ALBA Digital LLRF

Angela Salom
Francis Perez

- RF & Diagnostics Section -

Outline

- ✓ALBA Overview
- ✓SR RF Plants parameters
- ✓Digital LLRF Conceptual Design
- ✓Hardware Modules
  - Analog Front Ends
  - Timing Systems
  - Digital board: Lyrtech
- ✓Software
  - Loops: Amplitude, phase and tuning
  - Diagnostics
- ✓High Power tests results
- ✓Series Production of LLRF Crates
- ✓IFMIF-LLRF Prototype

ALBA Overview

- ALBA is a 3rd generation synchrotron light source, located at 20 km from Barcelona, Spain.

Picture August 08

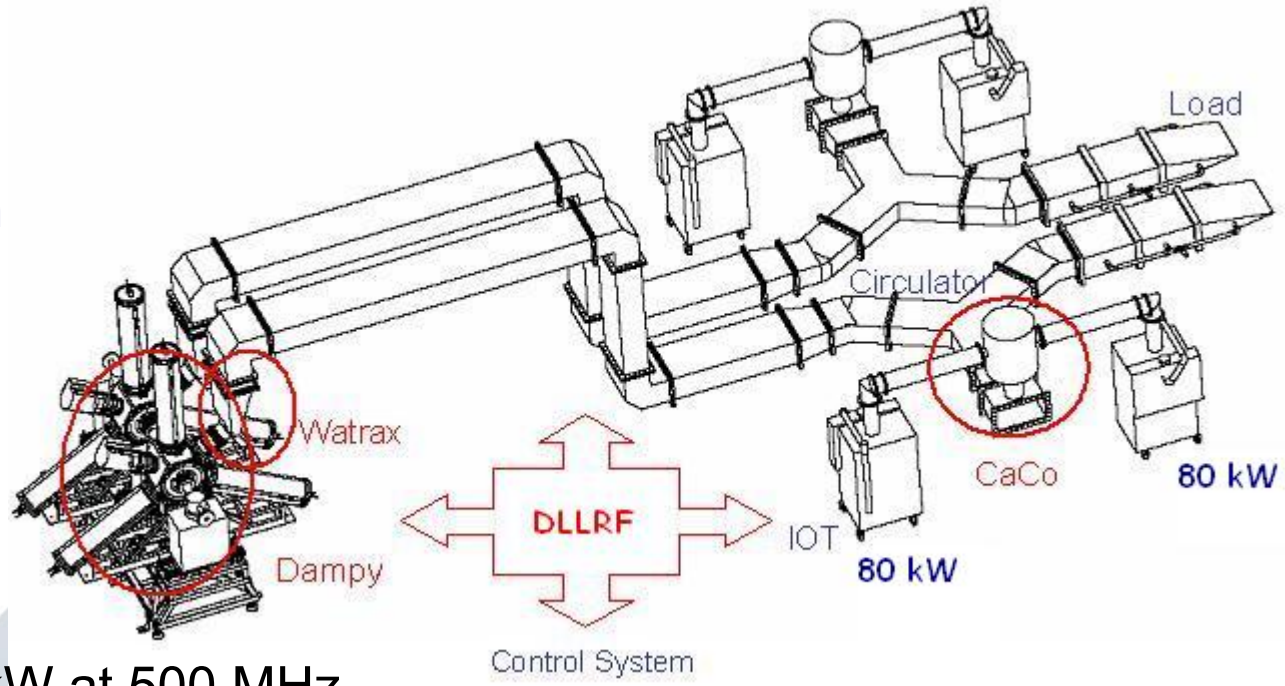
- Main parameters

Energy	3 GeV
Circumference	268m
Beam current	400mA
Emittance	4 nm.rad
Lifetime	≈10h
RF Freq	500MHz
Beamlines	7 at day 1

Storage Ring RF Plants

RF Parameters

U_0	1.3MeV/turn
V_{total}	3.6 MV
q	≈ 2.5
f_s	≈ 9kHz
P_{RF}	960kW



6 RF Plants of 160kW at 500 MHz

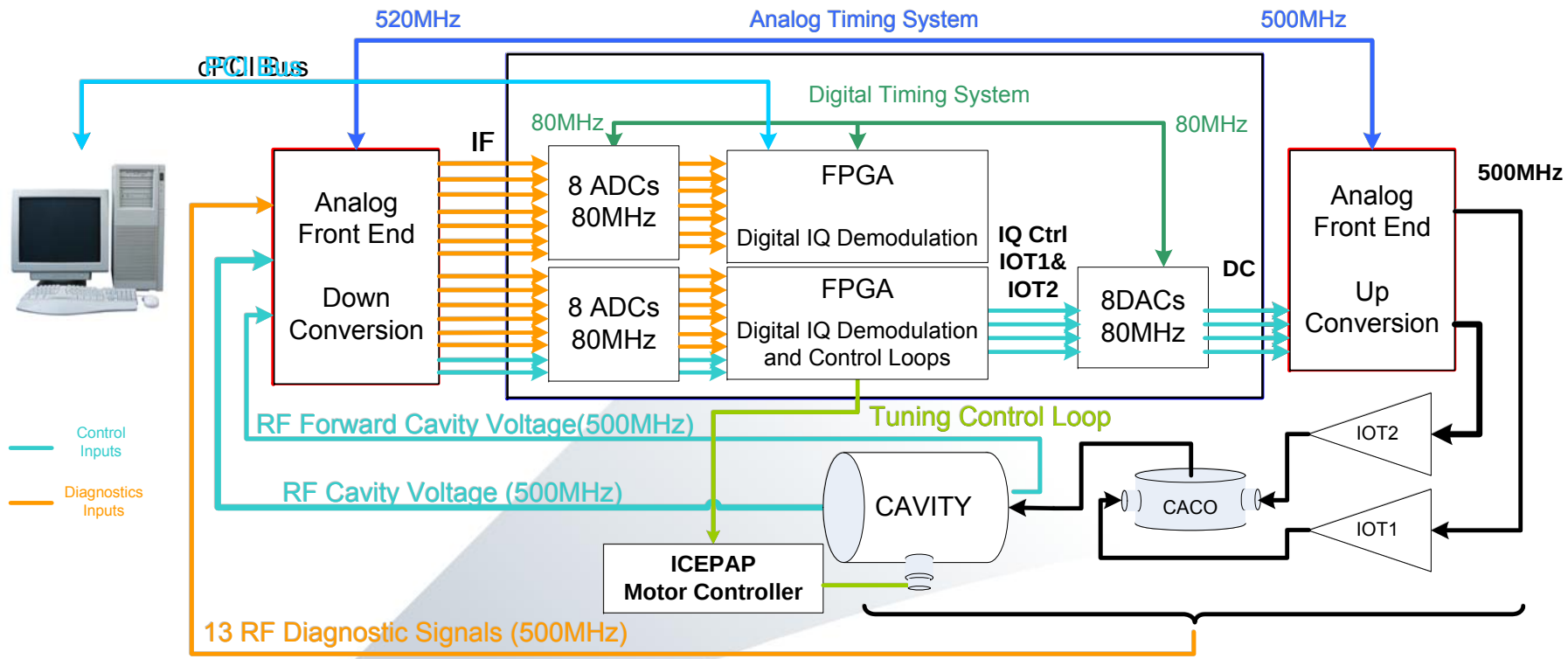
2 IOT Transmitters per RF cavity. Power combined in CaCo

Dampy Cavity

- Normal Conducting
- Single cell, HOM damped
- 3.3 MΩ

Digital LLRF System based on IQ mod/demod

Digital LLRF Conceptual Design



Conceptual Design and Prototype

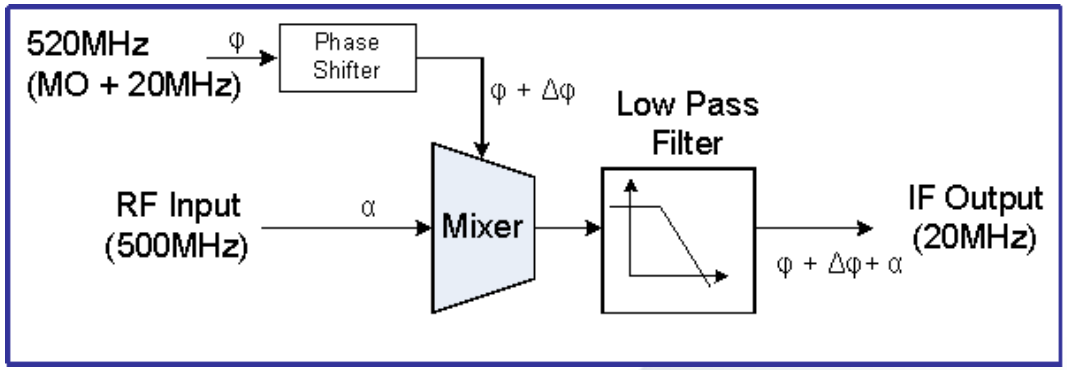
Digital Commercial Board: cPCI with 16 ADCs, 8 DACs and Virtex-4 FPGA

Analog Front Ends for Downconversion (RF to IF) and Upconversion (DC to RF)

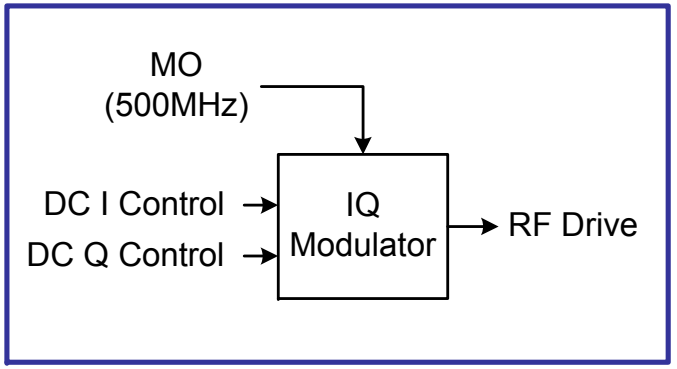
Timing systems: 520MHz (500 + 20 MHz) for downconversion synchronized with digital 80MHz clock for digital acquisition

Front Ends and Timing System

- Downconversion: From RF to IF



- Upconversion: From DC to RF

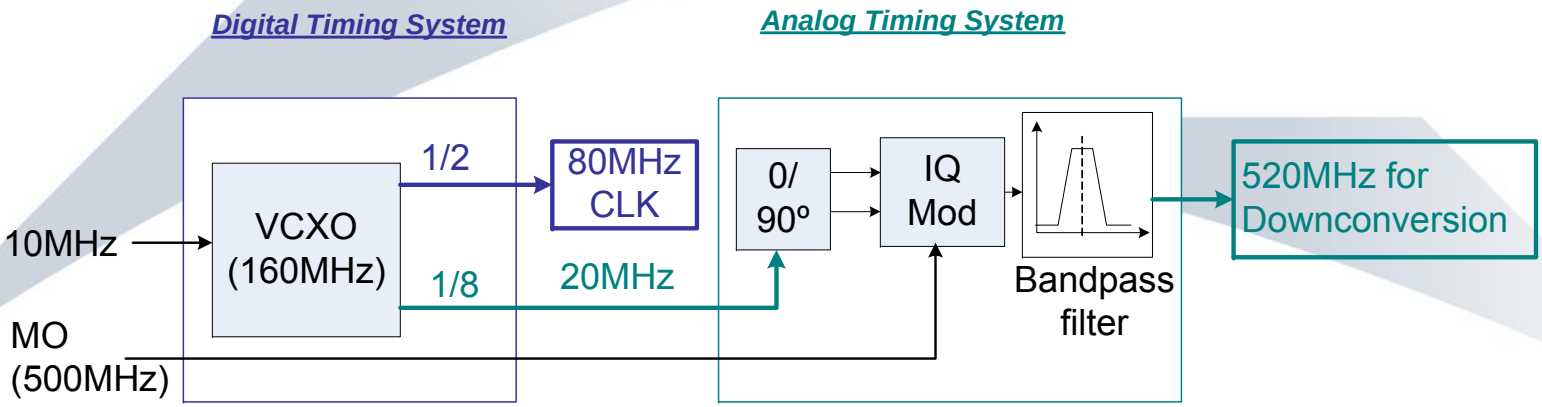


Ref Signal (520 MHz) = MO + IF

ADCs Clock = 4*IF

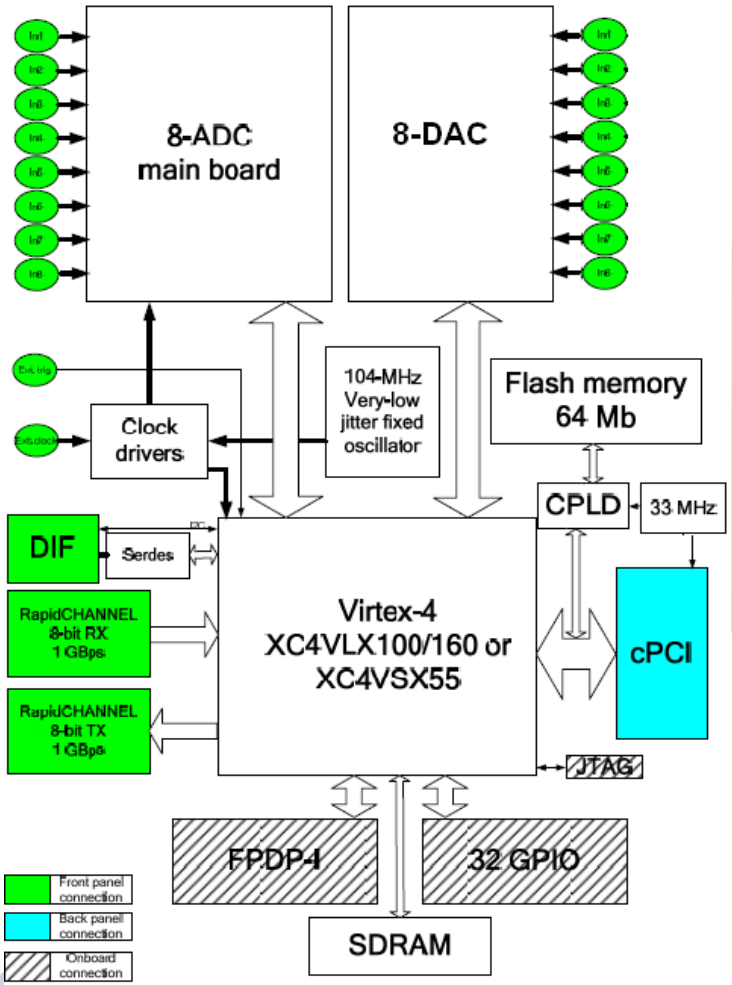
Phase shifter to adjust phase delay lines between RF plants

- Timing Systems



FPGA Board

- Lyrtech: VHS ADAC-4



cPCI format

2 x 8 ADCs 125 MHz 14 bits

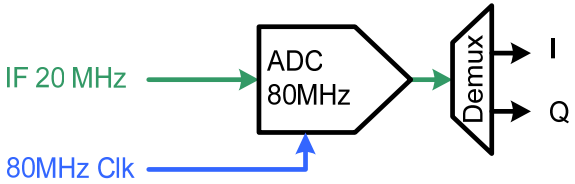
8 DACs 125MHz 14 bits

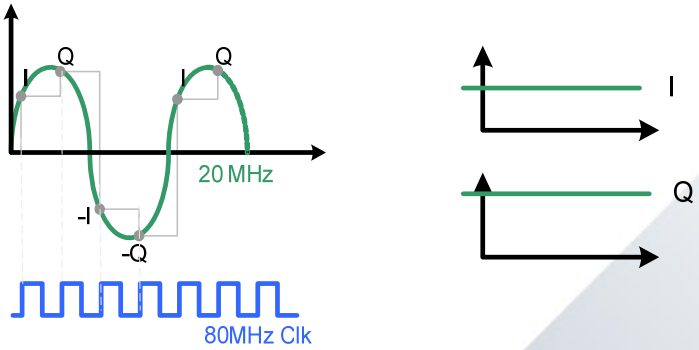
2 x Virtex 4

128 Mbytes RAM

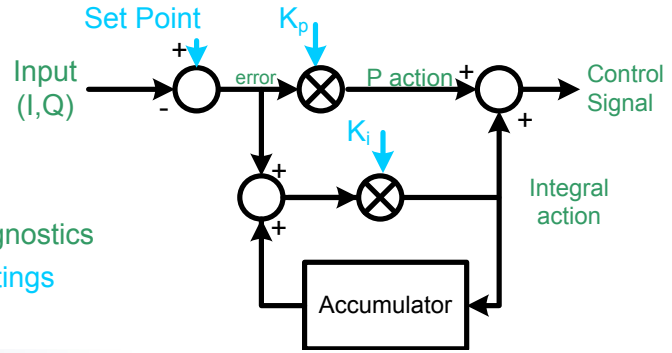
Amplitude and Phase Control Loops

Digital IQ Demodulation





PID Control Loop for IQ



Diagnostics signals of Loops

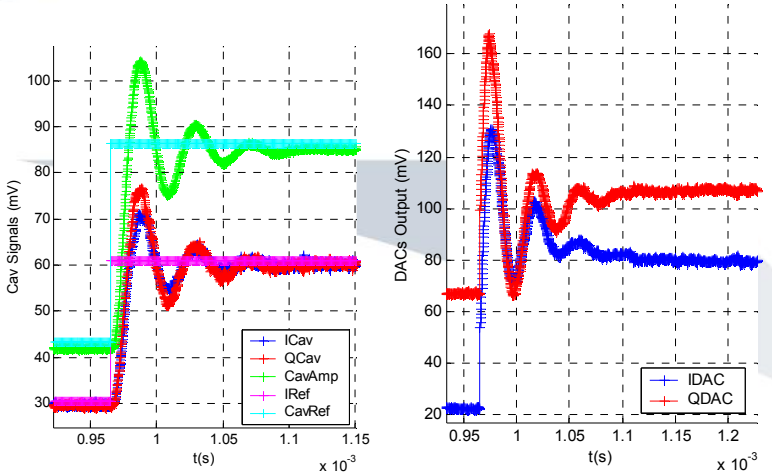
IQCav
Cav Amplitude
Cav Phase

IQ Error
IQ Integral Action
IQ PID Output

IQ Fw
Fw Amplitude
Fw Phase

Control Amplitude
Control Phase

Step response in Close Loop (Cav&DACs)

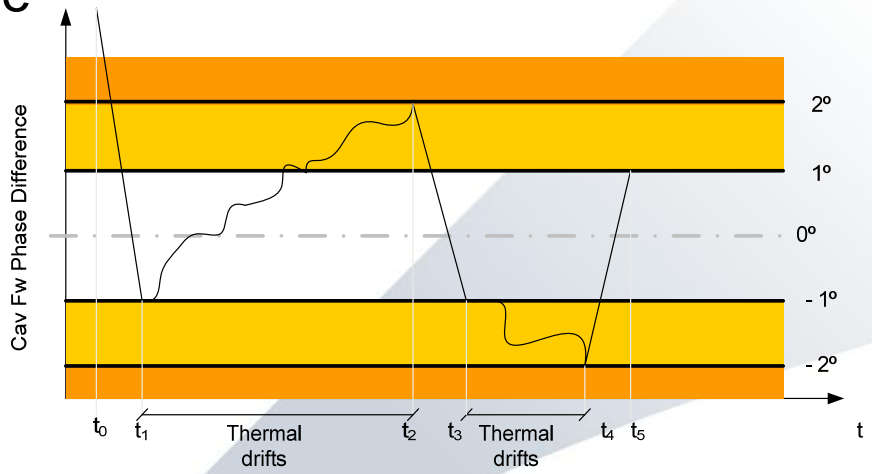


Tuning Loop

- Cordic Algorithm to calculate Cav – Fw phase difference

  Iterative process to calculate phase without employing any multipliers
  Resolution better than 0.001º after 16 iterations (1/80MHz * 16 = 0.2 µs)

- Tuning Loop not always active to avoid plunger oscillations around 0º phase



$t=t_0$	$\Delta\varphi > 2º$	Tuning On
$t=t_1$	$\Delta\varphi = -1º$	Tuning Off
$t=t_2$	$\Delta\varphi > 2º$	Tuning On
$t=t_3$	$\Delta\varphi = -1º$	Tuning Off
$t=t_4$	$\Delta\varphi < -2º$	Tuning On
$t=t_5$	$\Delta\varphi = 1º$	Tuning Off

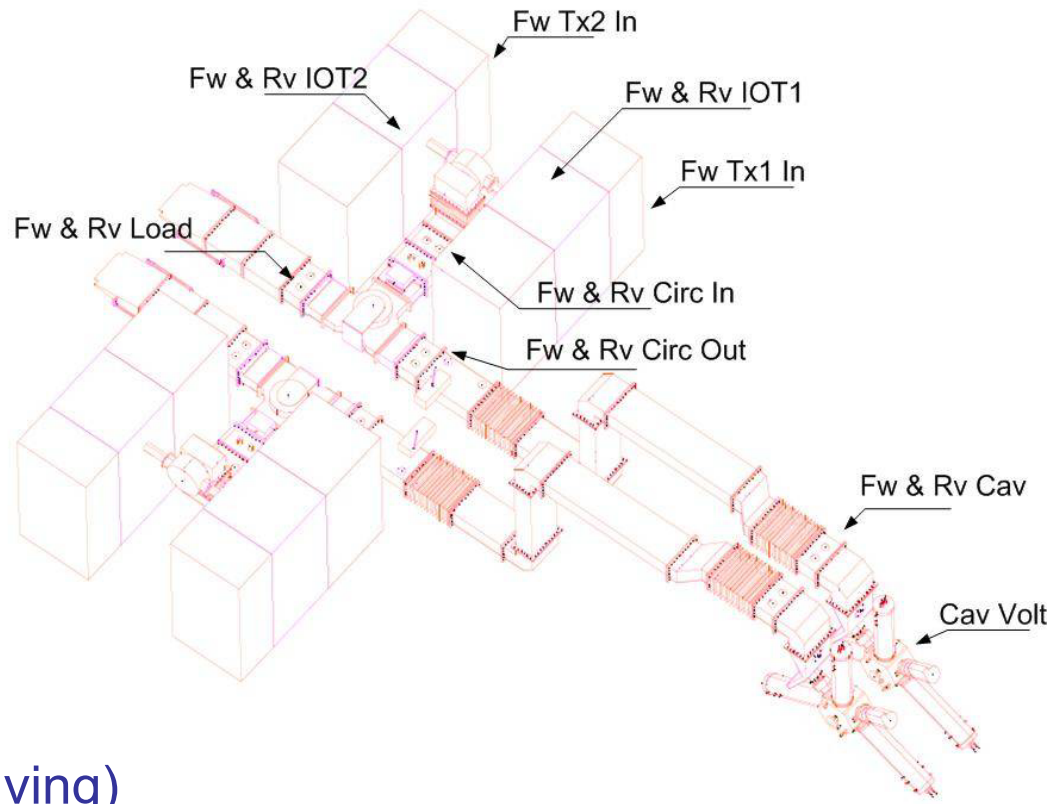
- Phase measurements filtered at 2.4kHz rate to remove any noise.

Resolutions achieved = 0.01º

Diagnostics

Other RF signals Digital IQ Demodulated

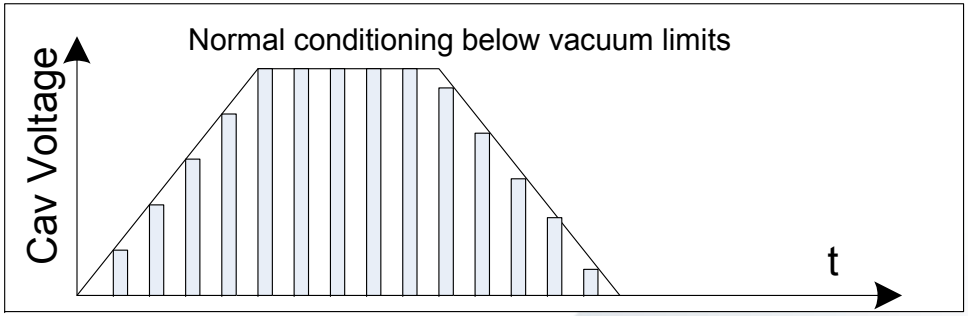
- ✓Cavity
  - Cavity Power
  - Forward and Reversed Cavity Power
- ✓ Waveguide System
  - Fw and Rv Circulator Input
  - Fw and Rv Circulator Output
  - Fw and RV Load Power
- ✓Transmitter Signals
  - Fw Transmitter1 Input Power
  - Fw Transmitter2 Input Power
  - Fw and Rv IOT-01 Power
  - Fw and Rv IOT-02 Power



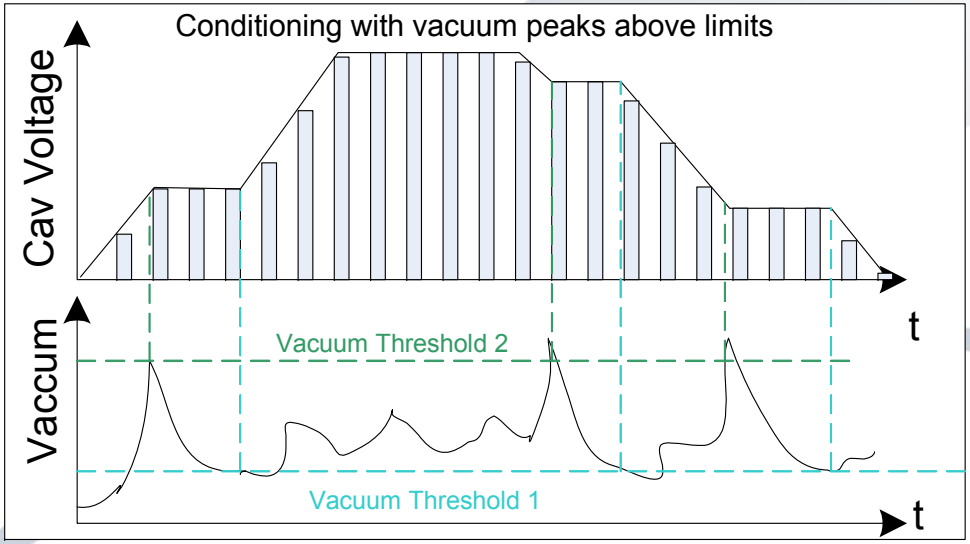
- ➢Slow Diagnostics: 1Hz rate (archiving)
- ➢Fast Diagnostics: Circular buffer of 128MBytes @ 80MHz (~ 50ms) Data retrieved after interlock happens or after user demand

Automated Conditioning

- Amplitude and duty cycle increase depending on vacuum levels
- 2 slow vacuum interlocks connected to LLRF



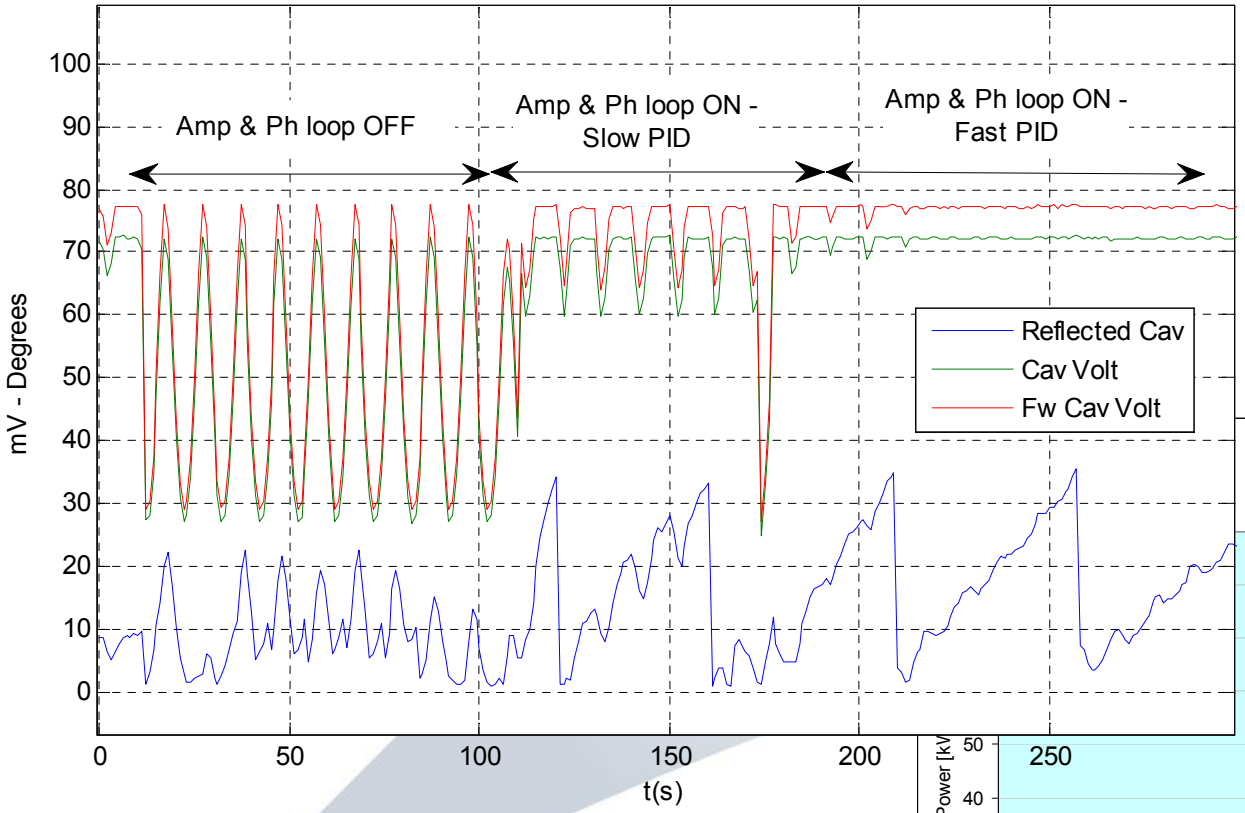
- No vacuum peaks
  - Adjustable amplitude slope
  - Adjustable duty cycle



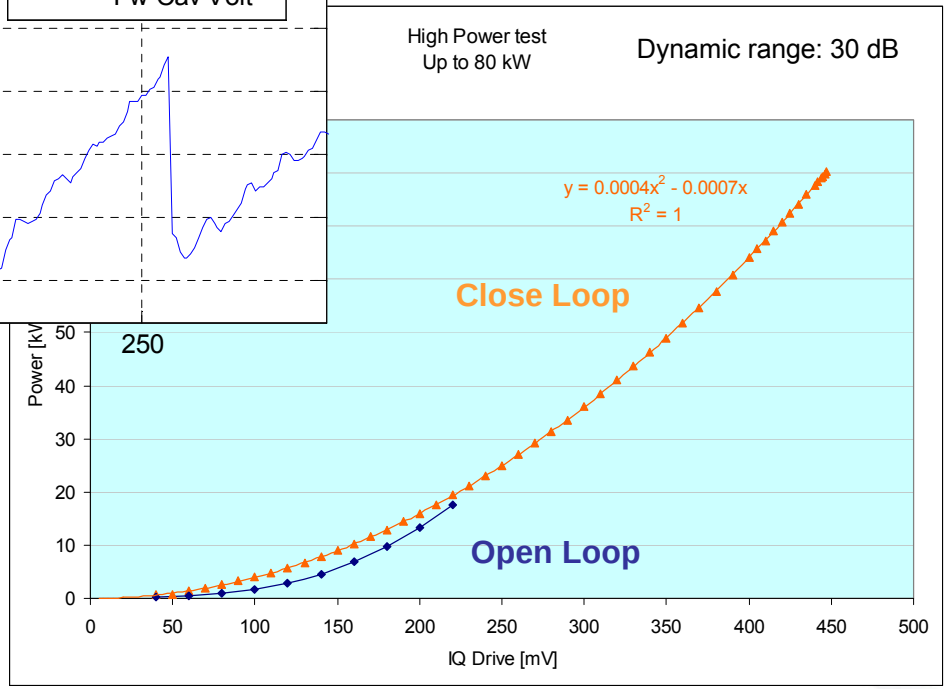
- Vacuum peaks above limits
  - Amplitude stops increasing when reaching upper vacuum limit, until vacuum comes back to lower limit

Power Tests

Loops performance:



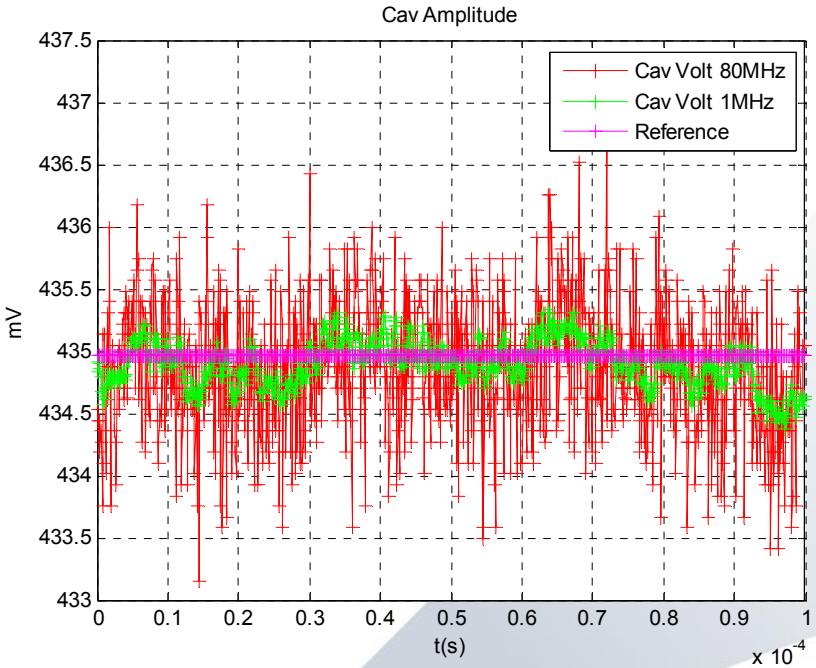
Amplitude, Phase and Tuning loops simultaneously in operation



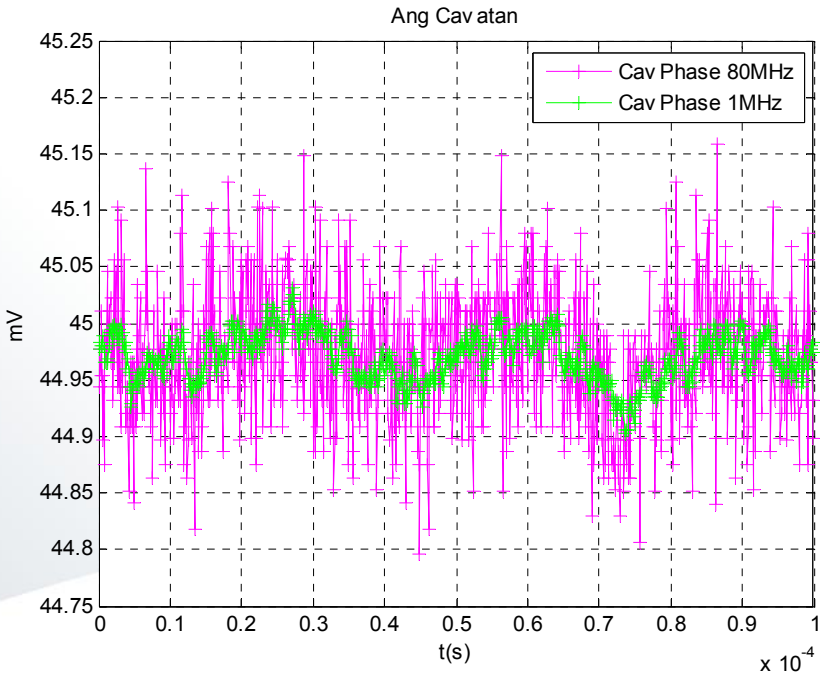
Power tests at ALBA High Power RF Lab from 80w to 80kW

Amplitude and Phase loops

Amplitude Resolution (75kW)



Phase Resolution (75kW)



Amplitude RMS Errors:

δV_{rms} = 0.50mV/435mV = 0.11% @ 80MHz

δV_{rms} = 0.18mV/435mV = **0.03% @ 1MHz**

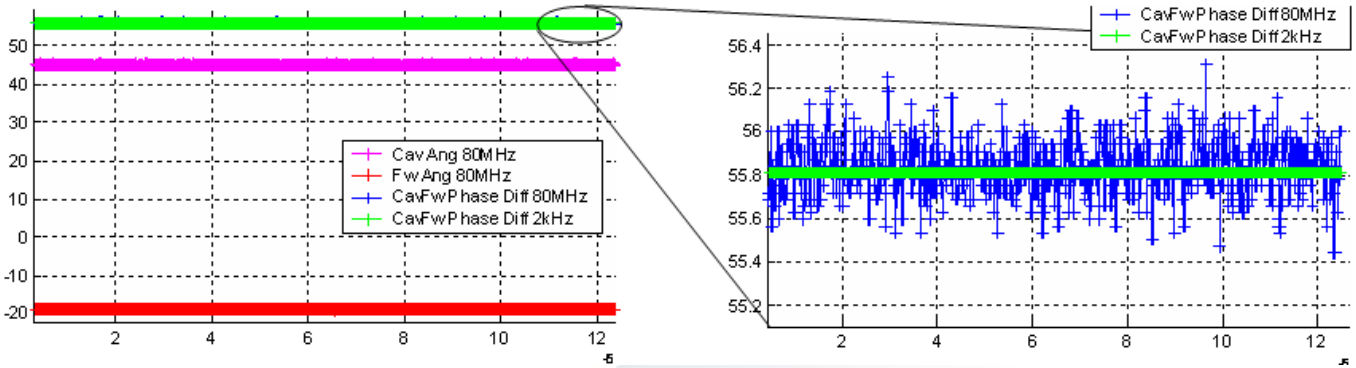
Phase RMS Errors:

δPh_{rms} = 0.05º @ 80MHz

δPh_{rms} = **0.02º @ 1MHz**

Tuning Loop

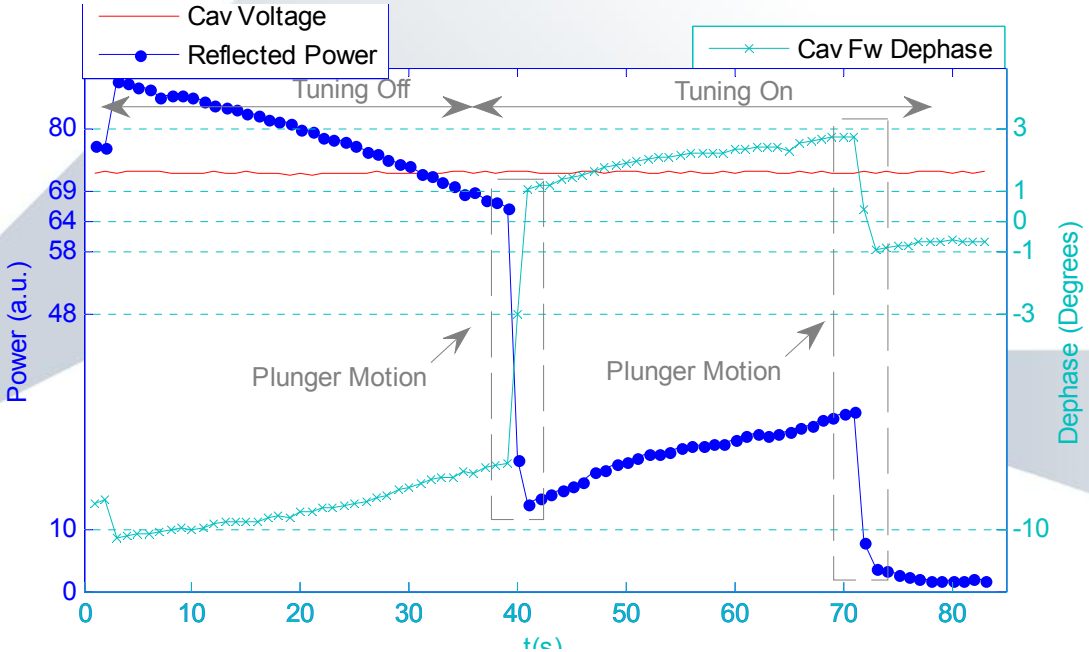
➢Tuning Inputs filtering



Cav-Fw Phase

< 0.01º @ 2.4kHz

➢Tuning Deadband

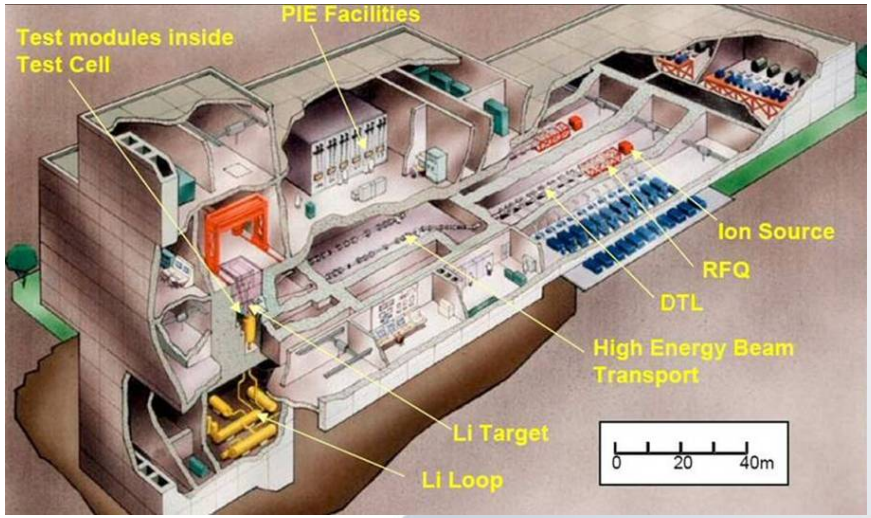


LLRF Crates Series Production

- All components received from January – June 2008
- Production started in July 2008
  - 66% completely finished
  - 10% in process
  - 20% to be finished in October
- LLRF racks pre-assembly starting in November 2008

IFMIF LLRF Prototype

➢ CELLS and CIEMAT have signed and agreement to develop a LLRF prototype for the accelerator IFMIF-EVEDA (**I**nternational **F**usion **M**aterials **I**rradiation **F**acility - **E**ngineering **V**alidation **E**ngineering **D**esign **A**ctivities)



✓ IFMIF: Future irradiation tool, aiming at qualifying advanced materials resistant to extreme conditions, specific to fusion reactors that will succeed to ITER

✓ IFMIF-EVEDA: the construction of prototypes of the main units (prototype accelerator, lithium target and test cells)

➢ IFMIF LLRF prototype

✓Based on ALBA Prototype (Lyrtech VHS-ADAC + Front module)
✓Control loops of two RF chain per LLRF
✓Fast Interlock Module integrated in LLRF
✓RF Frequency 175MHz
✓3 Kind of cavities: DTL, RFQ and SC HWR