Libera LLRF

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Outline

- Libera LLRF introduction
- Libera LLRF system topology
- Signal processing structure
- GUI and signal acquisition
- RF system diagnostics
- RF system tuning
- Demonstration of Libera LLRF on site
- Beam loading measurements
- Further developments

Introduction

- LLRF system with 38 RF input channels up to 12 GHz (in a 19” 2U chassis)
- Built-in sophisticated RF system diagnostics
- Reliable interlock system and chassis health monitoring
- Cavity field stabilization and cavity tuning
- Built in RF calibration and temperature stabilization systems
- Phase and amplitude stability meets 4th generation light sources’ requirements
- Compatible with normal-conducting and super-conducting RF systems in pulsed and continuous wave operation modes

System Topology

- **RF frontend acquisition modules:**

9 RF input channels with frequency conversion (up to 12 GHz)

9x 16 bit ADCs (130 MS/s)

Virtex 5 FPGA

DDR2 RAM (up to 8 Gbits)

- **Vector Modulation module:**

Virtex 5 FPGA

DDR2 RAM (up to 8 Gbits)

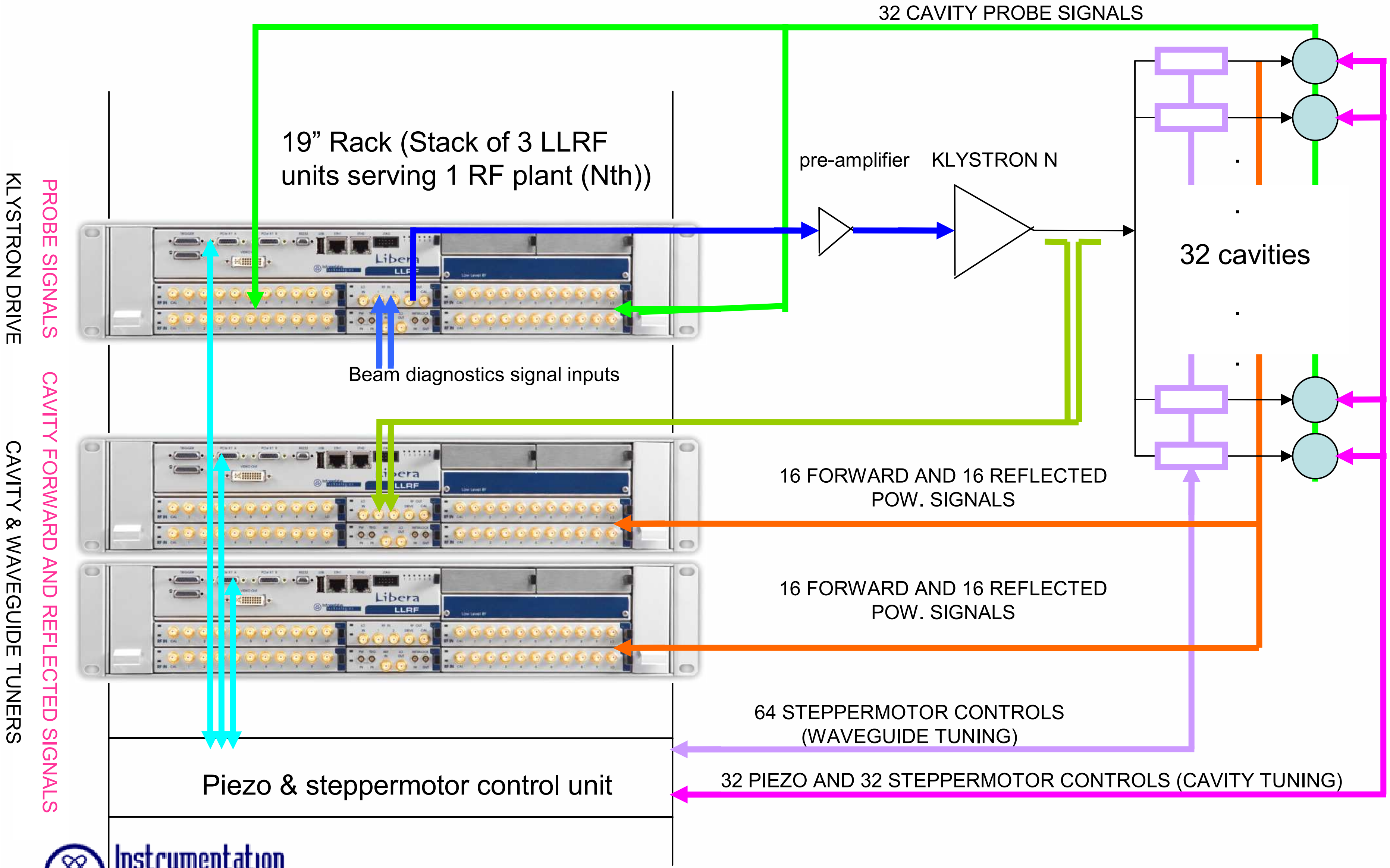
2 RF output channels

2 additional RF input channels

- **Timing module: Generates a low jitter local oscillator signal and the sampling clock.**
- **Computing ICB module: Provides additional computing power, connectivity and flexibility.**

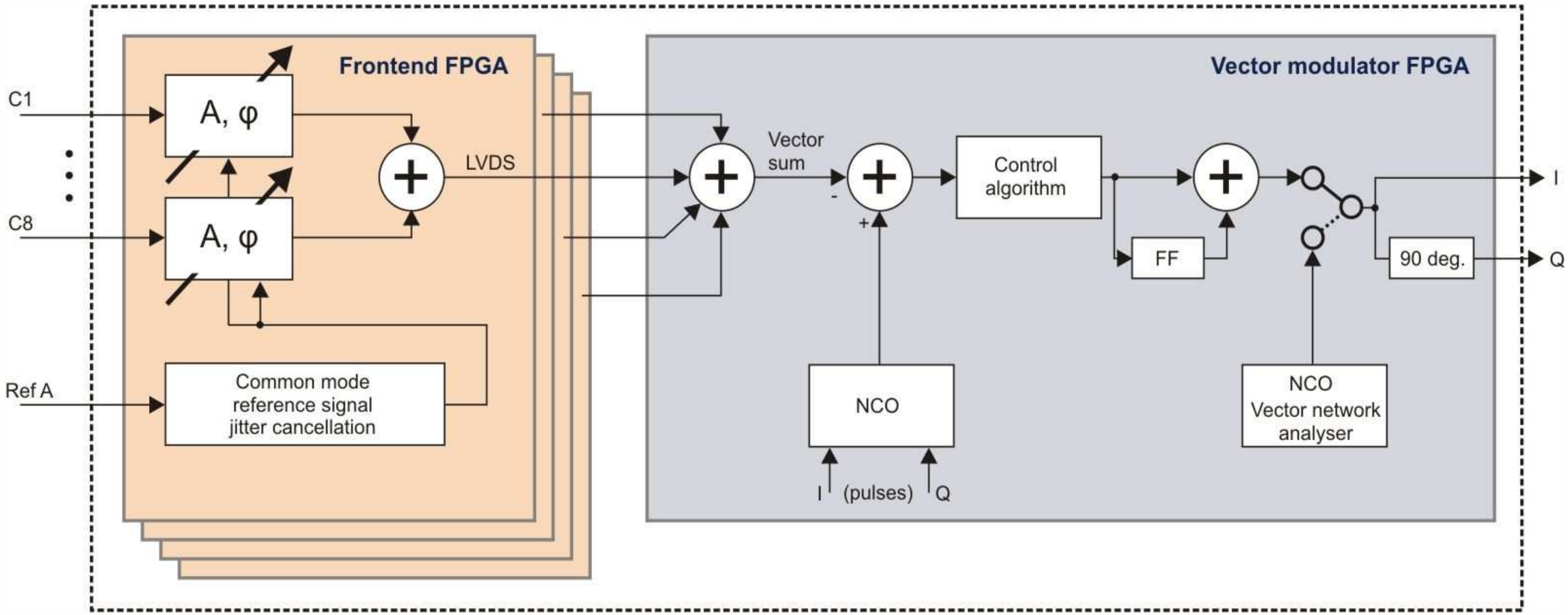
Instrumentation Technologies

32 Cavities LLRF System Example



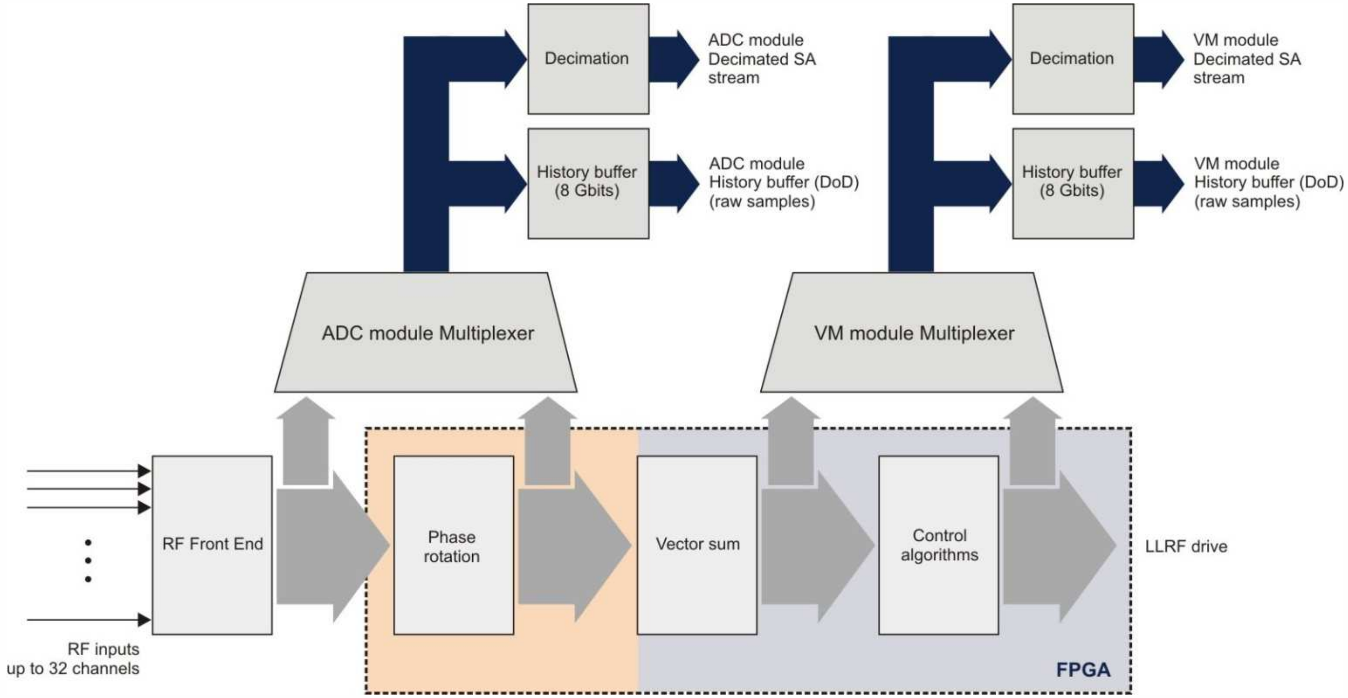
Signal Processing

FPGA block diagram: The powerful digital processing system, based on multiple FPGAs implements a low latency cavity field control loop.



- The vector sum signal is obtained as a particular linear combination of the probe signals, defined by the matrix rotation.
- A digital NCO set-point signal is used to calculate the error signal.
- The error signal is processed by the control algorithm and a drive signal is therefore generated.
- An additional NCO signal is used for FF drive and RF system diagnostics purposes.

Signal Acquisition



The signals can be acquired in each section of the processing chains.

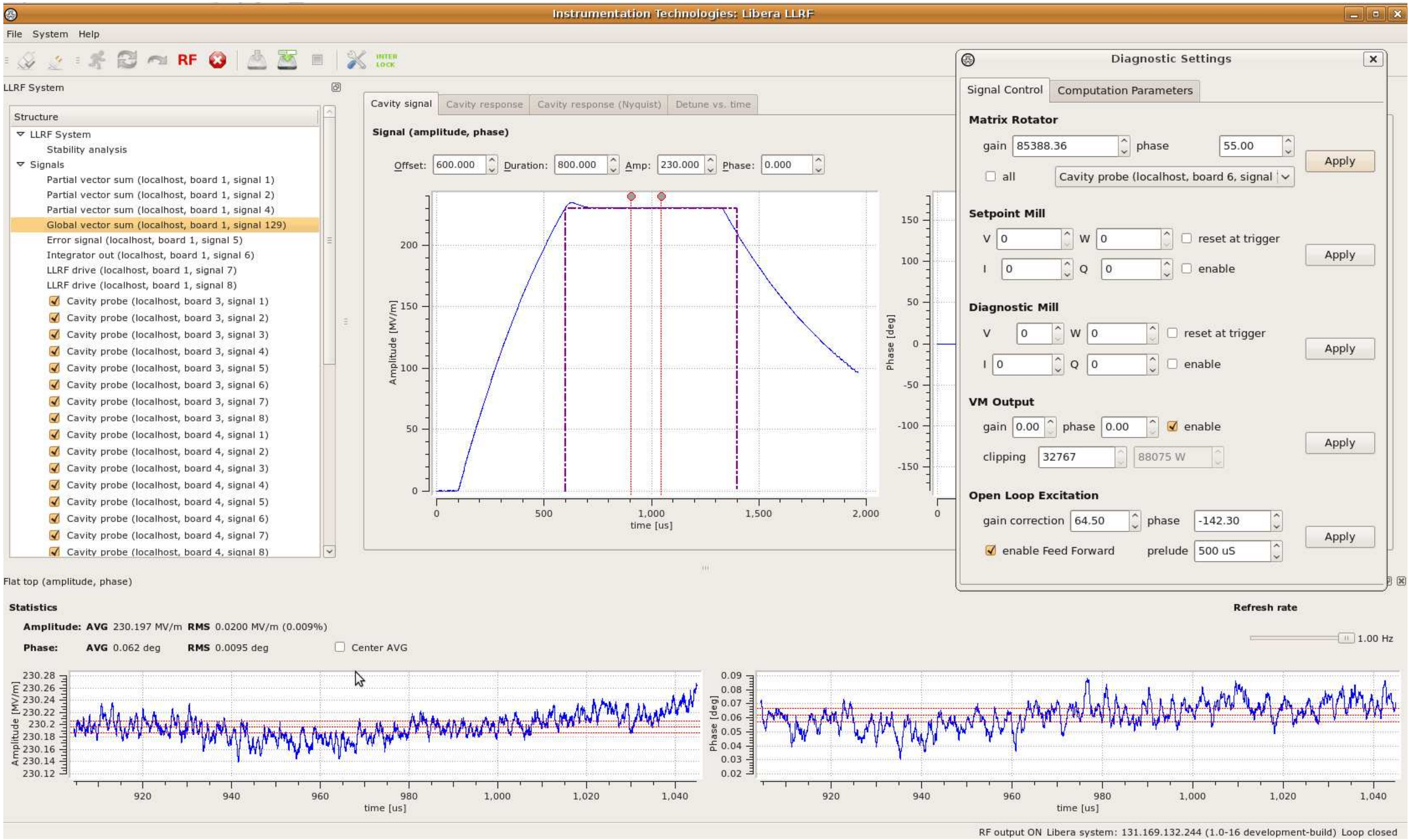
Two different acquisitions are simultaneously supported:

- **Circular buffer RAW samples (Data on Demand)**
- **Decimated stream (Slow Acquisition)**

Scope of the acquisitions:

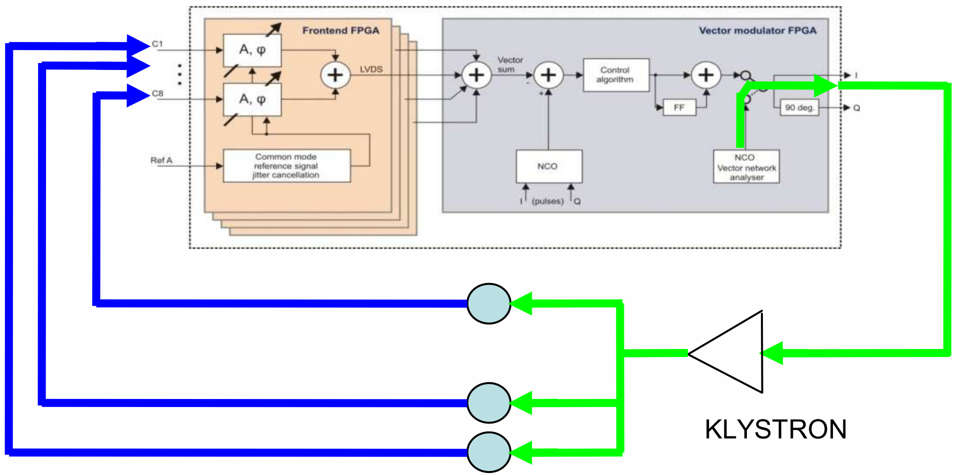
- **Signal monitoring purposes**
- **Input for LLRF specific algorithms instantiated at the ICB Computing Module level (RF system response analysis, RF system tuning, adaptive FF, pulse shaping, beam based vector-sum calibration…)**

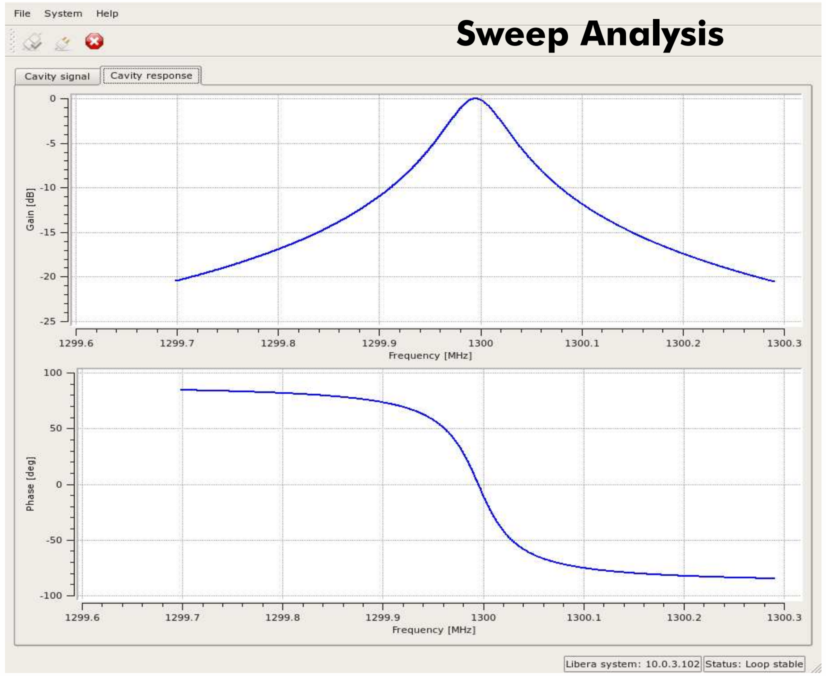
GUI Overview (FLASH ACC456)

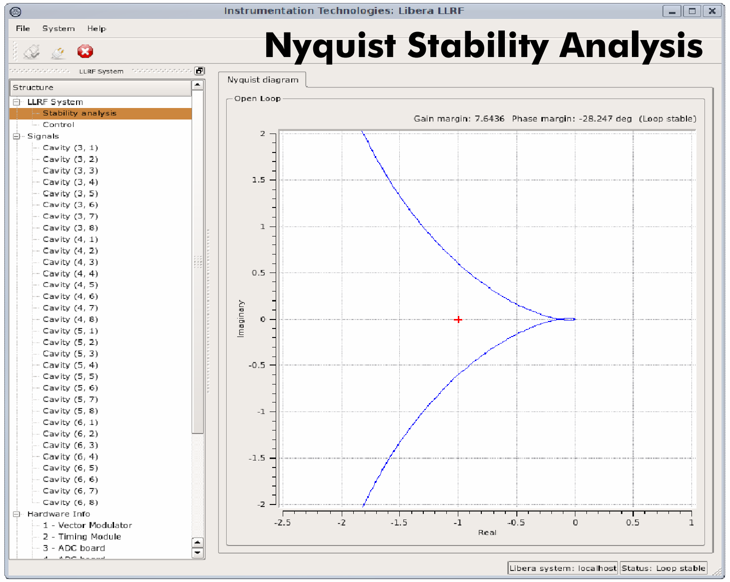


RF System Diagnostics

RF System Response Characterization







Each cavity response is measured and analytically modeled by means of:

- **Resonant frequency**
- **Loaded quality factor**
- **Amplitude and phase response at resonance**
- **RF system group delay**

The analytical models are passed to the Nyquist stability algorithm that automatically configures the phase rotation in order to maximize the stable region.

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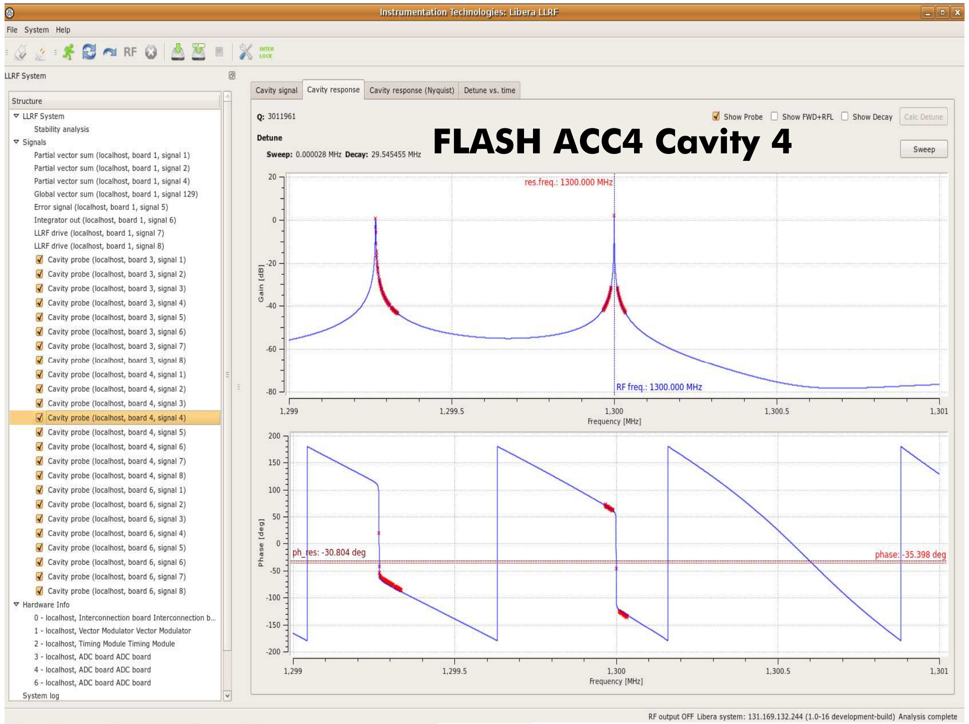
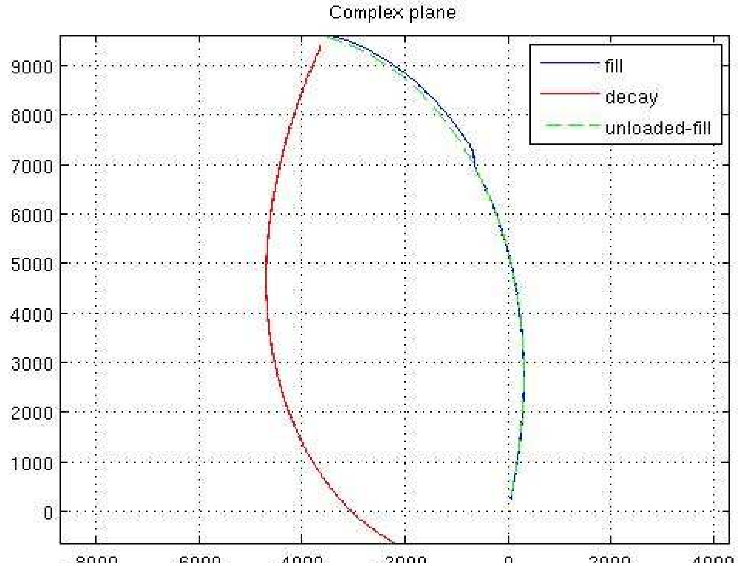
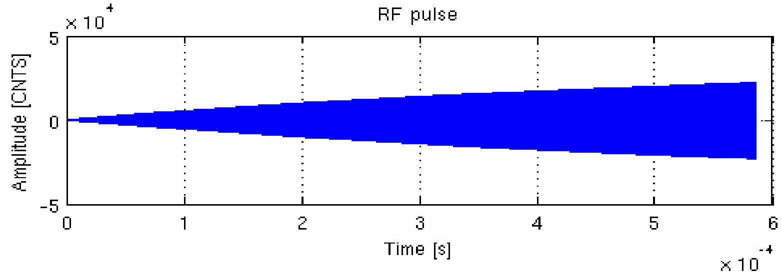
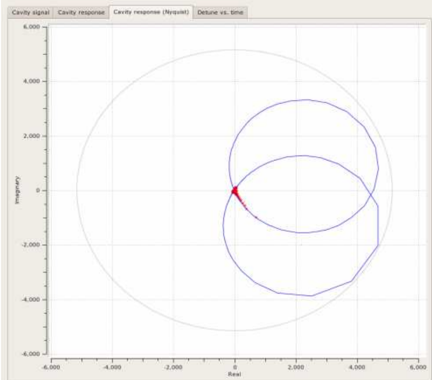
Advanced RF System Diagnostics

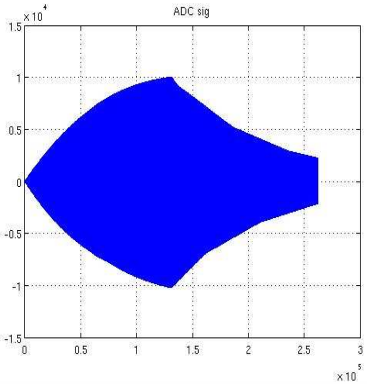
RF System Response Characterization Upgrade for SC Cavities

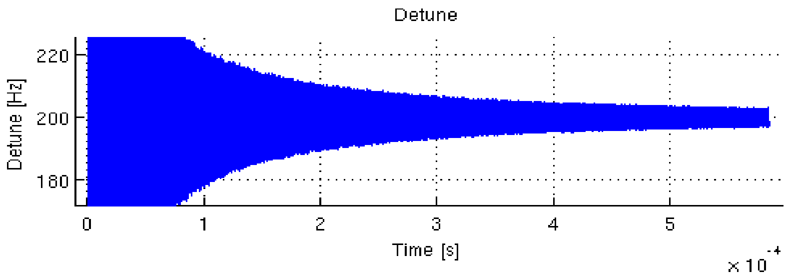












RF System Tuning

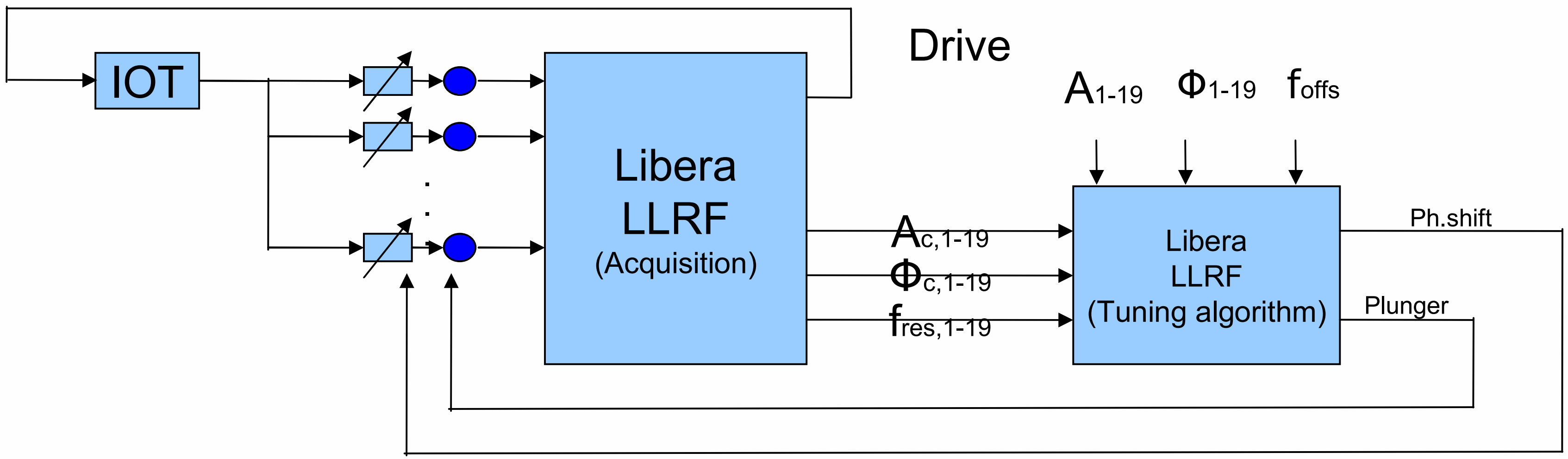
The acquired data and the RF system diagnostics are integrated into the RF system tuning.

In the specific case of the EMMA RF system 3 tuning loops involving independently the 19 cavities are implemented:

- <u>Phase control loops</u>: Each pulse the flat top phase is measured and normalized with respect to the first cavity. The normalized phases are compared to the normalized zero crossing phase table and the difference is used to drive the phase shifter stepper motors.

- <u>Amplitude equalization loops</u>: The amplitude of each pulse is normalized with respect to the first cavity. The difference from the ideal amplitude ratio is used to control the resonant frequency offset.

- <u>Cavity resonant frequency loops</u>: The measured cavity resonant frequency is compared to the amplitude loop output. The difference is used to control the cavity plunger stepper motor. In the case of the first cavity a fixed offset is applied to the frequency control algorithm.



Demonstration at Daresbury

High power tests on 2 EMMA NC 1.3 GHz cavities closed in a loop (April 2009)

Field stabilization:

Amplitude: 0.005 % (5E-5)

Phase: 0.008 deg

Peak power: 10 kW

(1.6 ms; rep rate 10 Hz)

Also demonstrated:

- RF system diagnostics

- IOT power sweep

- IOT frequency response

- Interlock system

Additional requirements:

- RF frequency variability

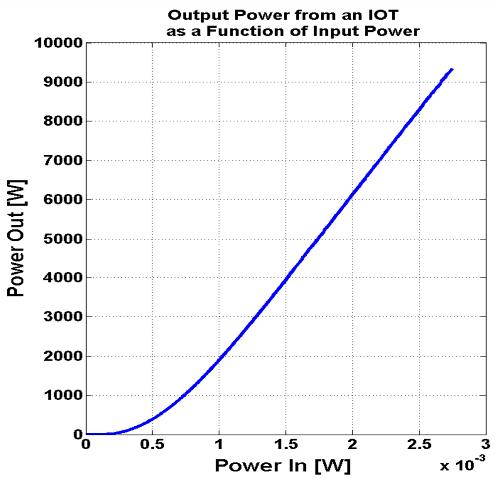
(-1.5 MHz + 4 MHz)

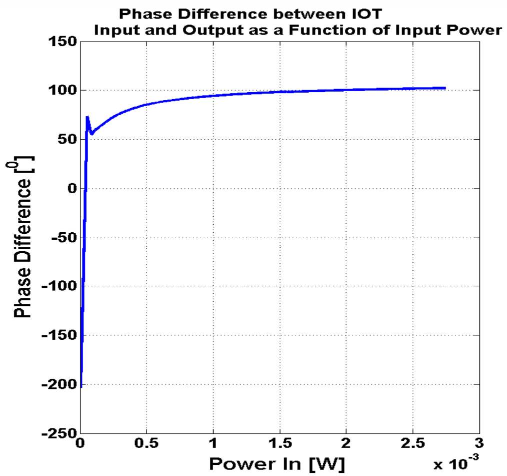
with Fixed MO frequency

and synchronization with ALICE

fixed RF ERL.

- Tuning system





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Demonstration at DESY (FLASH)

High power tests on the ACC456 24 SC 1.3 GHz cavities closed in a loop (July 2009)

Field stabilization:

Amplitude: 0.009 % (9E-5)

Phase: 0.0095 deg

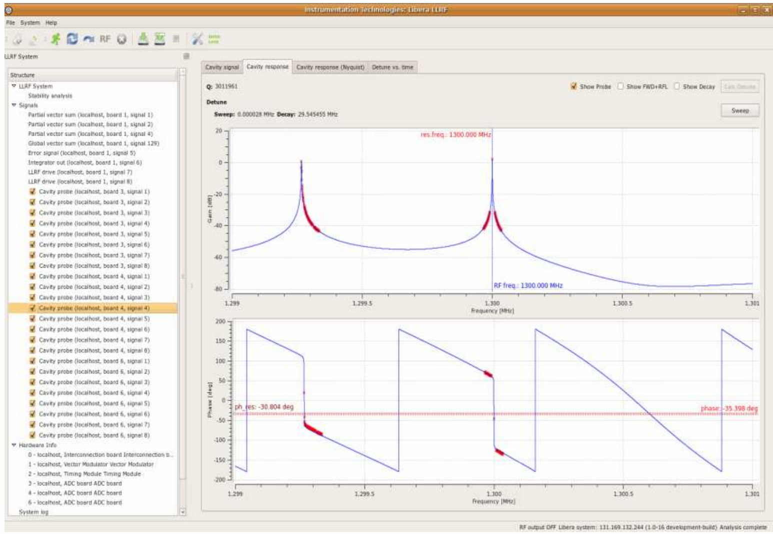
Vector sum of 24 cavities

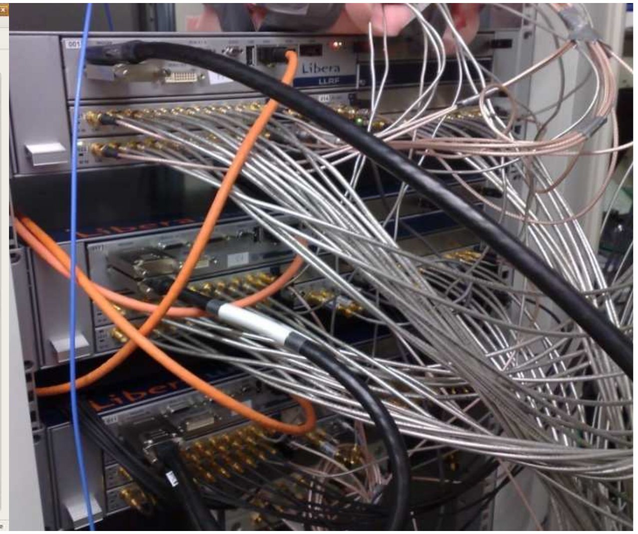
Avg. gradient: 10 MV/m

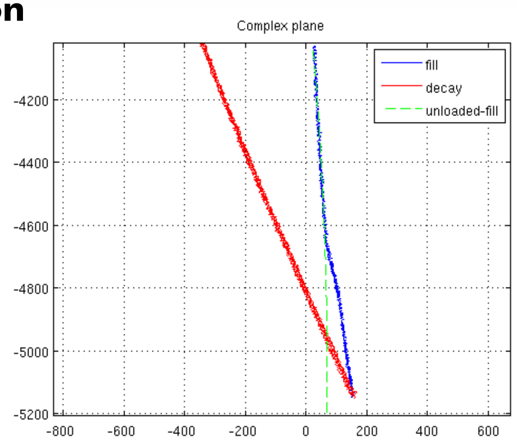
Loop gain: 71

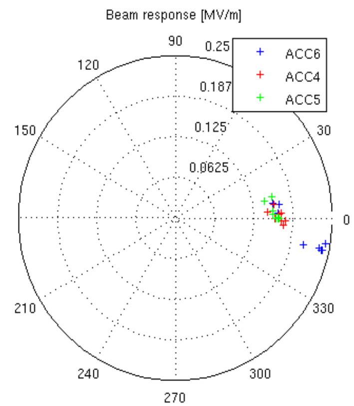
Also demonstrated:

- **Advanced RF system diagnostics**
- **basic FF flexibility**
- **passband modes diagnostics and suppression**
- **Operation at 30 MV/m**
- **Operation with beam loading**
- **Operation of FLASH in SASE mode**
- **Measurements of beam induced transients**
- **Energy spread measurements after ACC456**
- **Beam based vector sum calibration**









Detailed report: 20090716_Flash_Tests_Summary.pdf

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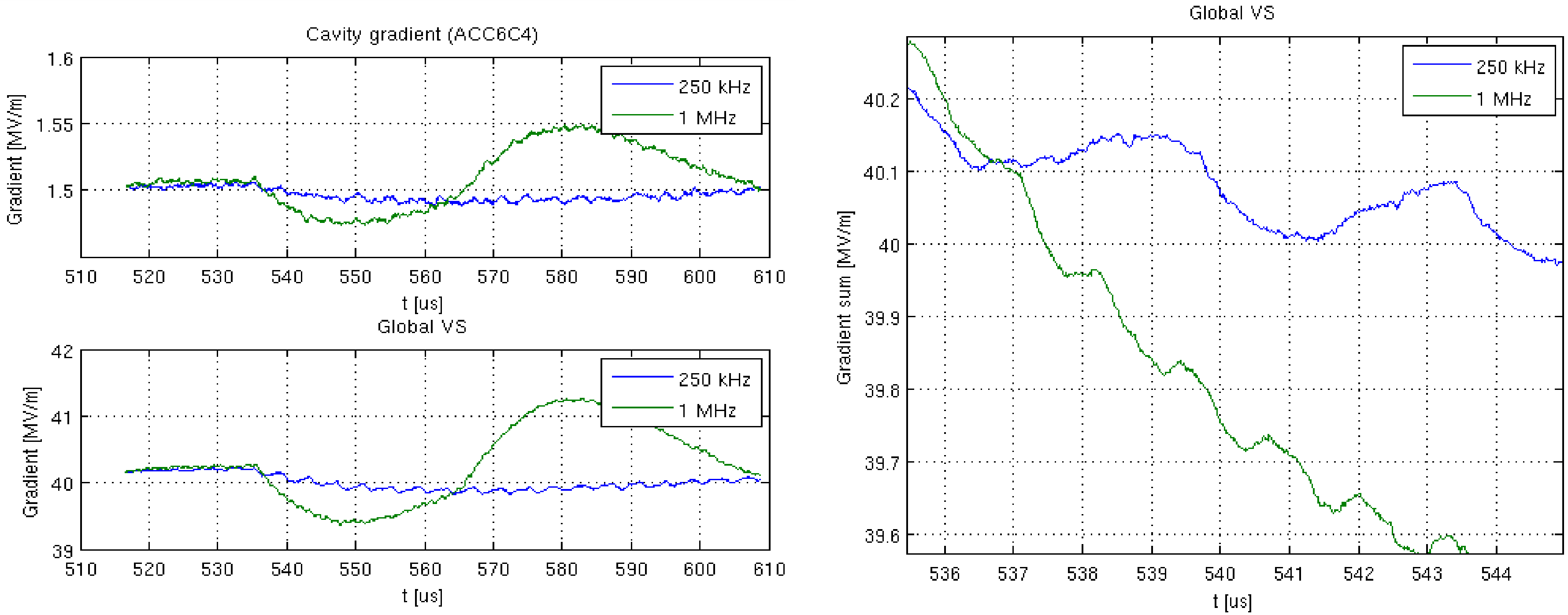
Beam Induced Transients Measurements (FLASH ACC456)

Transients induced in ACC456 by 30, 1.2 nC bunches at the repetition rates of 250 kHz and 1 MHz.



The contribution of individual bunches can be distinguished on the global vector sum flat top.

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