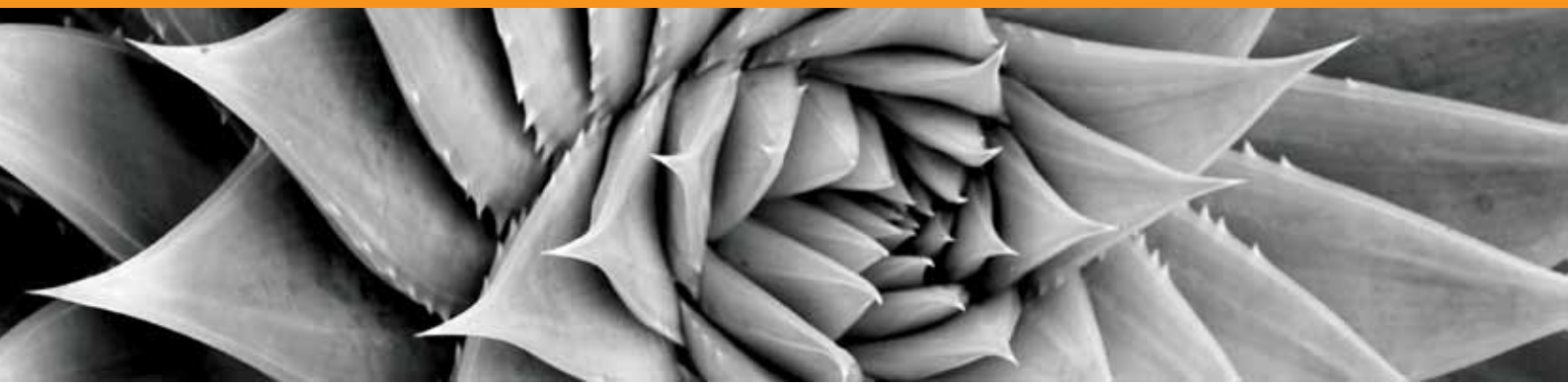
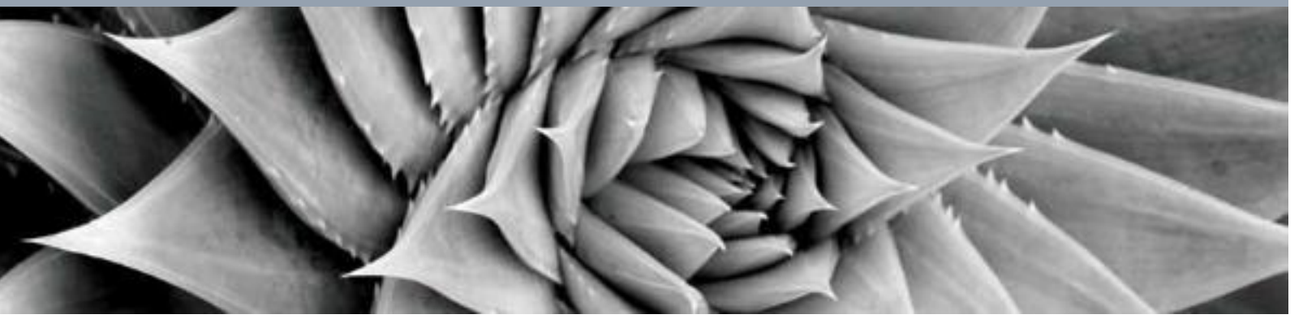
Libera

LLRF

Digital RF Stabilization System





Many instruments. Many people. Working together.

Stability means knowing your machine has innovative solutions. For users, stability means a machine achieving its full potential, enabling them to do more science. For us, stability means synchronized, connected, dynamic state-of-the-art instrumentation, working together as one system.

Because we know that the machine is more than just the sum of its parts.

Libera LLRF stabilizes the accelerator's RF field by applying real-time digital control algorithms.

Solution for your Needs

Libera LLRF covers your needs: from basic to the most demanding requests. Choose between different options for your LLRF system!

What you get / Solution you can choose	**Hardware (HW)** • chassis • ICB • RF acquisition module • vector modulator • timing module	**Software (SW)** • Libera BASE	**Development Kit** • SW + FPGA	**LLRF Application** • customer selected features
Option 1: **HW**	●			
Option 2: **implementation of LLRF application in SW and FPGA**	●	●	●	
Option 3: **complete solution with customizable feature list**	●	●		●
Option 4: **complete solution with customizable feature list and support for independent further development**	●	●	●	●

References

Used / tested at: ASTeC - EMMA (United Kingdom), DESY - XFEL (High power RF group, Germany), FAIR - pLINAC (Germany), INFN - DAØNE (Italy); CLS (Canada), DESY - FLASH 1,3 GHz (Germany), DESY - FLASH 3,9 GHz (Germany), FERMI@ELETTRA (Italy), SARAF (Israel).

Benefits

High reliability with excellent performance
- superior stability: amplitude stability RMS < 0.0001; phase stability RMS < 0.01 º at 1 MHz measurement bandwidth
- built on the proven and broadly used Libera HW and SW architecture
- detailed health monitoring enables fast fault identification
- modular HW design offers the possibility to minimize mean time to repair (MTTR)

Available as separate building blocks, combinations or complete solution
- *look at the related table

Configurable to specific accelerator's needs
- based on µTCA and AMC standards
- modular and configurable building blocks
- playground for RF specialists using FPGA development kit and optional AMC modules
- up to 12 GHz RF frequencies supported
- pulsed and CW modes of operation

Small form factor
- complete powerful control system is housed in standard 19˝ 2U box

Support
- experienced support from Instrumentation Technologies team
- various support packages available
- basic, advanced or customized trainings can be organized

Easy to use
- comprehensive Graphical User Interface (GUI) provides crucial information and commands
- time effective interactive training is supported through GUI from a remote PC
- many features available to save time and effort for commissioning, diagnostics, maintenance and machine studies
- management without integration in the Control System

Easy to be integrated into Control System
- digital system
- network-attached device
- EPICS ready
- High-level Application Programming Interface (API) for the integration in other Control Systems

Role in the Accelerator

LLRF system has a crucial impact to the beam quality. The digital LLRF system with its configurability allows further optimization during the machine life - cycle.

Parameters

Parameter	Value
Number of input channels	32 (8 per module)
ADC resolution	16 bits
Max. ADC sampling clock frequency	130 MHz
Memory size per module	up to 8 Gbits
Customizable topology	up to 32 cavities per plant
Customizable RF input	up to 12 GHz
Maximum RF input power	20 dBm

How Does It Work?

Libera LLRF offers a unique combination of hardware, digital signal processing and software. The following features are implemented in Virtex5 FPGA to cover the need from basic to most demanding LLRF systems:

1. Signal monitoring:
- values (voltage, phase, power, frequency, I/O status)
- slow acquisition (sampling rates 1 Hz – 10 kHz)
- fast acquisition (fixed sampling rates up to 130 MHz)

2. Cavity tuning:
- detune measurement algorithm based on forward, probe (CW mode)
- detune measurement algorithm based on cavity voltage decay (pulsed mode)
- display of resonance frequency
- display of phase difference between forward and probe signals
- feedback with a PID controller
- stepper motor driver interface (serial commands, step and direction)

3. Control loops for the RF field:
- fast feedback loop (amplitude and phase)
- COMB loop
- pulse-to-pulse
- klystron feedback loop (gain, phase)
- beam based feedback
- stabilization and control of the accelerator's variable RF frequency
- equalization of the accelerating gradient in the several cavities driven by same klystron
- beam loading compenzation

4. Operation mode
- CW
- pulsed
- combined CW and pulsed

5. RF diagnostics tools for super and normal conducting cavities
- RF system's transfer function characterization (to the measured frequency sweep applied mathematical model)
- Feed-back loop nyquist stability plot and stability characterization

6. Compensation of the Libera LLRF receiver modules' temperature drifts

7. Slow analog and digital interfaces

8. Fast interlock interface with active low logic (programmable interlock levels)

Additional features can be implemented on user's request.

Hardware Interfaces

1. **Interconnection board (ICB):** implements functions of the QTCA Carrier Hub (MCH) with interfaces: 2x PCIe, 2x LXI, JTAG, RS-232, DVI, management USB, management ETH, USB and 2x ETH. A fast PCIe bus is used for the data transfer between COM Express module and AMC application boards. This high performance combination supports the implementation of low-latency control algorithms, real-time data processing and dedicated RF system diagnostics tools.

2. **RF acquisition modules:** double width mid-size AMC modules can process up to 8 RF inputs. The Libera LLRF system is configurable and can host from one to maximum four such modules. A Libera LLRF receiver module includes a calibration system and a LO distribution. The high performance FPGA mounted on the board is used for hardware control and digital signal processing.

3. **Vector modulator module:** single width mid-size AMC module with two RF inputs and two RF outputs. The two inputs can be used in feedback. One of the two RF outputs is used for the drive signal generation. The other can be used for different purposes (pilot signal, reference for the longitudinal feedback). The high performance FPGA mounted on the board is used for hardware control and digital signal processing.

4. **Timing module:** single width mid-size AMC module. Generates a low jitter local oscillator (LO) signal and a suitable sampling clock for the down-conversion and acquisition processes.

5. **Optional single width mid-size AMC modules** provide the possibility to add additional features to the Libera LLRF system.

- fits into a 19 inch industrial rack
- 8 or up to 32 RF inputs for one RF output
- 2U height
- integrated power supply: 12 V DC
- mechanical structure of the chassis: up to eight application specific Advanced Mezzanine Cards (AMCs) connected via integrated backplane
- all interface connectors at the front
- cooling by two hot-swap replaceable fan modules on both sides of the chassis

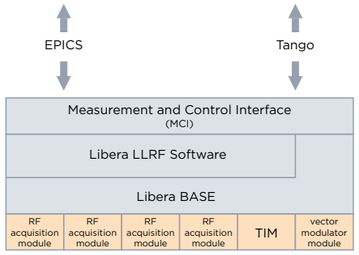
Powered by **Libera**
BASE

Basic Application
Support Environment

High-level Software Architecture

Software modules are implemented using the Libera BASE framework, which provides HW abstraction and simplifies development and integration. The Libera BASE also takes care of all common tasks such as platform management and health monitoring. Besides this, the Libera BASE is an extensible application layer with configuration parameters (registry tree) and signal acquisition, processing and dispatching functionality. On the top layer, it provides the Measurement and Control Interface (MCI) with a development package and an example CLI utility for open interaction in different control systems. All the software runs on a standard Linux Ubuntu distribution.

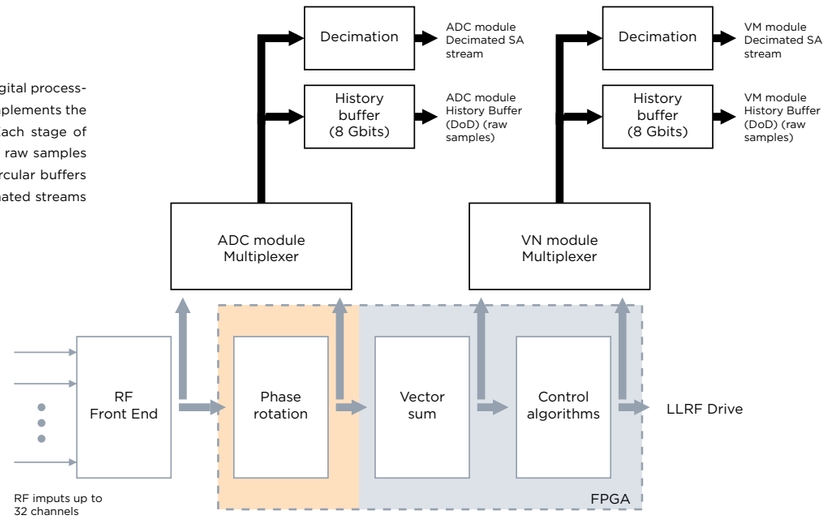
The FPGA software resides in different modules and is smoothly integrated into the Libera BASE framework. Using the development kit, it is also possible to change the functionality and implement different processing algorithms.



LIBERA HW GENERATION B

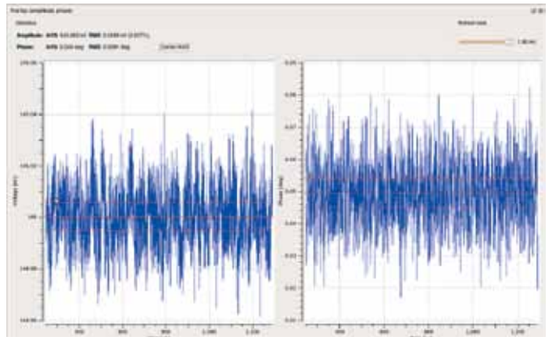
Data Paths

Libera LLRF data paths. The powerful digital processing system, based on multiple FPGAs, implements the low latency cavity field control loop. Each stage of the processing chains is monitored. The raw samples are stored in large DDR2 RAM-based circular buffers or decimated in order to produce decimated streams for easier monitoring.

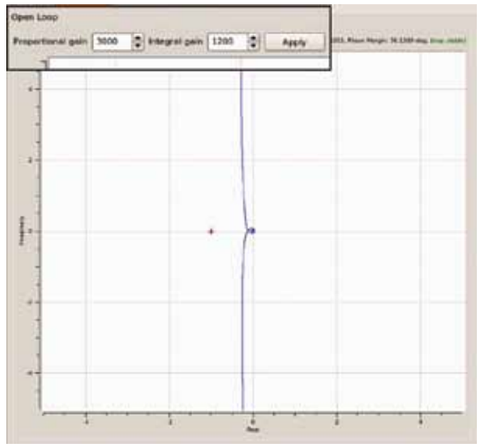


The powerful features of Libera LLRF enable RF system monitoring, configuration and diagnostics. The diagnostic algorithms automatically characterize the RF system transfer function by means of built-in vector network analysis. The RF parameters are then passed to a cavity field control loop stability analysis algorithm, which optimally configures the Libera LLRF parameters for closing a stable loop. Cavity decay analysis is then used in the case of pulsed applications to continuously monitor the cavity behavior for tuning and interlock purposes.

Graphical User Interface

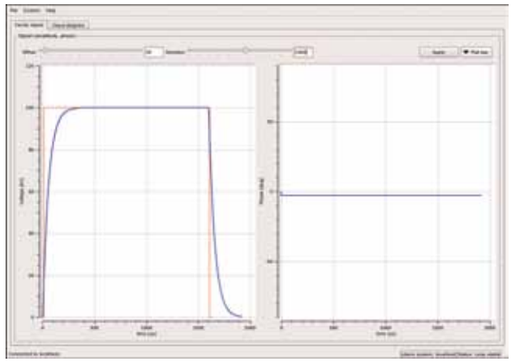


Decimated signals ▸
All the signals of the Libera LLRF system are also available in a decimated form for easy processing and displaying on control system screens. The cavity response to RF pulses is already available in the form of amplitude and phase signals.

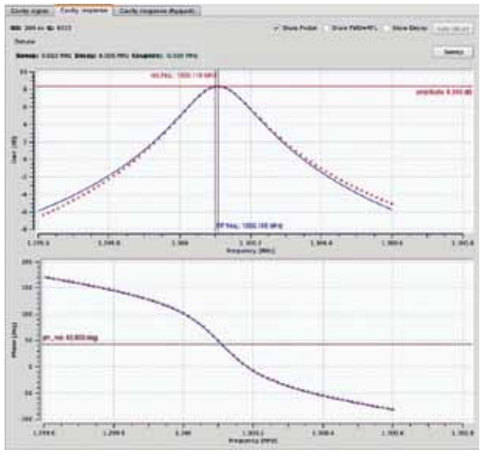


RF system diagnostics ▸
During operation, the cavity decay analysis and directional coupler signals are used to monitor and control the cavity tuning.

◂ **Flat top analysis**
The cavity voltage amplitude and phase stability can be easily measured to high resolution from the acquired samples. The effectiveness of the control algorithms in suppressing disturbances of the cavity field can be measured.

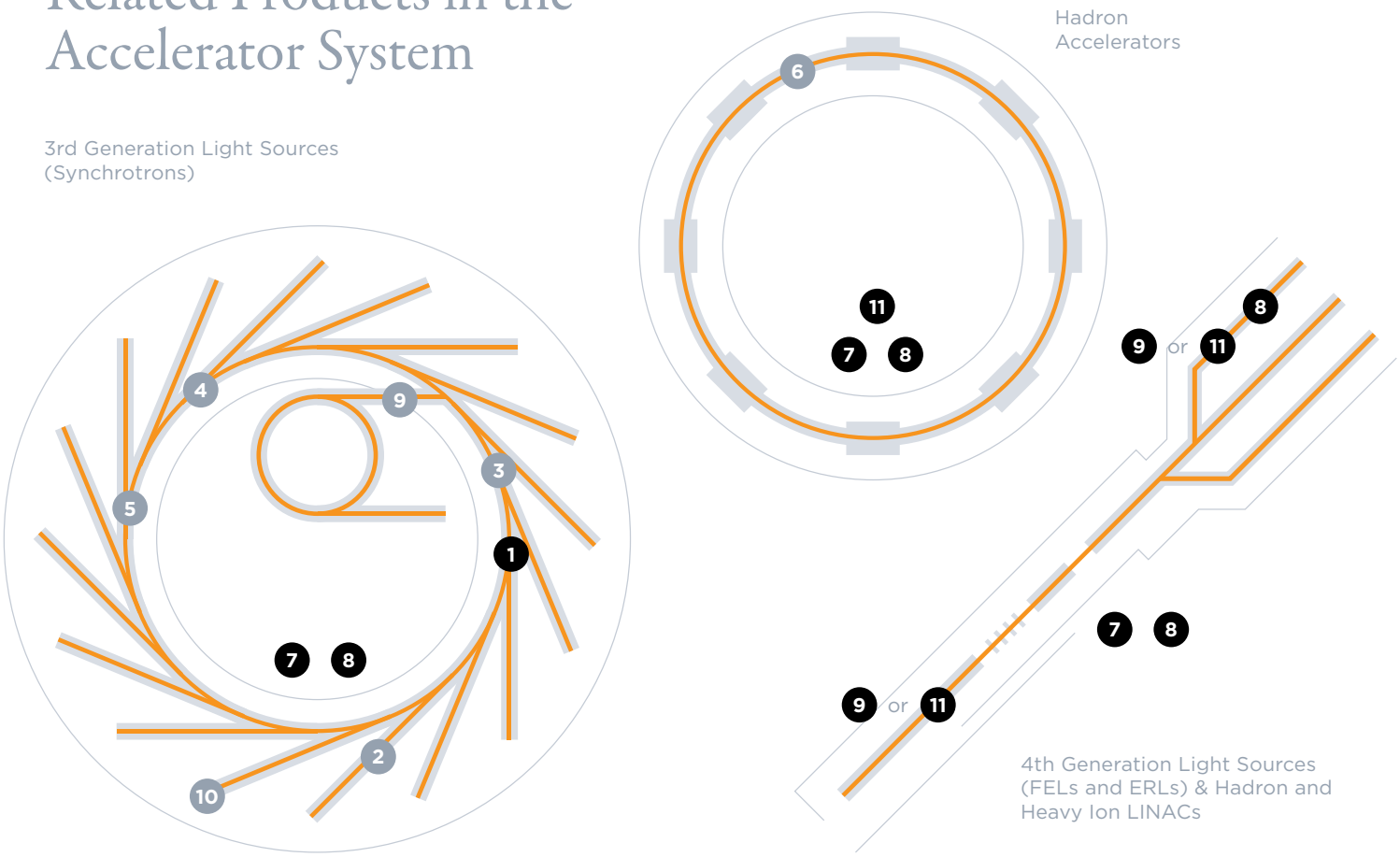


◂ **Nyquist stability analysis**
A powerful RF diagnostics system completely characterizes the RF system by means of built-in network vector analysis. Libera LLRF automatically uses diagnostic measurements to compute the optimal phase rotation for enabling a stable LLRF loop. The user is also provided with phase and gain stability margins. The open loop transfer function is displayed on a Nyquist diagram. The application suggests the optimum working parameters.



◂ **System monitoring**
The Libera LLRF system has an advanced health monitoring system that takes care of fans, currents, voltages and temperature.

Related Products in the Accelerator System



1 **Libera Brilliance**
Electron beam position processor

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Electron beam position processor

1 **Libera Electron**
Electron beam position processor

7 **Libera LLRF**
Digital RF stabilization system

8 **Libera Sync**
Low-jitter clock distribution system

9 **Libera Brilliance Single Pass**
Electron beam position processor for single pass machines

Solution	Building Block
Linac energy stabilization	Libera LLRF + Libera Sync + Libera Brilliance Single Pass
Beam dump for injection efficiency studies	Libera Brilliance + Libera LLRF
Turn-by-turn beam studies	Libera Brilliance + Libera LLRF
Longitudinal beam stabilization	Libera LLRF + Libera Single Pass H

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Visit our website to read more about Libera products, download conference papers on the use of Libera at different accelerators around the world, subscribe to the I-Tech Newsletter and learn about the next gathering of the community at the Libera Workshop.

Technical Support

Prompt and reliable. You can ask for on-site support or we can assist you remotely. You are also welcome to join us at the Libera Workshop training sessions to get the most out of Libera products.

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