.2 | 9.1 | 9.0 | 9.1 | 9.1 | 9.2 | 9.0 | 9.2 | 8.9 | 9.3 | 9.1 | 9.3 | 9.1 | 9.4 | 9.1 | 9.2 |
| 6 | 4.2 | 4.0 | 9.1 | 9.3 | 9.0 | 9.2 | 8.8 | 9.3 | 8.9 | 9.2 | 9.1 | 9.2 | 9.1 | 9.3 | 9.1 | 9.3 | 9.0 | 9.1 | 9.3 | 9.3 | 9.3 | 9.1 |
| 7 | | | 8.8 | 9.2 | 9.1 | 9.0 | 9.0 | 9.3 | 9.1 | 9.3 | 8.8 | 9.0 | 9.0 | 9.2 | 9.1 | 9.1 | 9.1 | 9.3 | 9.1 | 9.3 | 9.0 | 9.2 |
| 8 | | | 9.2 | 9.3 | 9.1 | 9.1 | 9.2 | 9.3 | 8.8 | 8.9 | 8.9 | 9.0 | 9.3 | 9.1 | 9.1 | 9.4 | 9.0 | 9.3 | 9.0 | 9.0 | 8.9 | 9.2 |
| Pi/Pr | | | 2.3 | 0.0 | 2.6 | 0.0 | 2.2 | 0.0 | 2.6 | 0.0 | 2.4 | 0.0 | 2.4 | 0.0 | 2.6 | 0.0 | 2.2 | 0.0 | 2.4 | 0.0 | 2.3 | 0.0 |
| Pi/Pr | | | 2.5 | 0.0 | 2.4 | 0.0 | 2.6 | 0.0 | 2.5 | 0.0 | 2.4 | 0.0 | 2.4 | 0.0 | 2.4 | 0.0 | 2.4 | 0.0 | 2.2 | 0.0 | 2.2 | 0.0 |
| 8 (BAS) | | | 8.9 | 9.1 | 9.2 | 9.2 | 9.4 | 9.5 | 9.0 | 9.2 | 9.4 | 9.4 | 9.1 | 9.4 | 8.9 | 9.1 | 9.3 | 9.5 | 9.4 | 9.6 | 9.2 | 9.5 |
| 7 | | | 9.1 | 9.1 | 9.2 | 9.3 | 9.0 | 9.3 | 9.0 | 9.1 | 9.2 | 9.2 | 9.2 | 9.3 | 9.3 | 9.5 | 9.2 | 9.4 | 9.0 | 9.2 | 9.2 | 9.3 |
| 6 | | | 8.7 | 9.0 | 9.3 | 9.1 | 8.9 | 9.2 | 9.3 | 9.1 | 9.5 | 9.4 | 9.1 | 9.4 | 9.0 | 9.1 | 9.4 | 9.5 | 9.1 | 9.1 | 9.2 | 9.2 |
| 5 | | | 9.1 | 9.1 | 9.2 | 9.3 | 9.2 | 9.2 | 9.2 | 9.1 | 8.9 | 8.9 | 9.2 | 9.2 | 9.2 | 9.1 | 9.2 | 9.3 | 9.1 | 9.2 | 9.5 | 9.6 |
| 4 | | | 9.0 | 9.3 | 8.9 | 9.0 | 9.0 | 9.2 | 9.1 | 9.3 | 8.9 | 9.2 | 9.0 | 9.1 | 9.1 | 9.3 | 9.3 | 9.4 | 9.1 | 9.4 | 8.9 | 9.2 |
| 3 | | | 8.9 | 8.9 | 9.2 | 9.3 | 9.0 | 9.1 | 9.1 | 9.1 | 9.1 | 9.0 | 9.2 | 9.3 | 8.9 | 9.2 | 9.3 | 9.3 | 9.1 | 9.2 | 9.3 | 9.3 |
| 2 | | | 8.9 | 9.1 | 8.8 | 9.3 | 9.2 | 9.1 | 9.2 | 9.2 | 9.2 | 9.3 | 9.1 | 9.2 | 8.9 | 9.2 | 9.6 | 9.5 | 9.0 | 9.3 | 9.0 | 9.0 |
| 1 | | | 9.0 | 9.1 | 9.2 | 9.4 | 9.4 | 9.3 | 9.2 | 9.3 | 9.2 | 9.4 | 9.0 | 9.0 | 9.1 | 9.1 | 9.2 | 9.3 | 9.1 | 9.4 | 9.2 | 9.3 |
| 0 | | | 7.2 | 7.1 | 0.0 | 0.1 | 6.9 | 7.1 | 0.1 | 0.0 | 7.3 | 7.3 | 0.0 | 0.0 | 7.2 | 7.3 | 0.0 | 0.0 | 7.6 | 7.7 | 0.0 | 0.0 |

Dissipater n°

$I_{1,2}$ for the 9 upper modules

Pi, Pr @ 2.5 kW

$I_{1,2}$ for the 9 lower modules

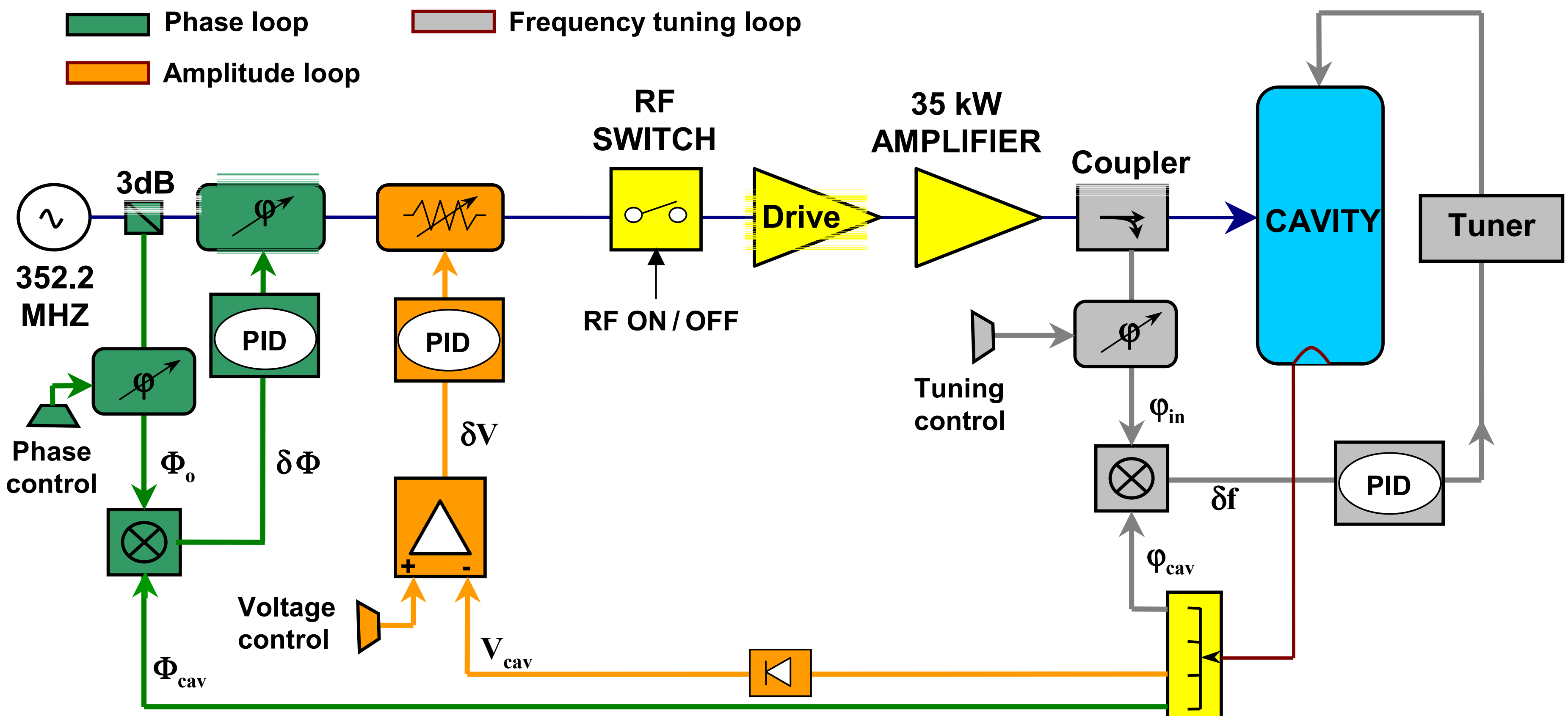
1st stage or stand-by

SOLEIL SYNCHROTRON

R.SREEDHARAN

# Booster LLRF system

3 conventional « slow » control loops for the frequency, amplitude & phase
remake of a LURE design adapted to the SOLEIL needs

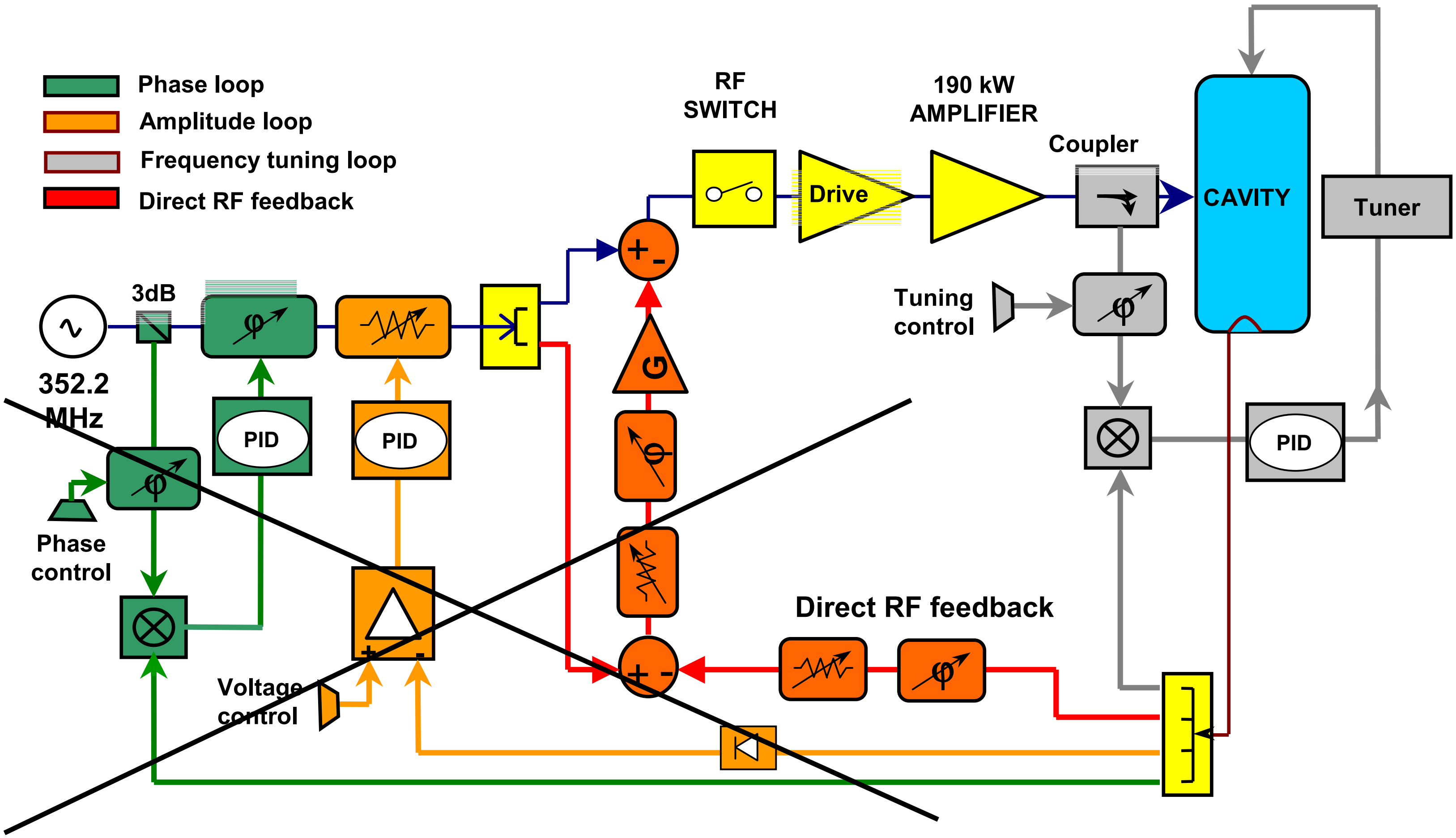



| | Amplitude | Phase | Frequency |
|---|---|---|---|
| Accuracy | ± 0.25 % | ± 0.4° | ± 30 Hz |
| 3 dB BW | 3 kHz | 1.5 kHz | 5 Hz |

R.SREEDHARAN

# Storage Ring LLRF system phase 1

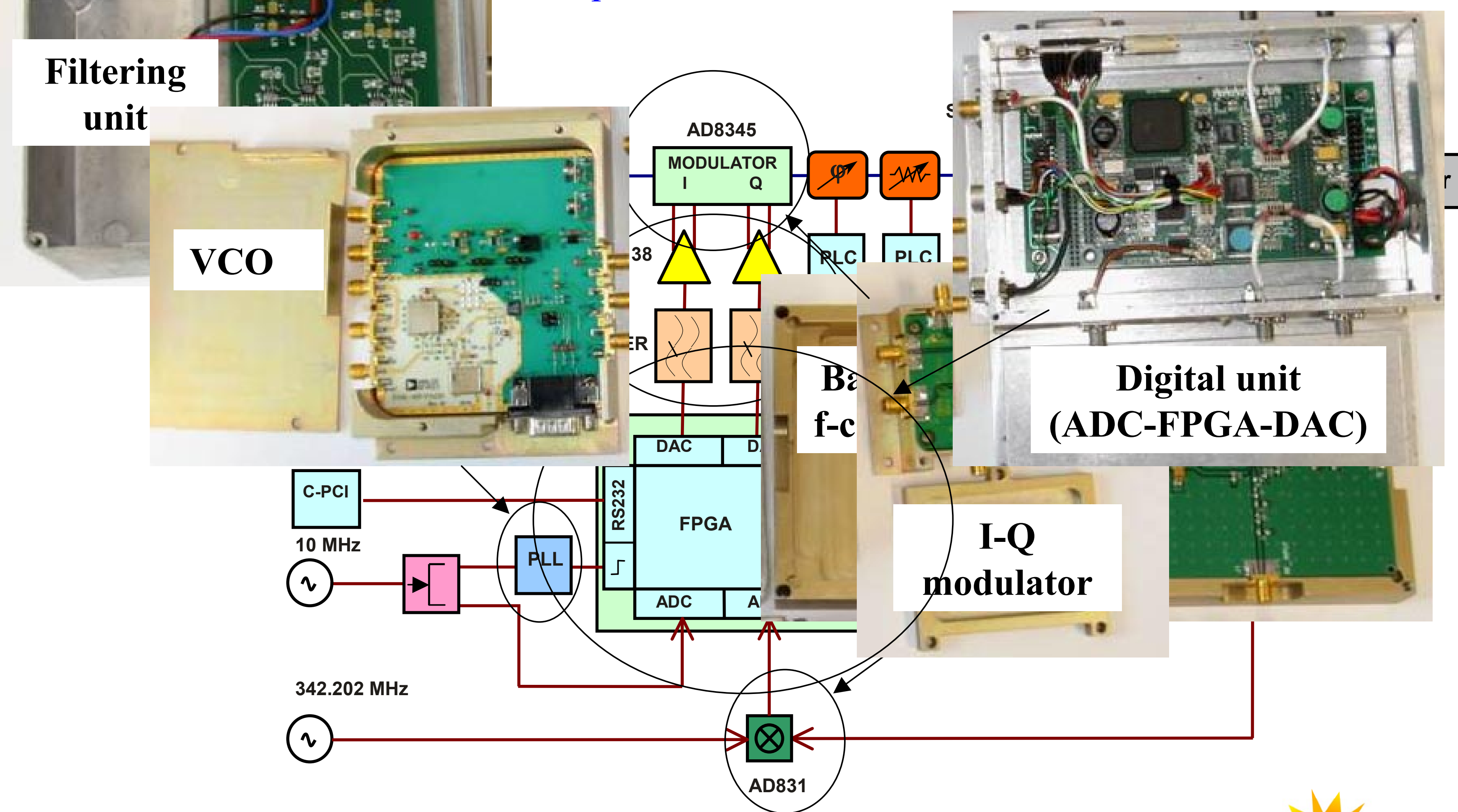
SR LLRF = BO LLRF + direct RF feedback




R.SREEDHARAN

# Storage Ring digital LLRF Phase 2

…tal (FPGA based) phase and amplitude loops,
…development in collaboration with CEA

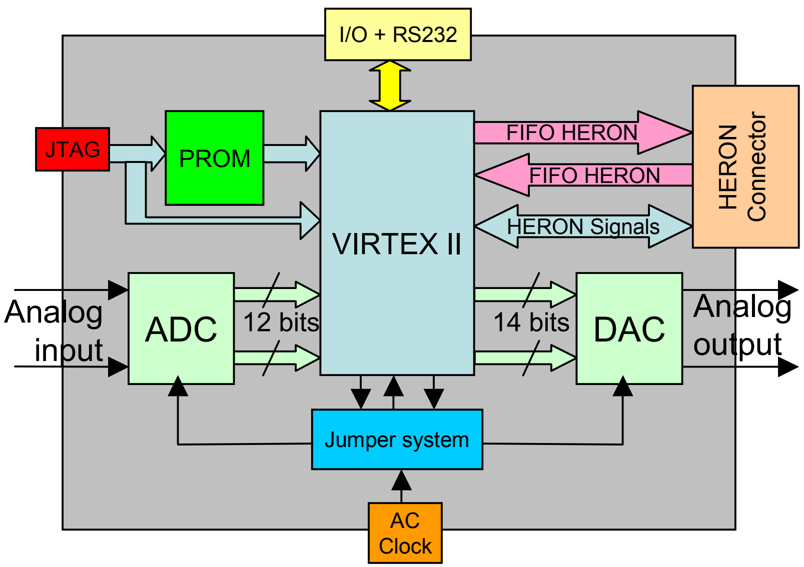




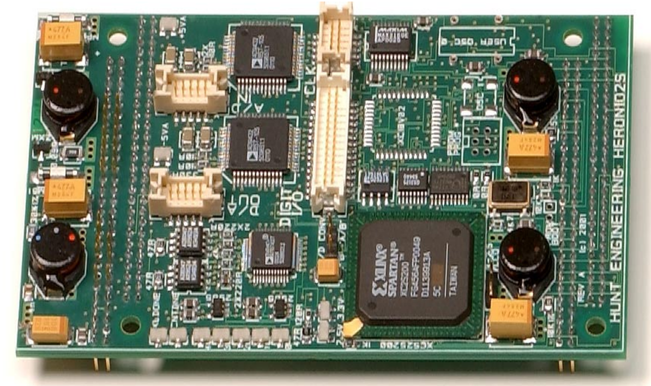

SOLEIL SYNCHROTRON

# Architecture of FPGA

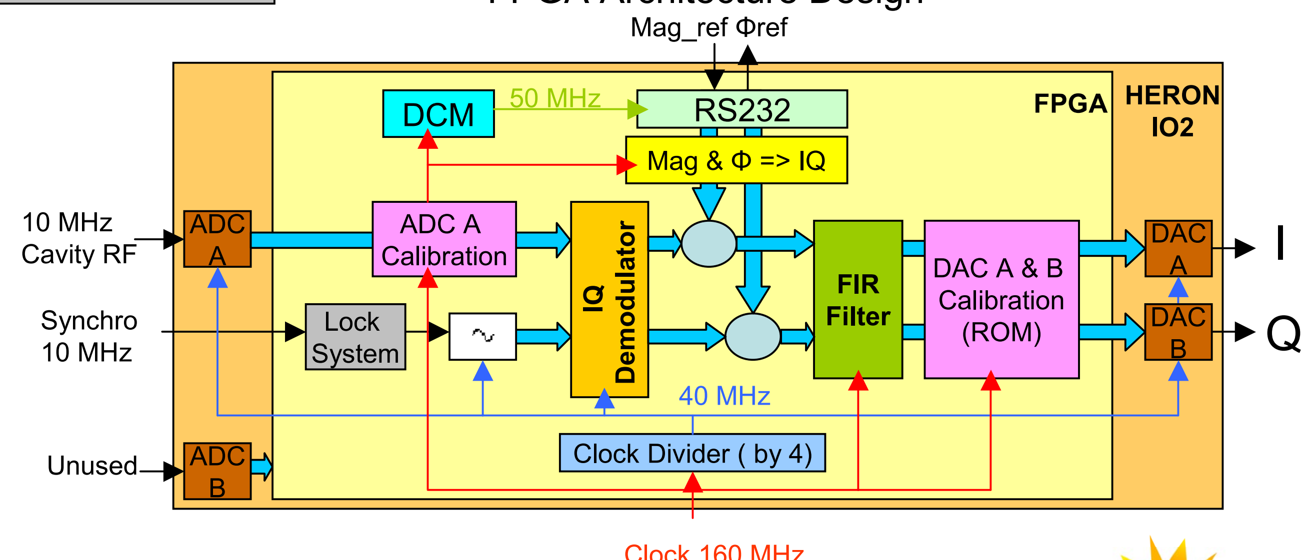
**Module Architecture**




**Heron IO2V2 board**



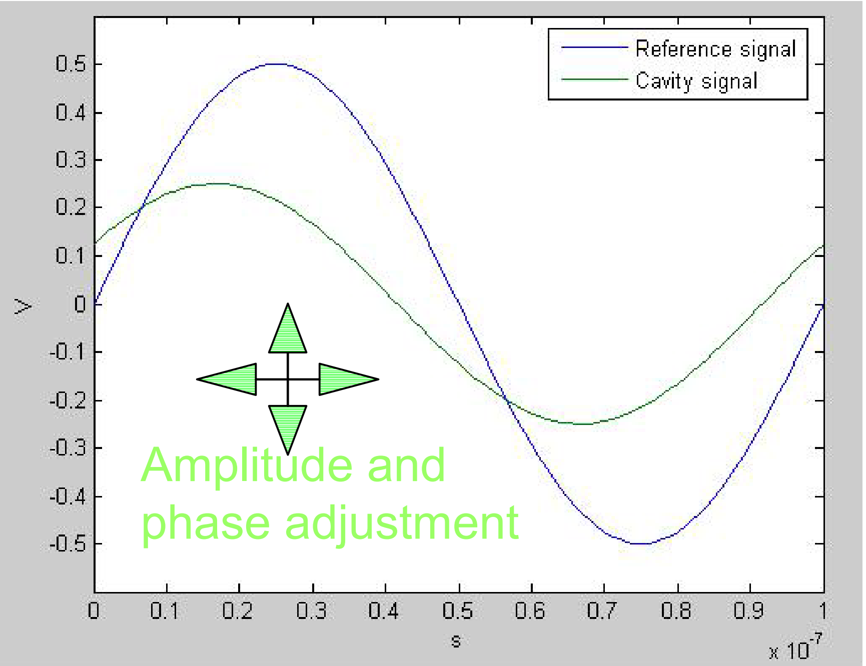
FPGA Architecture Design



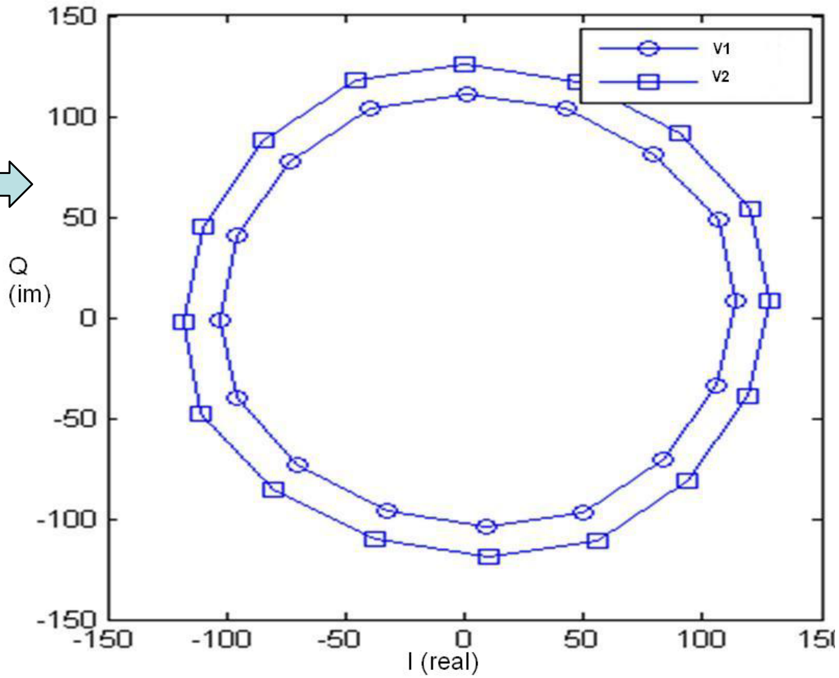

SOLEIL SYNCHROTRON

R.SREEDHARAN

# Digital IQ Demodulator



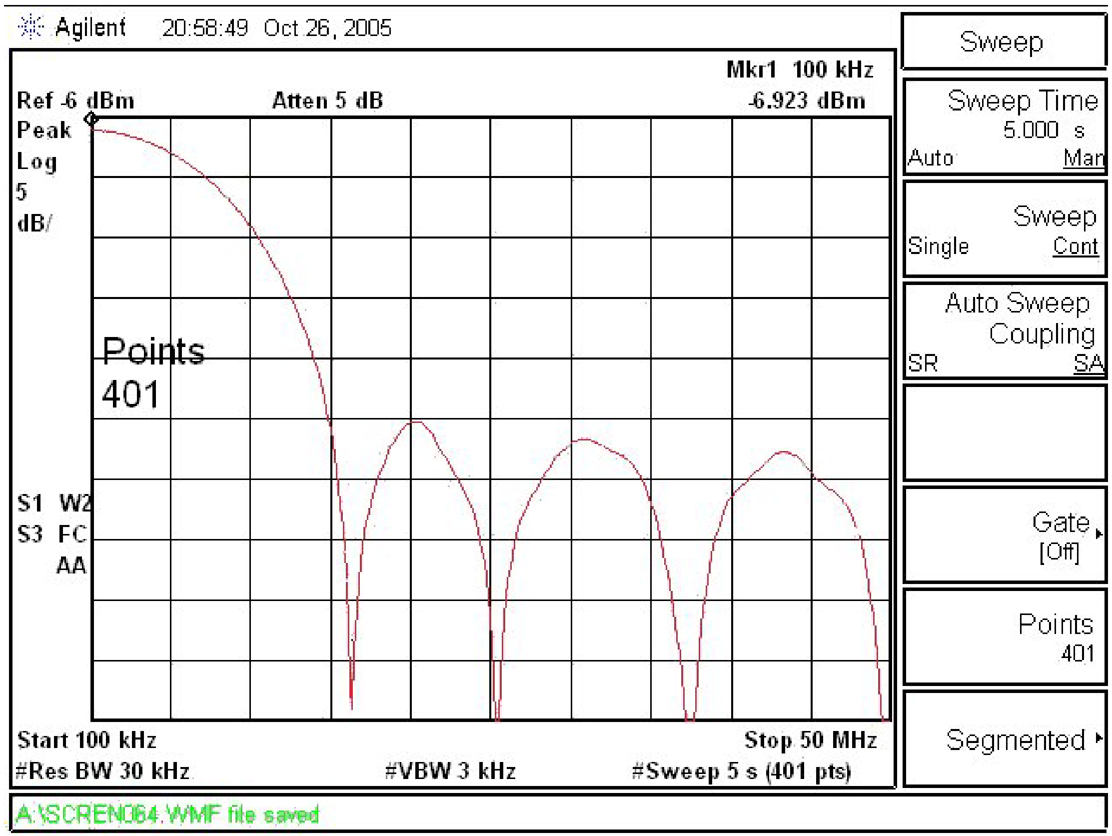

The experiments shows that we cover 0 to 360° as shown with different amplitude.






SOLEIL SYNCHROTRON

# Low pass FIR filter

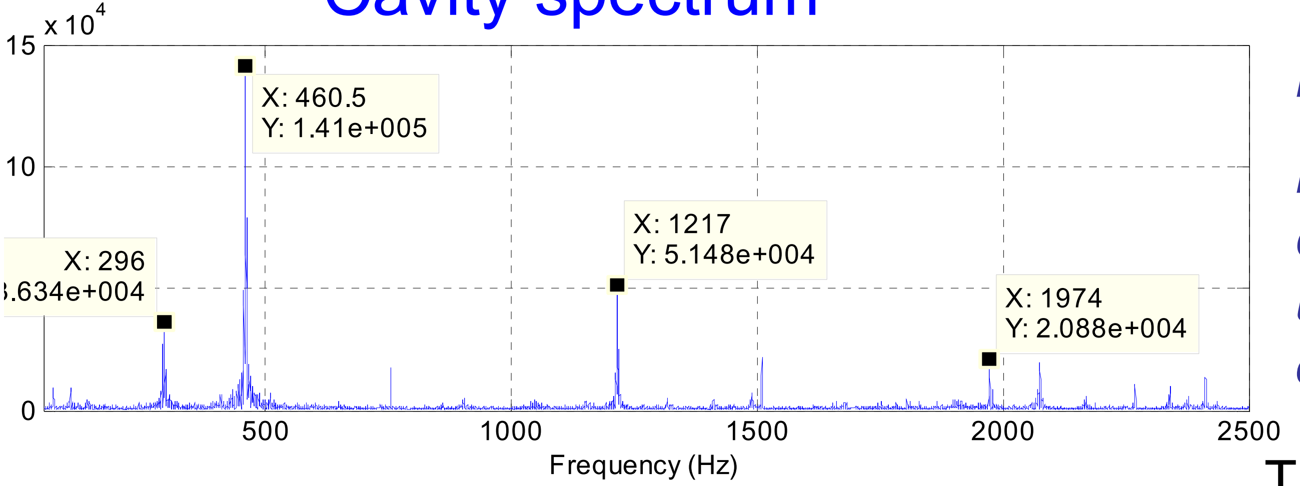



FIR filter was simulated with MATLAB Toolbox which provides a filter coefficients file. This file is added in ISE project root for FIR filter.

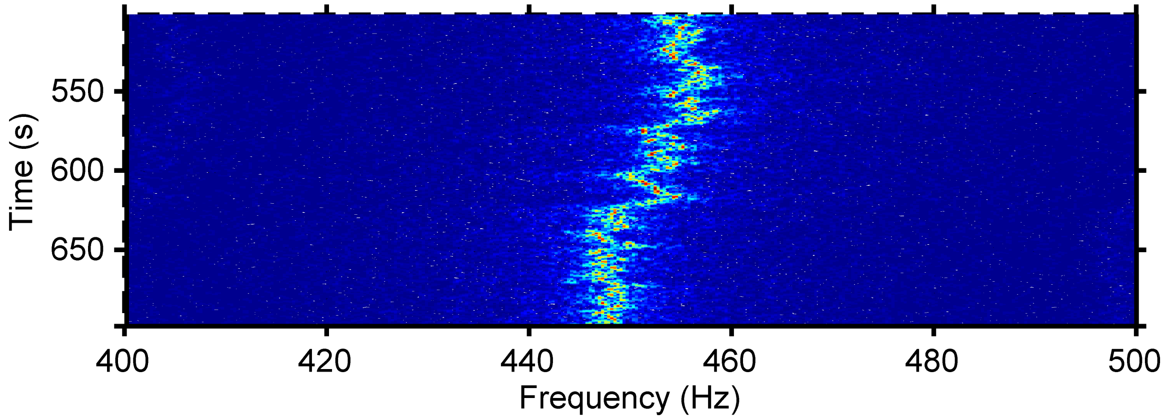
The theoretical results agree with the measurements, as shown.

# Microphonic measurements

## Cavity spectrum




## Cavity 2D spectrogram




*Method :*

*Measurements of cavity microphonic using phase detector on tuning loop.*

The major disturbance, around 460 Hz, is likely related to a mechanical eigenmode of the cavity

The eigenfrequency associated to this mode may change according to the helium pressure.

SOLEIL SYNCHROTRON

R.SREEDHARAN

# Direct and digital feedback simulation model

## First order cavity model

$$\dot{V}_{cr} = \frac{1}{\tau}\left[V_{gr} - V_{cr} - \tan\psi . V_{ci}\right]$$

$$\dot{V}_{ci} = \frac{1}{\tau}\left[V_{gi} - V_{ci} + \tan\psi . V_{cr}\right]$$

## Beam loading

$$V_{cr}^{+} = V_{cr} + \omega_{RF}\left(\frac{R}{Q}\right) q \cos\phi_b$$

$$V_{ci}^{+} = V_{ci} + \omega_{RF}\left(\frac{R}{Q}\right) q \sin\phi_b$$

## Synchrotron motion

$$\Delta E_i^{n+1} = \Delta E_i^{n} - V_c \cos\left[\phi_{b0} + (\delta\phi_b)_i^n - \phi_c\right] - \left(U_0 + D\,\Delta E_i^n\right)$$

$$(\delta\phi_b)_i^{n+1} = (\delta\phi_b)_i^{n} - \frac{2\pi f_{RF}\,\alpha}{f_0\,E_0}\left\{\Delta E_i^n - V_c \cos\left[\phi_{b0} + (\delta\phi_b)_i^n - \phi_c\right] - \frac{U_0 + D\,\Delta E_i^n}{2}\right\}$$

## Direct feedback

$$\tilde{V}_g = \tilde{V}_{g0} + G\left(V_{c0} - \hat{D}\,\tilde{V}_c\right)$$

## Fast I/Q feedback

$$\tilde{V}_g = \tilde{V}_{g0} + G_I\left(V_{c0} - \hat{D}\,V_{cr}\right) - j\,G_Q\,\hat{D}\,V_{ci}$$

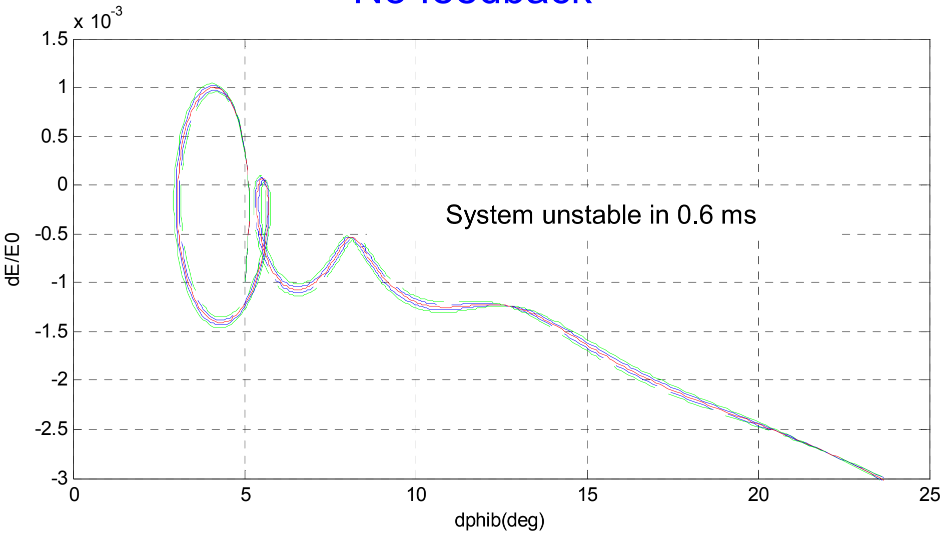
R.SREEDHARAN

# Disturbed beam stability study

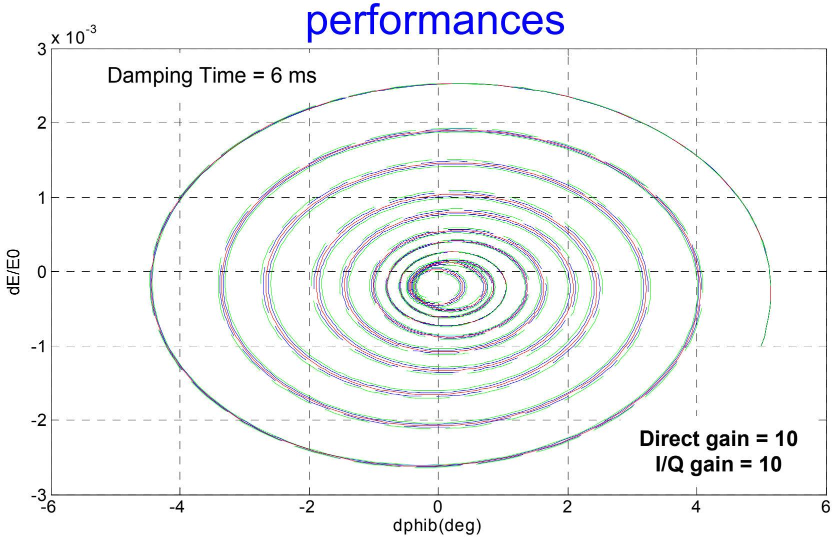
## Disturbance parameters used in simulation

| | |
|---|---|
| Injection phase error (°) | 5 |
| Relative injection energy error (%) | -0.1 |
| 'Real' microphonics (~200 Hz pk-pk detuning) | |

No feedback




Direct RF and Digital I/Q feedback loop performances




Stabilized steady state : microphonics disturbance included

| | |
|---|---|
| Cavity phase residual error | 0.6 ° pk-pk |
| Cavity voltage residual error | 0.08 % |

SOLEIL SYNCHROTRON

R.SREEDHARAN

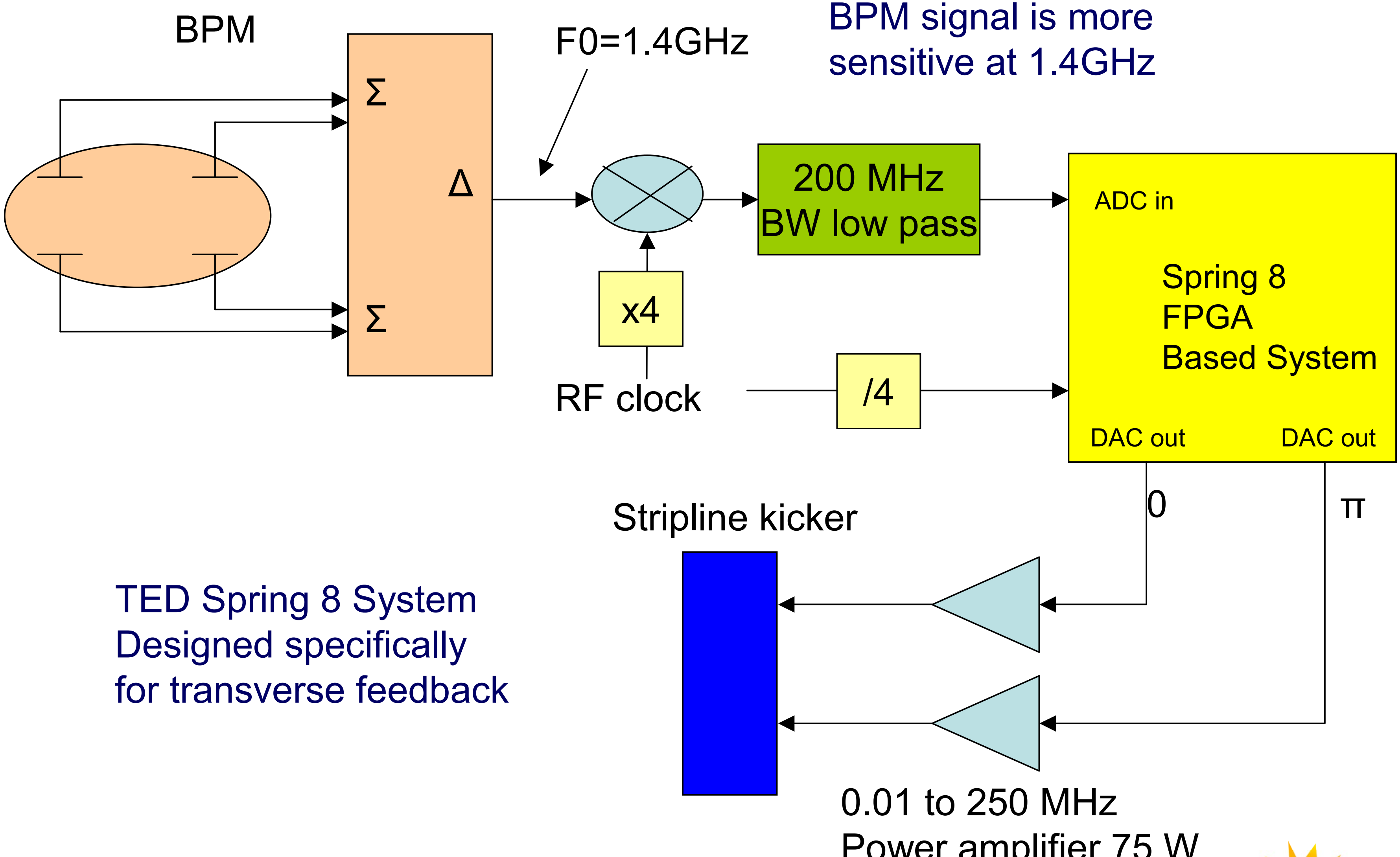
# Transverse feedback under development

Multibunch transverse feedback:

To deal with multibunch instabilities

Status : starting of this project

# Transverse feedback under development




BPM signal is more sensitive at 1.4GHz

TED Spring 8 System
Designed specifically
for transverse feedback