Digital LLRF: ALBA and Max-IV cases

RF&Linac Section - ALBA Accelerators Division

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Outline

- ✓ ALBA Overview
- ✓ ALBA LLRF
  - Conceptual Design
  - Main Functionalities and extra utilities
  - Future upgrades
- ✓ Max-IV Overview
- ✓ Max-IV LLRF
  - Conceptual Design
  - Extra Utilities
  - Future upgrades
- ✓ Summary and conclusion

ALBA Overview

ALBA Overview

ALBA is a 3rd generation synchrotron light source, located at 20 km from Barcelona, Spain, in operation with users since May 2012

Accelerators Main Parameters

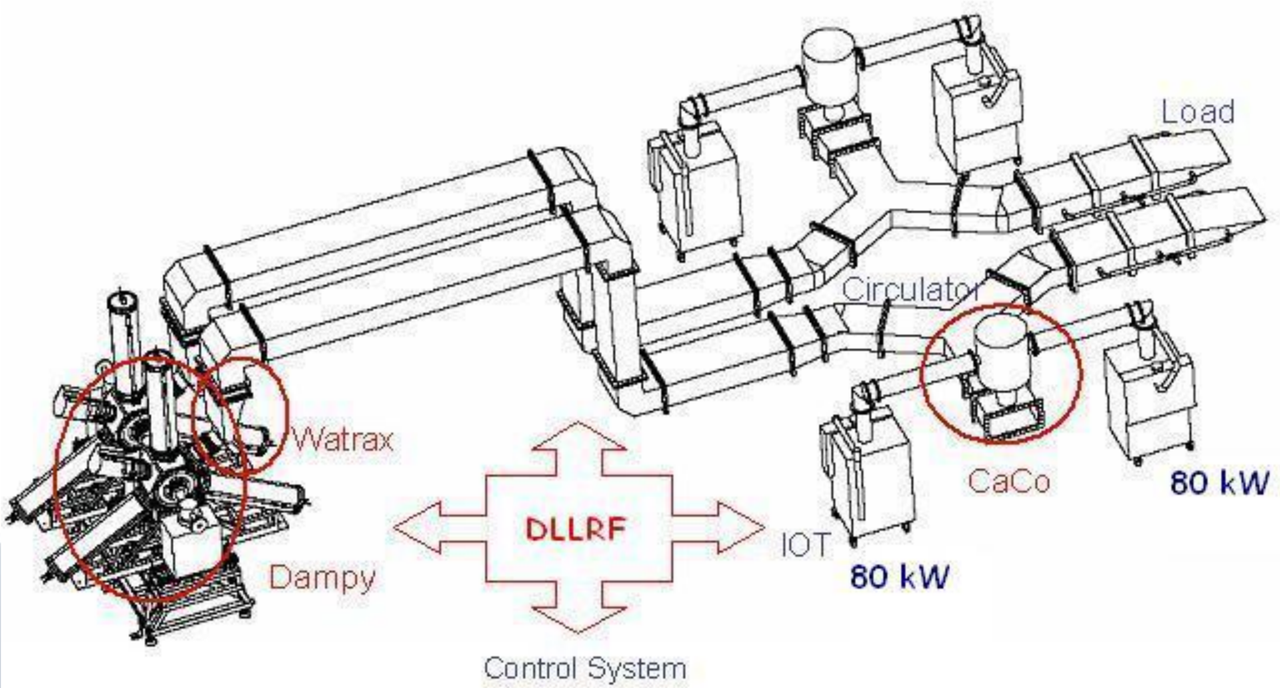
Energy	3GeV
Circumference	268m
Beam Current	400mA
Emittance	4nm.rad

Lifetime	≈10h
RF Freq	500MHz
Beamlines	up to 34

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

ALBA LLRF Conceptual Design

ALBA LLRF

Main Characteristics

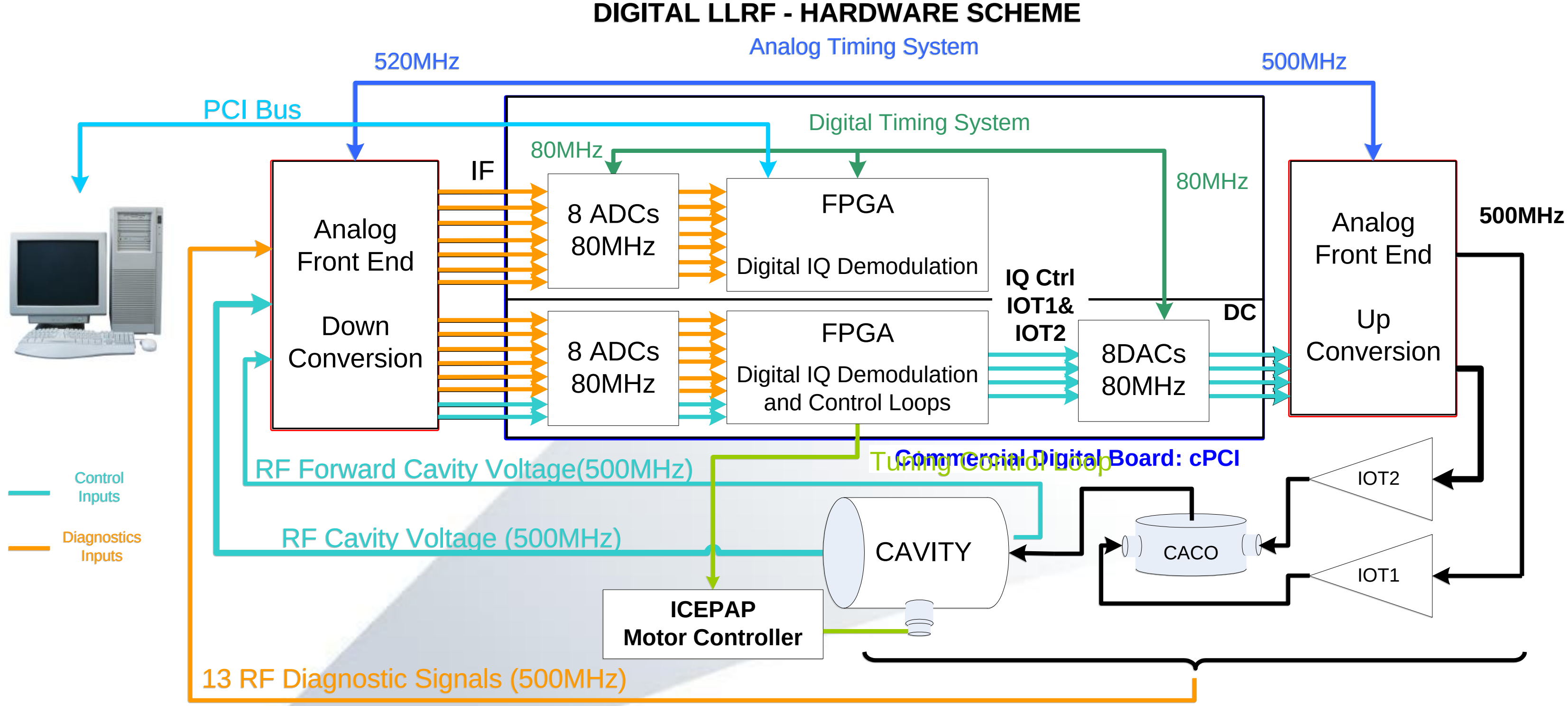
- ✓ Based on digital technology using a commercial cPCI board with FPGA
- ✓ Signal processing based on IQ demodulation technique
- ✓ Main loops: Amplitude, phase and tuning

Digital board: VHS-ADC from Lyrtech

Loops Resolution and bandwidth (adjustable parameters)

	Resolution	Bandwidth	Dynamic Range
Amplitude Loop	< 0.1% rms	[0.1, 50] kHz	30dB
Phase Loop	< 0.1º rms	[0.1, 50] kHz	360º
Tuning	< ± 0.5º	--	< ± 75º

LLRF Conceptual Design



Conceptual Design and Prototype

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

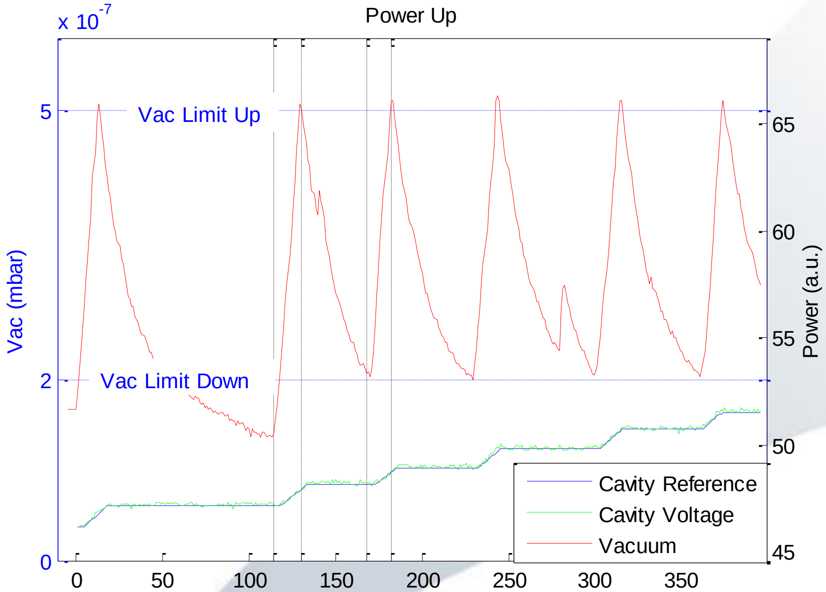
Digital Commercial Board: cPCI with 16 ADCs, 8 DACs and Virtex-4 FPGA

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

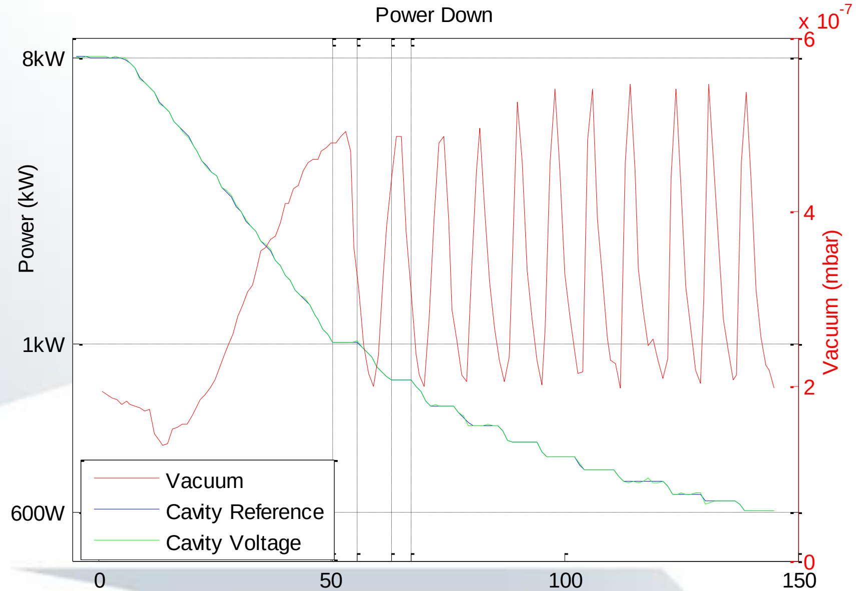
Extra Utilities of ALBA LLRF

Automatic Conditioning

- ✓ Square modulation of RF Drives at 10Hz
- ✓ Amplitude and duty cycle of RF Drive automatically adjusted by LLRF depending on vacuum pressure levels



Voltage Increase rate set to 0.03mV/s



Voltage Decrease rate set to 1mV/s

- Vacuum < Limit Down → Voltage Amplitude Increases/Decreases
- Vacuum > Limit Up → Voltage Amplitude remains constant until vacuum is below limit down

This system allowed to condition the last SR cavity in less than a week

RF Autorecovery with beam

✓ **Why we need Autorecovery with beam?**

- One cavity -out of six- trips
- Beam is not lost
- One wants to recover the tripped cavity with heavy beam loading

✓**New Automatic Start up – to take into account beam loading:**

- When RF trip

- Open loops (I&Q)
- Disable tuning
- Detune cavity (parking) by moving the plunger 30,000 steps up

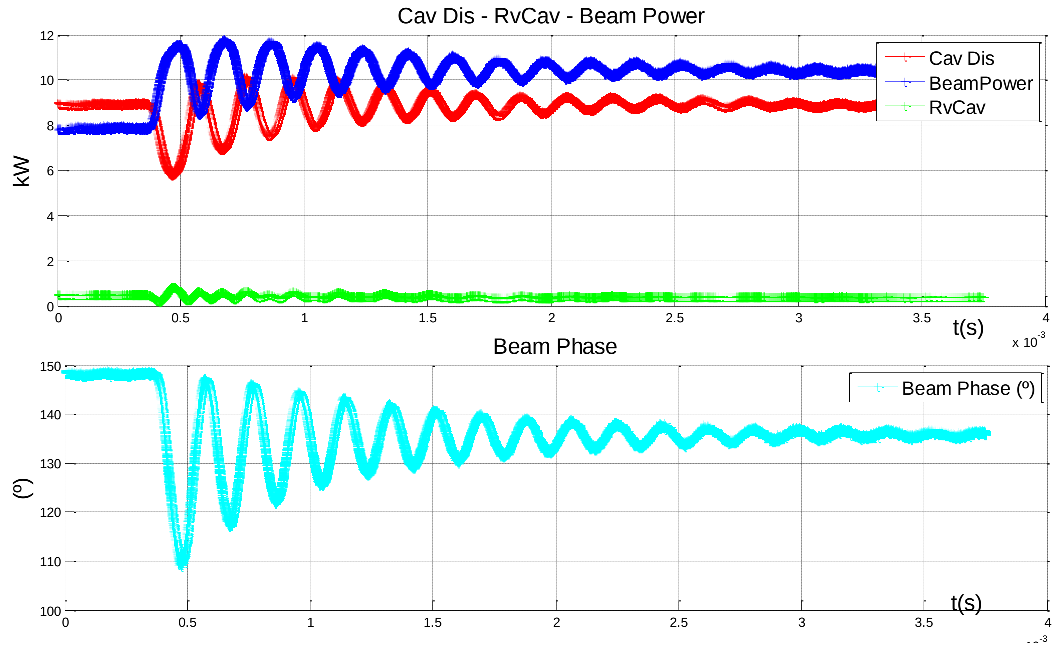
- When RF ON:

*- **IOT power high enough** to induce more voltage in the cavity than the beam loading after unparking*
- Amplitude and phase loops open because cavity is completely detuned
- Phase and amplitude of LLRF adjusted to have very similar conditions in open loop and close loop
- Plunger moved back 30,000 steps to tune cavity (unparking)
- Tuning enabled
- Amplitude and phase loops closed
- Smooth power increase

Fast Data Logger

Post Mortem Analysis Example: Transient after one cavity failure and beam survival

- ✓Power to beam increases
- ✓Beam phase gets reduced
- ✓Frequency oscillations ~ 6kHz (synchrotron freq)
- ✓Stabilization time ~ 3ms (longitudinal damping time)

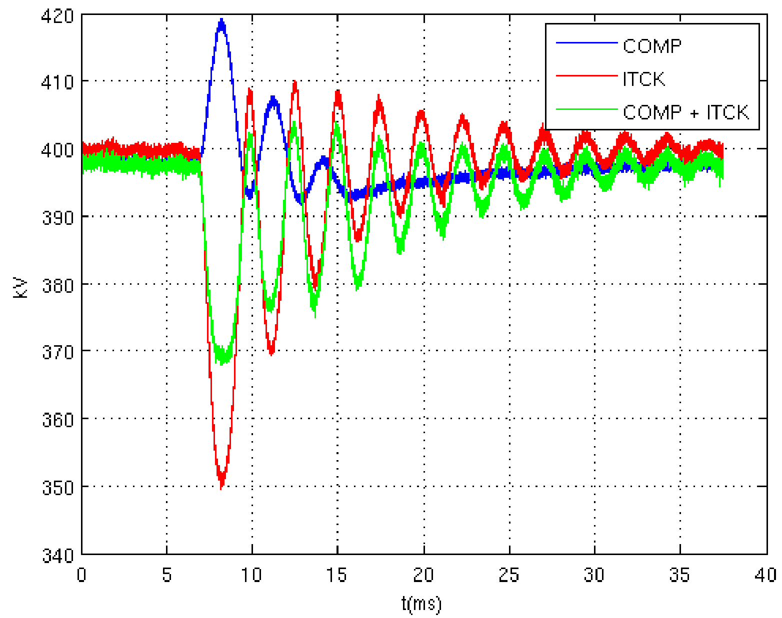


Behavior of one cavity and a trip in another cavity at 61mA and no beam dump (61mA)

Future upgrades of ALBA LLRF

Feedforward Loop for RF Trip transient

Feedforward loop to compensate transient when RF cavity trips



✓When cavity trips

- Cavity Voltage oscillates with frequency equal to synchrotron tune
- Transient time equal to damping time of machine

✓Compensation

- Amplitude modulation triggered when one cavity trips
- Frequency, amplitude and phase of modulation are adjustable parameters

✓ First tests with beam

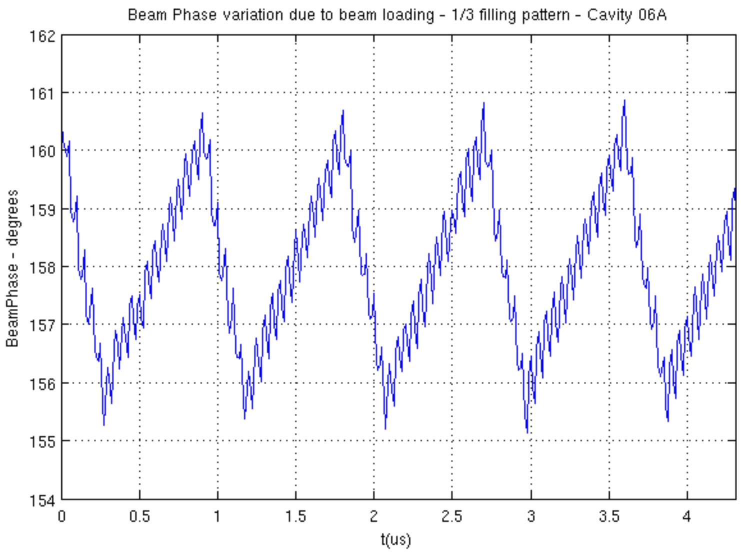
- First ripple of transient reduced, but following increased
- **Next step: to modulate phase of the RF Drive instead of Amplitude**

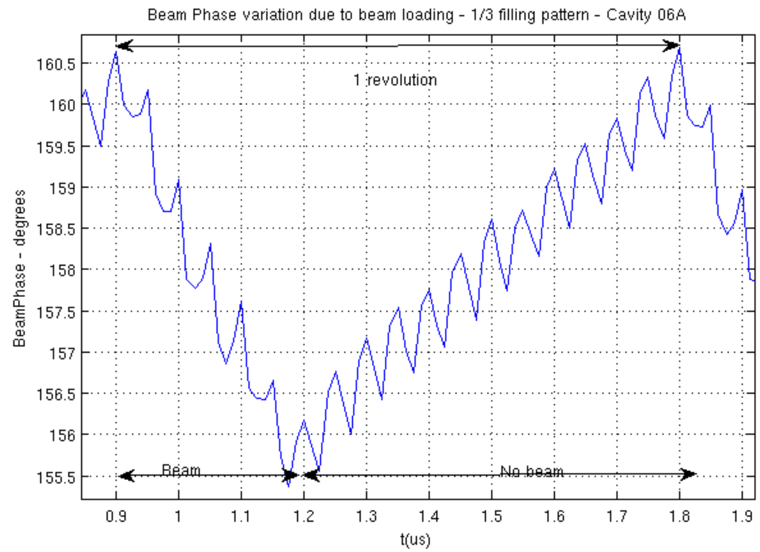
FF Loop for beam loading compensation

✓ **In Normal Operation: Effect of beam loading negligible**

- *Revolution frequency ~ 1MHz*
- *90% Filling Pattern*
- *10 trains: 10 x (32 bunches + 12 empty buckets)*

✓ **Filling Pattern modified to 1/3 to measure beam loading**



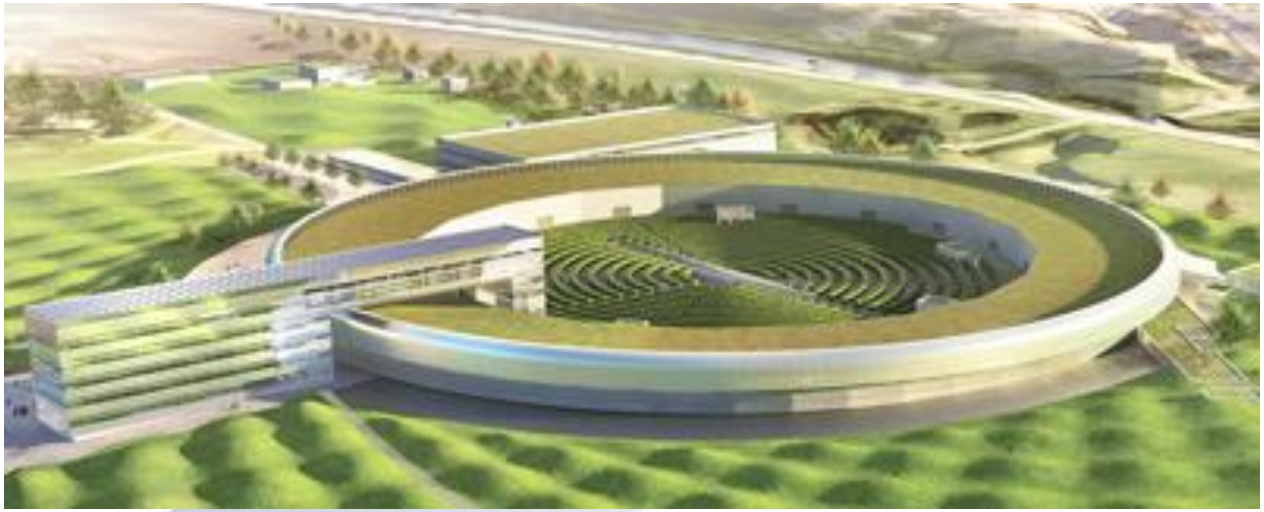


- *Beam Phase modified by 5º due to beam loadign effect*
- *Future upgrade: Phase modulation (feed-forward loop) to compensate this effect*

Max-IV Overview

ALBA Overview

Max-IV will be a 3rd generation synchrotron light source, located in Lund, Sweden. Inauguration foreseen for June 2016



Accelerators Main Parameters

Full Injector Linac + 2 SR (1.5GeV and 3GeV) → Option for FEL upgrade

Circumference	528m
Beam Current	500mA
Emittance	< 0.3 nm.rad
RF Freq	100MHz

Max-IV LLRF

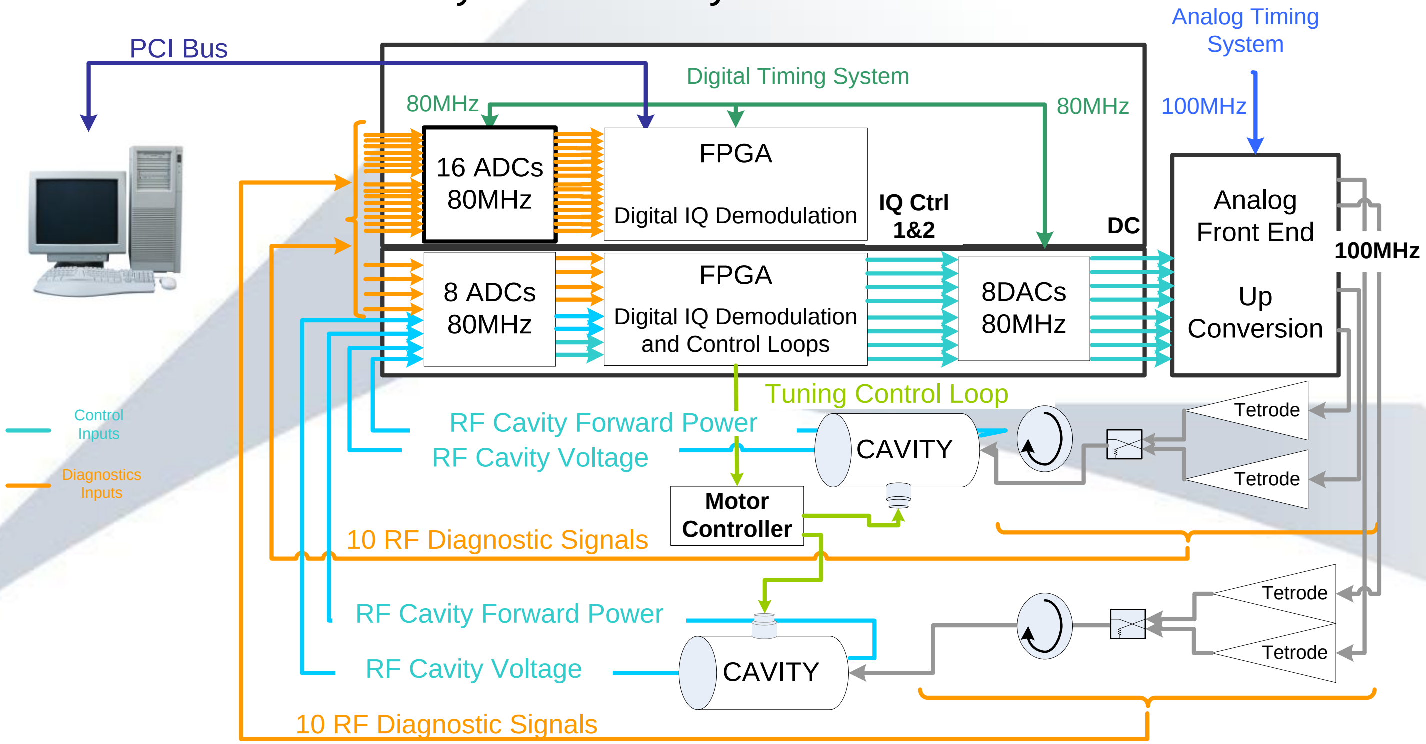
Max-IV LLRF Design based on ALBA LLRF

Similarities:

- ✓ Based on digital Commercial Boards with FPGA, ADCs & DACs
- ✓ Based on IQ modulation/demodulation technique
- ✓ Main Loops: Amplitude, Phase and Tuning of the Cavity

Main differences:

- ✓ 100MHz RF Signals sent directly to ADCs – No Downconversion
- ✓ Two Cavities controlled by one LLRF system



Max-IV Extra Utilities

Fast Interlock Utility

- ✓ When fast interlock detected, RF Drive cut in less than 10us
- ✓ Fast interlocks are:
  - ✓Reverse power of cavity
  - ✓Arcs
  - ✓ Vacuum peak

3rd Harmonic Cavity Tuning - 300MHz

Possibility to control Cavity Voltage or Forward Power of Tetrode

Automatic Startup

Automatic Conditioning

Fast Data Logger for post-mortem analysis

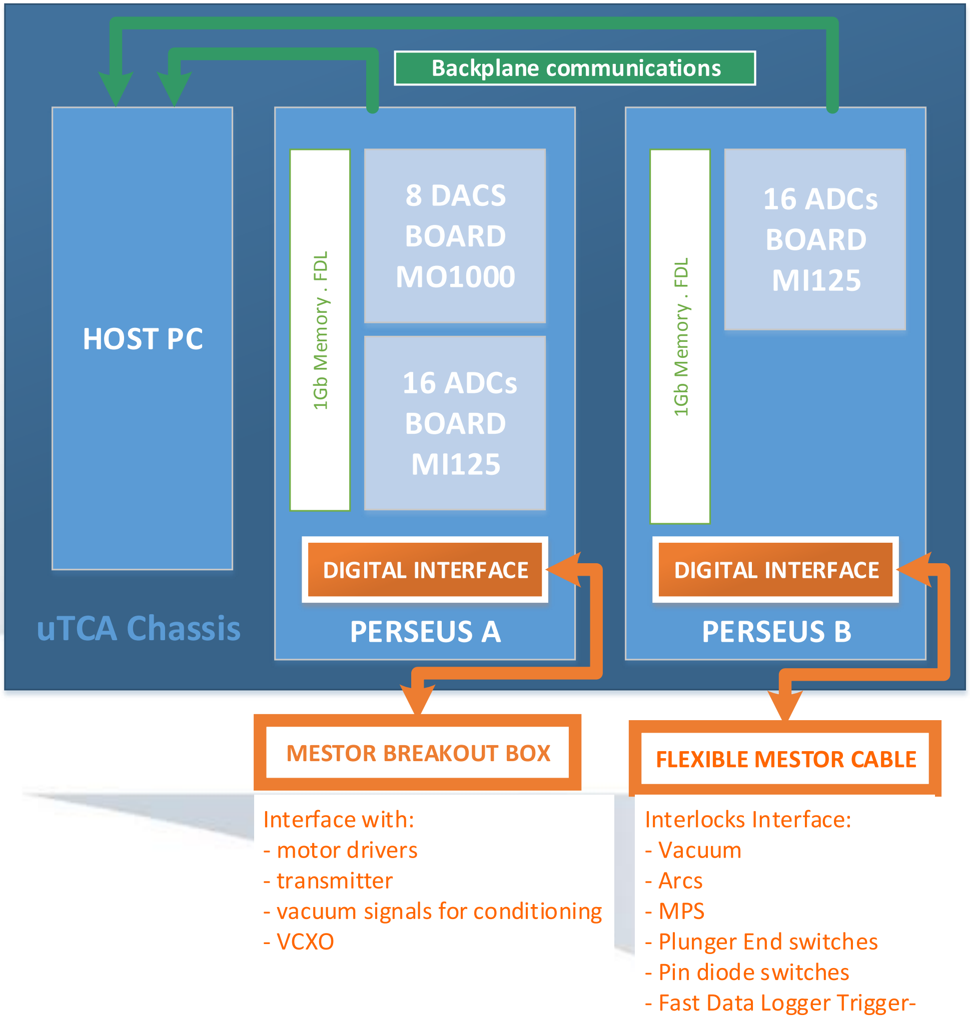
Max-IV Status and future upgrades

Status:

- ✓ Prototype tested in Max-II with 2 cavities
- ✓ Prototype being used for conditioning of cavities of Max-IV Rings
- ✓ 97% of the FPGA resources already used

Future Upgrades: Perseus

- ✓ New hardware platforms available for same price and more powerful
- ✓ Perseus System: uTCA carrier with FPGA Virtex-6 + FMC modules (daughter boards) with fast ADCs and DACs
- ✓ Firmware already migrated to new FPGA board. Only 12% of resources were used
- ✓ Tests with high power to be done in Summer 2014



Summary and Conclusions

ALBA LLRF system:

- ✓ In operation for several years and meets requirements
- ✓ Constant upgrades to improve reliability of RF systems: Automatic recovery + feed-forward loops

Max-IV LLRF System

- ✓ Main functionality of system already tested
- ✓ Working on hardware upgrade before starting series production

Main advantages of Digital Low Level RF Systems:

- ✓ High flexibility
- ✓ Upgrades based just on firmware modifications (low cost)
- ✓ Firmware can be easily migrated to different hardware platforms

Thanks for your attention

Questions?