Architecture Design for the SwissFEL LLRF System

PAUL SCHERRER INSTITUT PSI

LLRF

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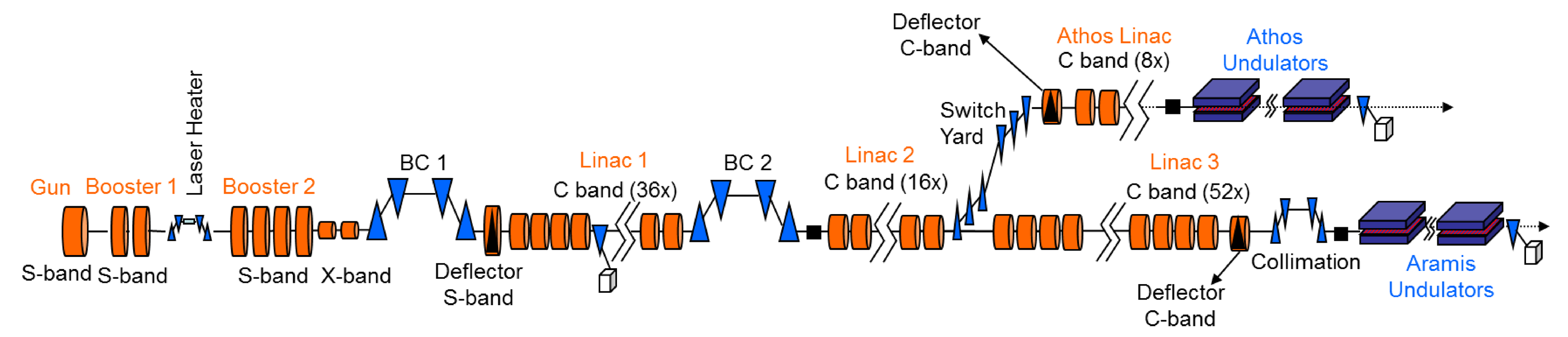
Abstract

The SwissFEL under construction at the Paul Scherrer Institut (PSI) requires high quality electron beams to generate X-ray Free Electron Laser (FEL) for various experiments. The Low Level Radio Frequency (LLRF) system is used to control the klystrons to provide highly stable RF field in cavities for beam acceleration. There are more than 30 RF stations in the SwissFEL accelerator with different frequencies (S-band, C-band and X-band) and different types of cavities (normal conducting standing wave cavities or traveling wave structures). Each RF station will be controlled by a LLRF node and all RF stations will be connected to the real-time network in the scope of the global beam based feedback system. High level applications and automation procedures will be defined to facilitate the operation of the RF systems. In order to handle the complexity of the LLRF system, the system architecture is carefully designed considering the external interfaces, functions and performance requirements to the LLRF system. The architecture design of the LLRF system will be described in this paper with the focus on the fast networks, digital hardware, firmware and software.

SwissFEL Layout

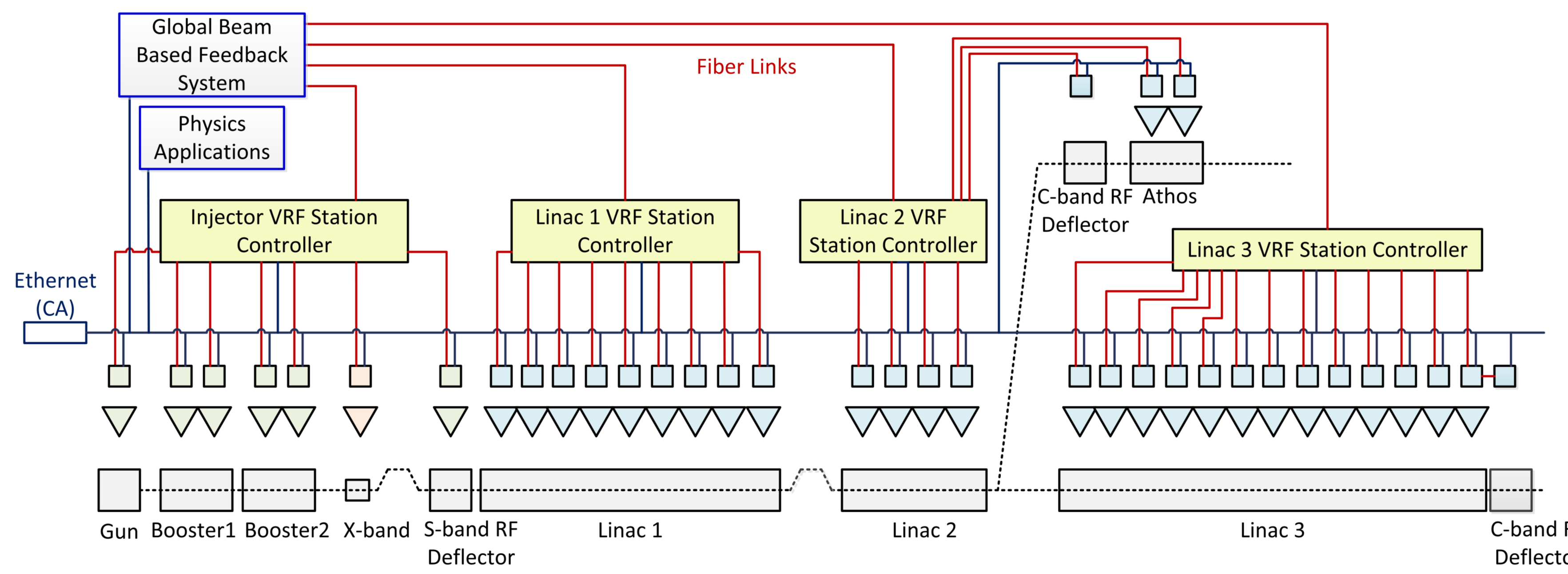


RF Stability Requirements

RF Station	Phase Tolerance (rms)	Voltage Tolerance (rms)
S-band	0.018 degS	0.018 %
C-band	0.036 degC	0.018 %
X-band	0.072 degX	0.018 %

Virtual RF Station

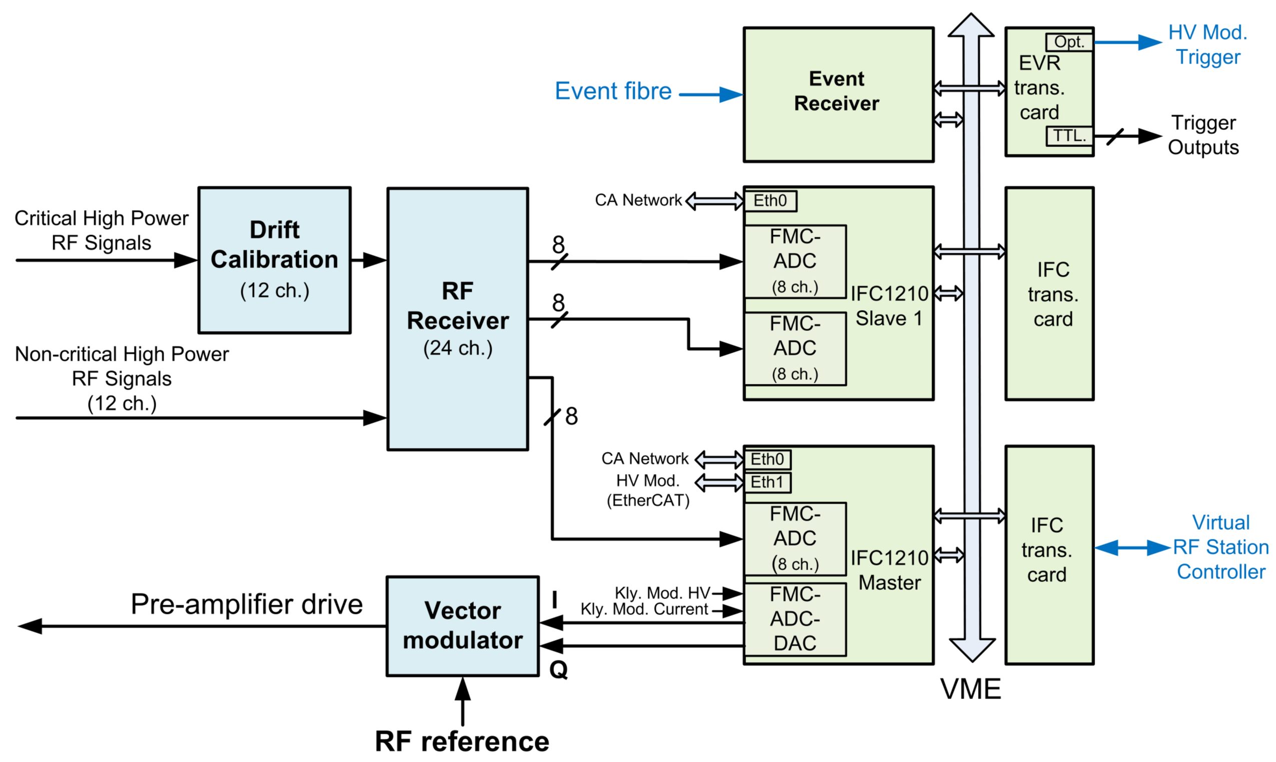
- Virtual RF Station (VRF) is an abstraction of a group of RF stations whose vector sum is of more interests for the beam physicists.
- The VRFs simplify the interfaces between LLRF and beam based feedback system. VRFs accept vector sum settings and are responsible to determine the settings of individual RF stations.
- Optical fiber links are used to interconnect the VRF controllers, beam based feedback controller and individual RF station controllers.



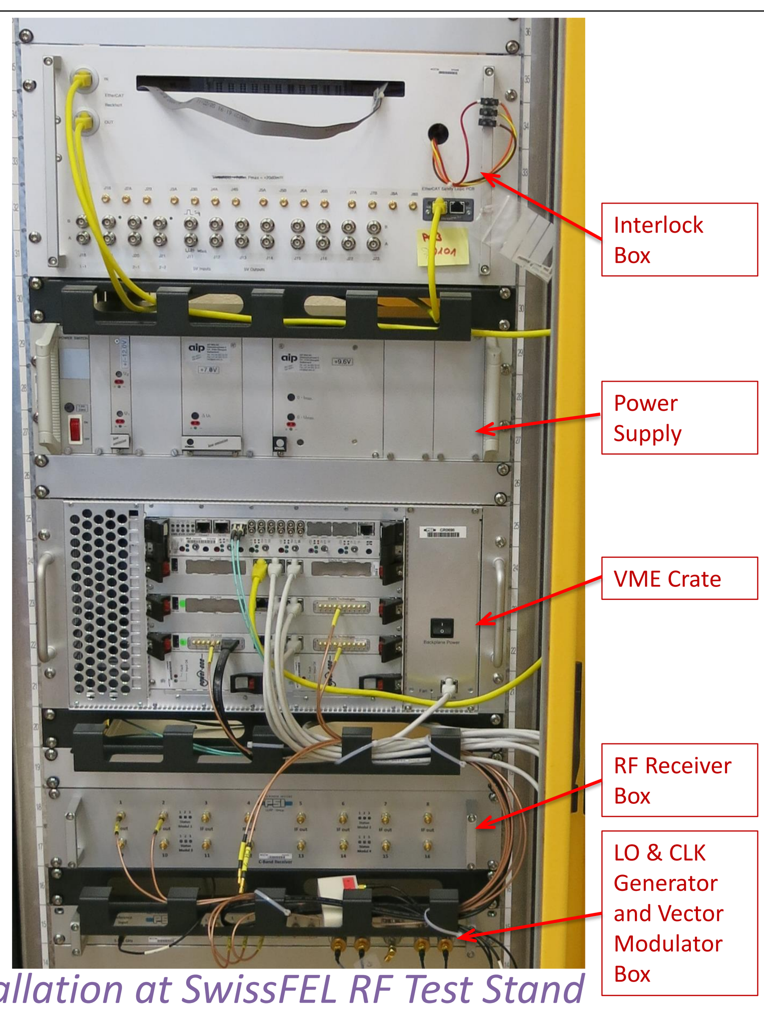
Virtual RF Stations in SwissFEL

VRF Station	Member RF Stations
VRF Booster 1	2 S-band RF stations
VRF Booster 2	2 S-band RF stations
VRF Linac 1	9 C-band RF stations
VRF Linac 2	4 C-band RF stations
VRF Linac 3	13 C-band RF stations
VRF Athos	2 C-band RF stations

LLRF Hardware Architecture



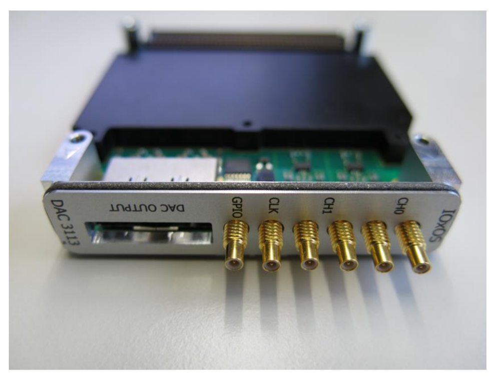
Overview of LLRF Hardware for Individual RF Station Control



Installation at SwissFEL RF Test Stand

IFC1210 VME Carrier Board

- VME64x 6U Single Board Computer
- Two HPC FMC slots
- Xilinx Virtex-6 FPGA
- Dual-core PowerPC CPU
- Up to 2 Gbytes DDR3 memory



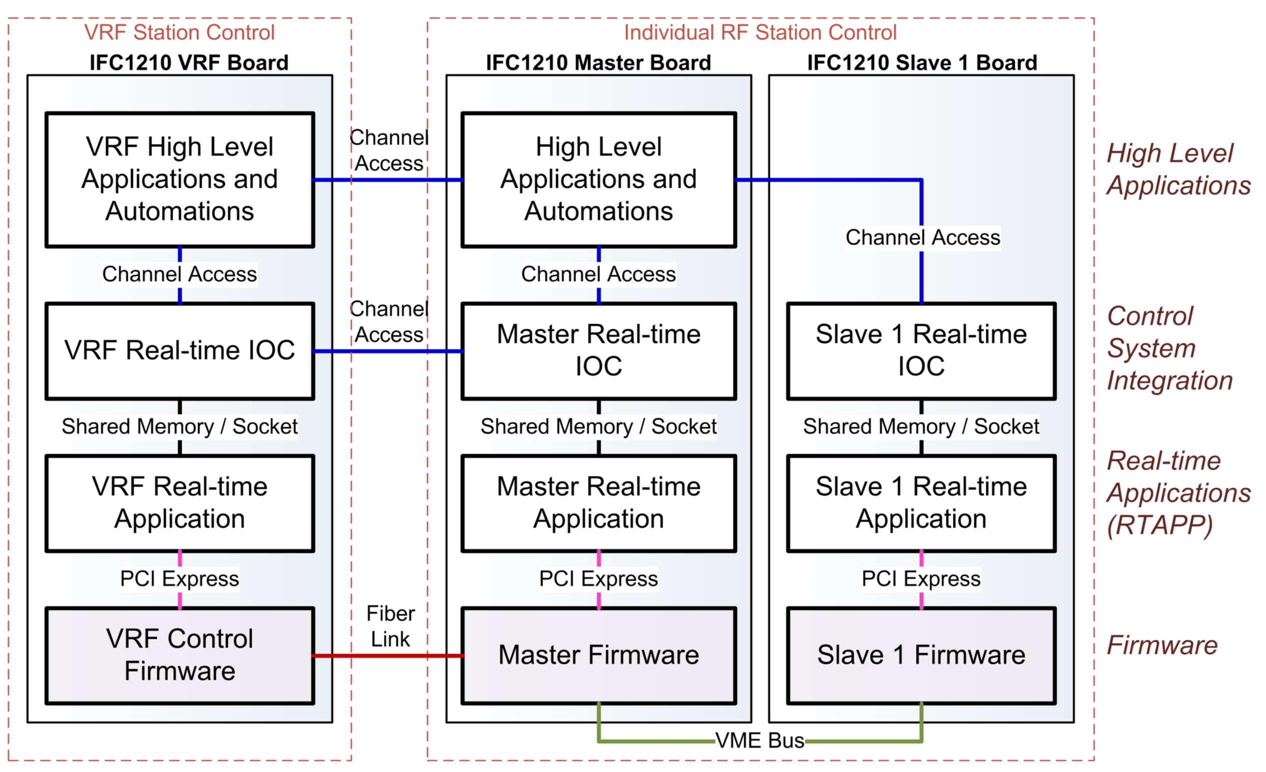
DAC3113 FMC Board

- Two channel DC coupled 250 MSPS 16-bit DAC
- Two channel DC coupled 250 MSPS 16-bit ADC

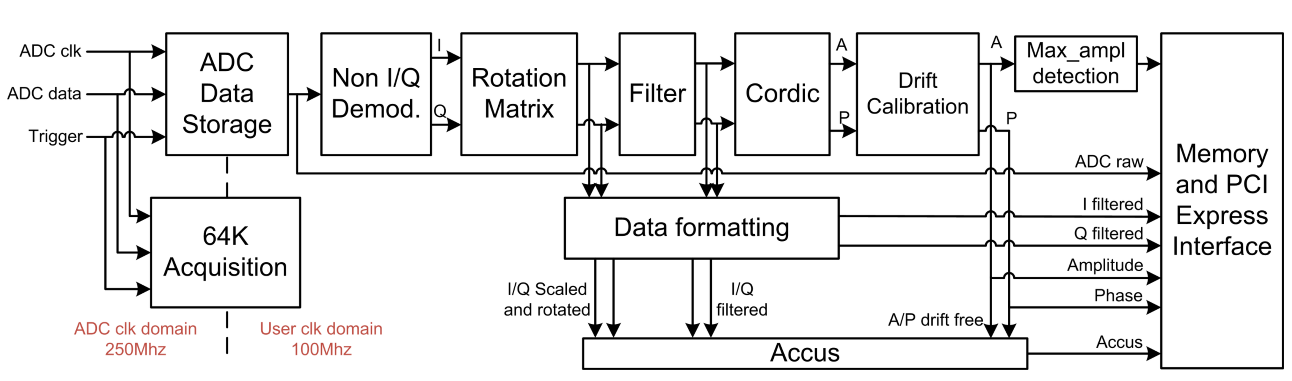
ADC3110 FMC Board

- Eight channel AC coupled 250 MSPS 16-bit ADC

LLRF Firmware/Software Architecture

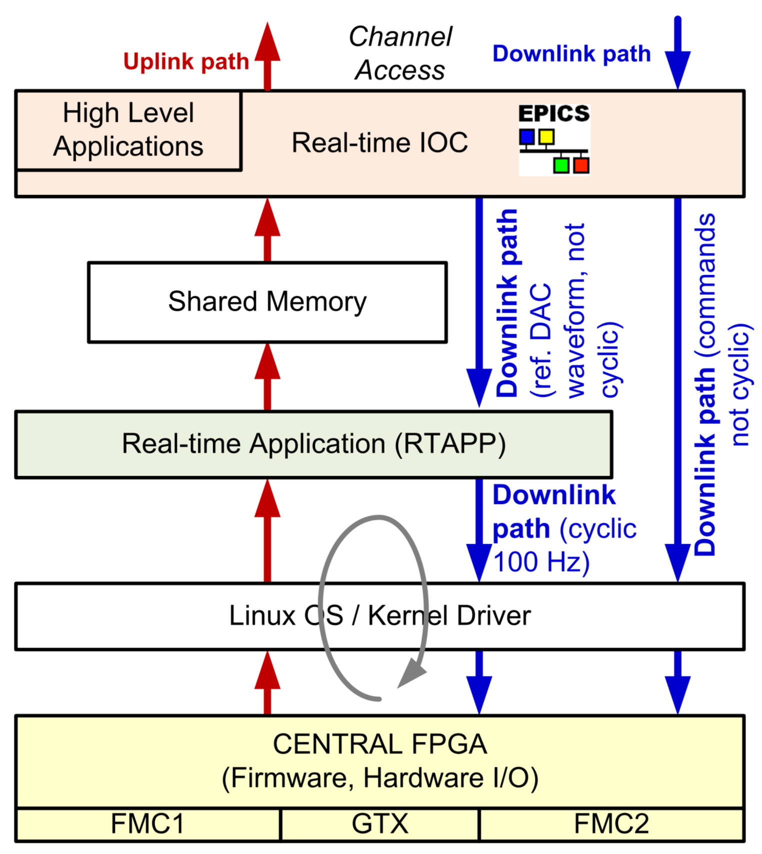


RF Signal Processing and DAQ in Firmware



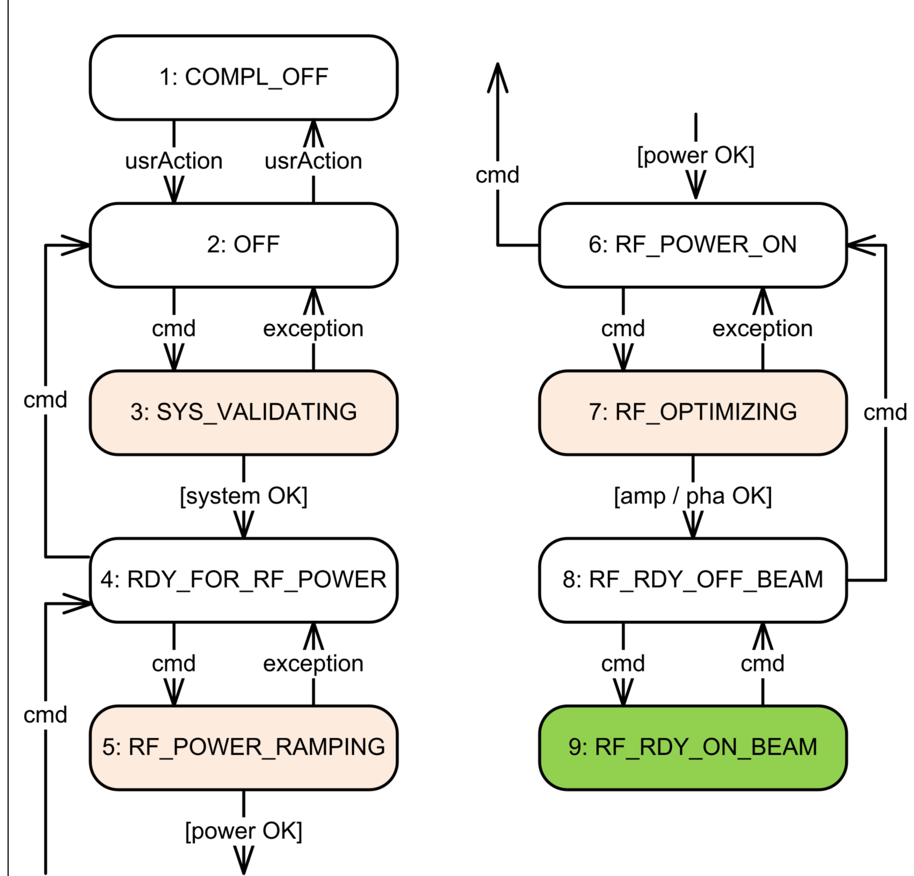
- It is for individual RF station control and will be implemented in both of the master and slave IFC1210 central FPGAs.
- Firmware in the master board also generates RF pulses with the DACs driving the vector modulator and provides interfaces to communicate with the VRF controller via the fiber link.

Real-time Software



- A standalone Linux real-time application performs pulse-to-pulse (100 Hz) data acquisition via DMA, further RF signal processing and feedbacks.
- The real-time application saves all data in a shared memory which can be accessed by EPICS records.
- 100 Hz scalar and waveform archiving is supported.
- Parameter settings to the firmware can be done synchronously for each pulse by the real-time application or asynchronously directly via EPICS record processing.

High Level Applications and Automation



Finite State Machine for Starting up/Stopping the RF Station

Functions of the software tools provided by High Level Applications:

- Optimize the parameters like the DAC reference tables for desired RF pulse shape and the DAC offsets to reduce the RF power leakage from the vector modulator.
- Calibrate the coefficients for RF power, vector sum, accelerating gradient and beam phase calculation.
- Identify the parameters like the cavity detuning, vector modulator imbalances and klystron non-linearity.
- Diagnose the system status.

Conclusion

The architecture of the SwissFEL LLRF system was carefully designed based on the system requirements and the available state-of-the-art hardware and software platforms. It provides good modularity, maintainability, extendibility and reusability. The prototype of the LLRF system has been installed on the C-band RF test stand for SwissFEL. It was well integrated in the control system and provided good support for 100 Hz operation of the klystron including the pulse-to-pulse waveform data acquisition. It was proved to have good robustness for long term operation and has been providing good support to the testing of the high power RF components.

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