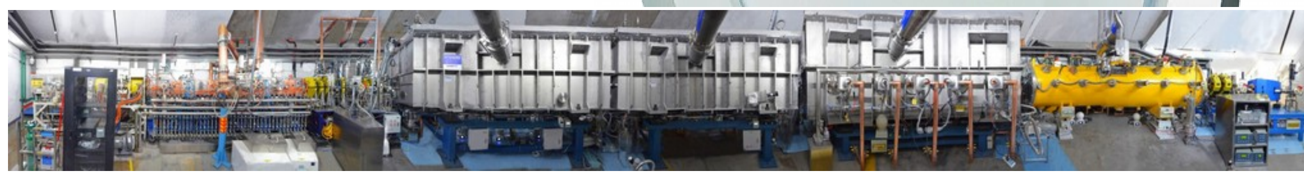

LLRF Activities at IMP

Xianwu Wang, IMPCAS

Contents

- IMP Facilities Introduction
- LLRF Systems in IMP
  - Cyclotrons LLRF
  - Synchrotrons LLRF
  - ADS Linac LLRF
  - Prototype LLRF
- Future Porjects
  - HIAF
  - CiADS
  - ...

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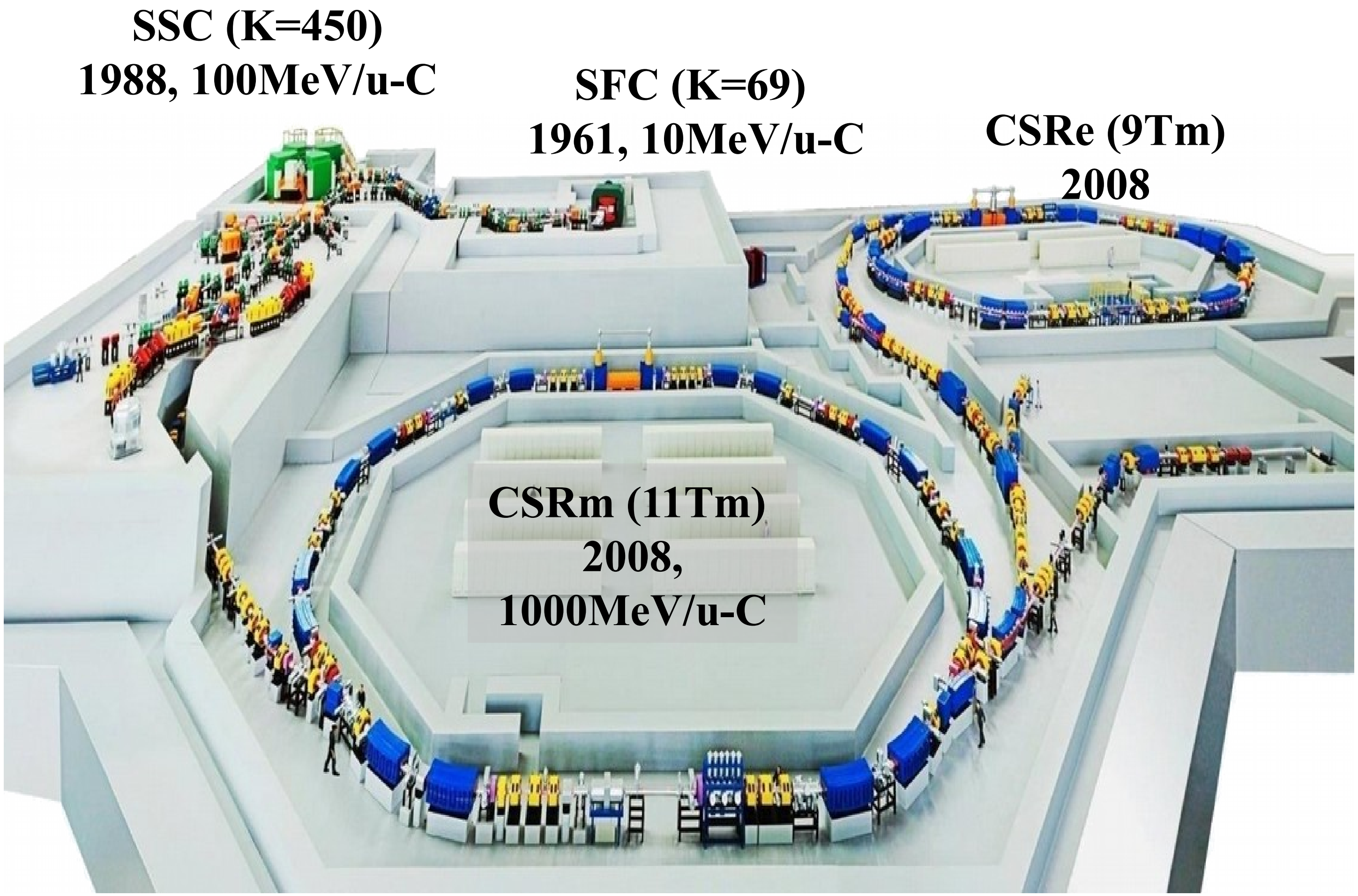
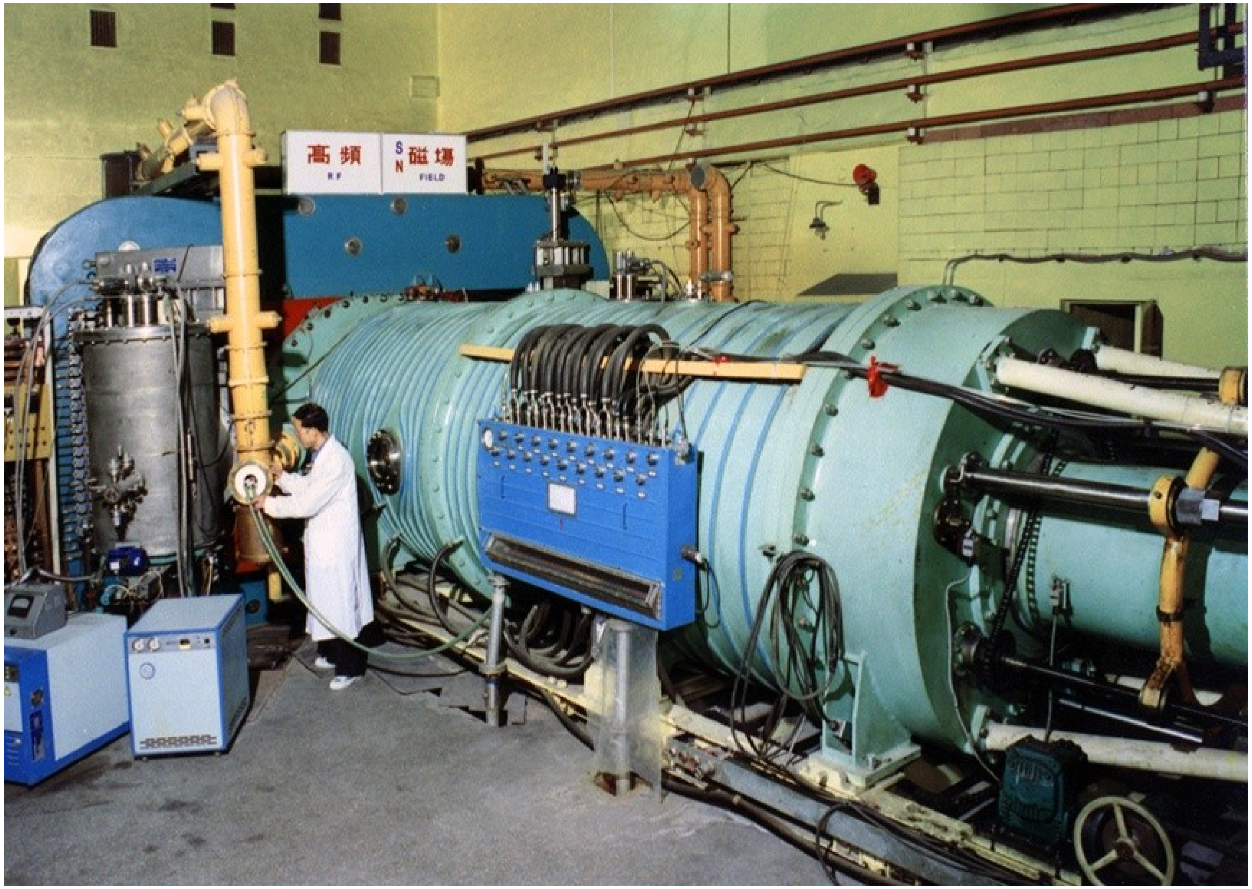
Overview of HIRFL

- Heavy Ion Research Facility in Lanzhou (HIRFL)
  - The largest ion-accelerator complex in China



The Injector SFC

- Built in 1961 with the assistance of the Soviet Union
- H&He 1970s, upgraded, Carbon~Uranium
  - K ~ 69
  - R ~ 0.75 m
  - E ~ 10 MeV(C)
  - 1 MeV/u(U)



The Main Cyclotron SSC

- 1988
  - K ~ 450
  - R ~3.203 m
  - α~U
  - E : 100 MeV/u(C)
  - 10 MeV/u (U)

CSR

- Synchrotron and Storage Rings (CSR)
  - CSRm 161.0m
  - G_{max} = 11.3Tm

  - CSRe 122.8m
  - G_{max} = 9.0 Tm

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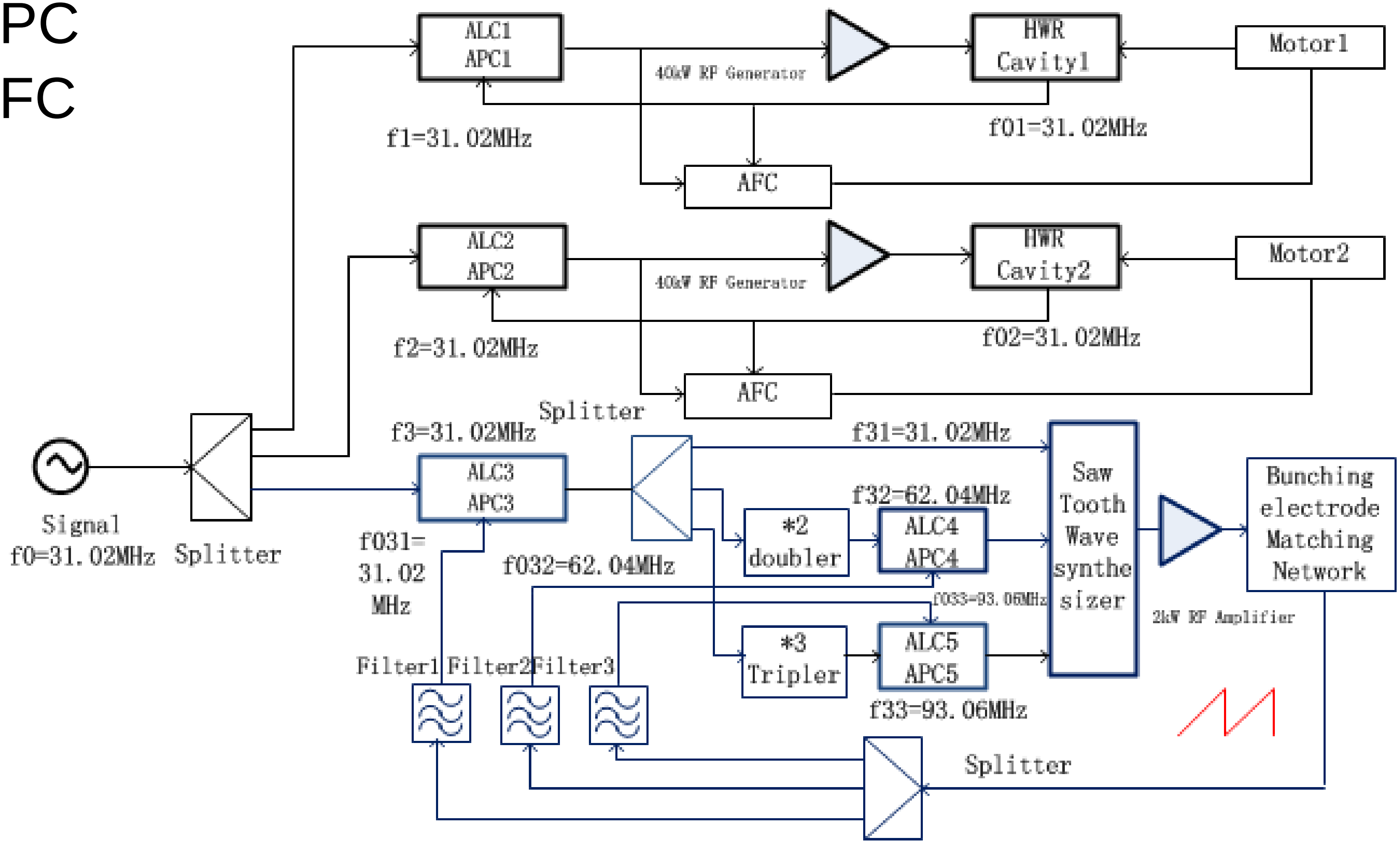
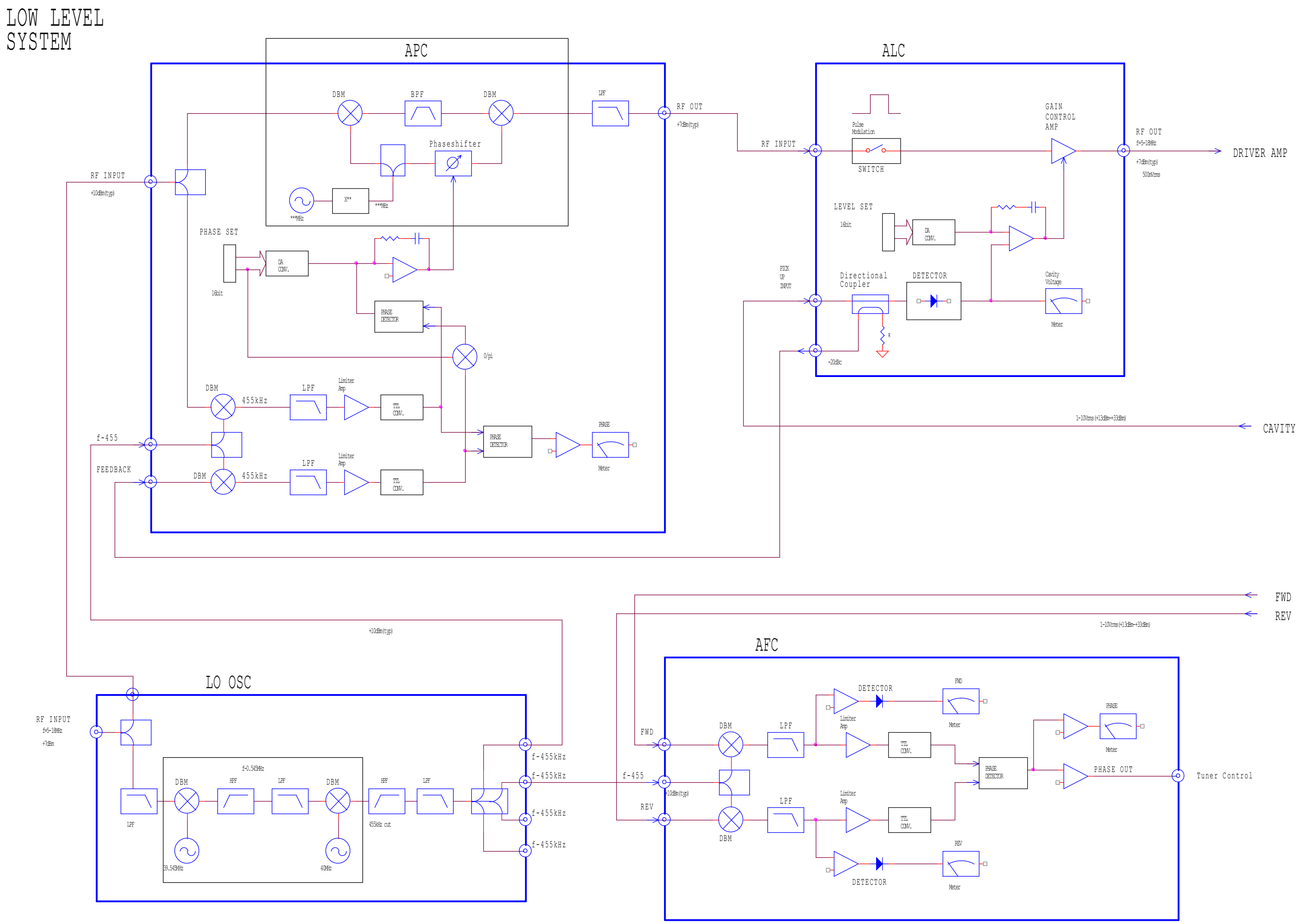
LLRF System for Cyclotrons

- Analog system
  - ALC
  - APC
  - AFC



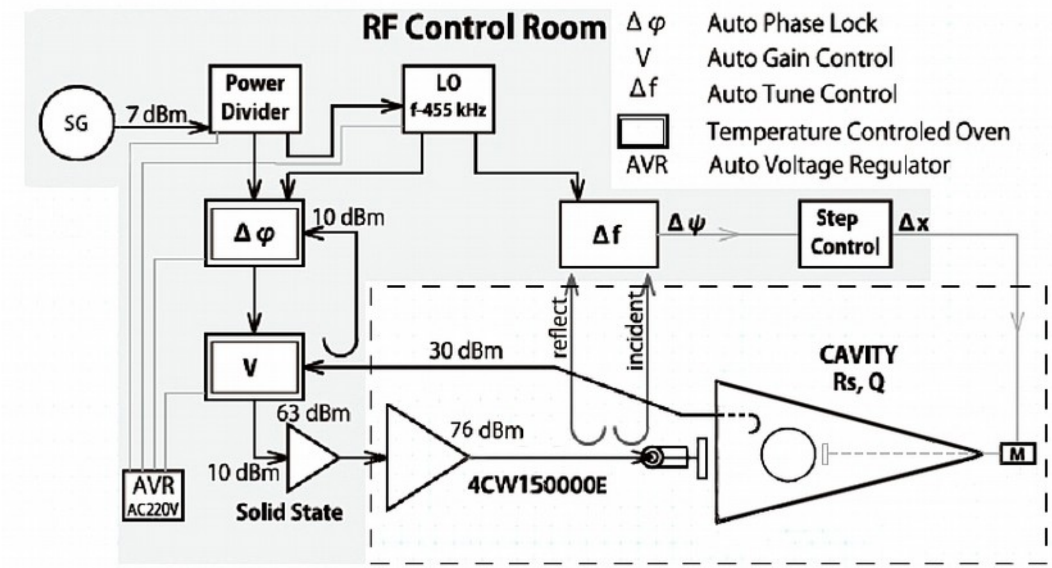
LLRF System for Cyclotrons

- Details

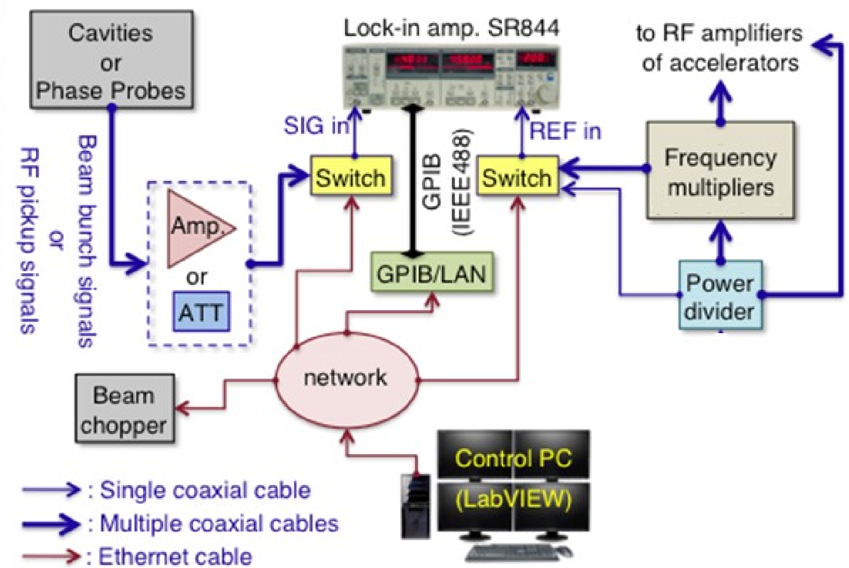


LLRF System for Cyclotrons

- One master oscillator for all cavities
- Analogue feed back
- Temperature controled oven



Functional Diagram of Analog LLRF system

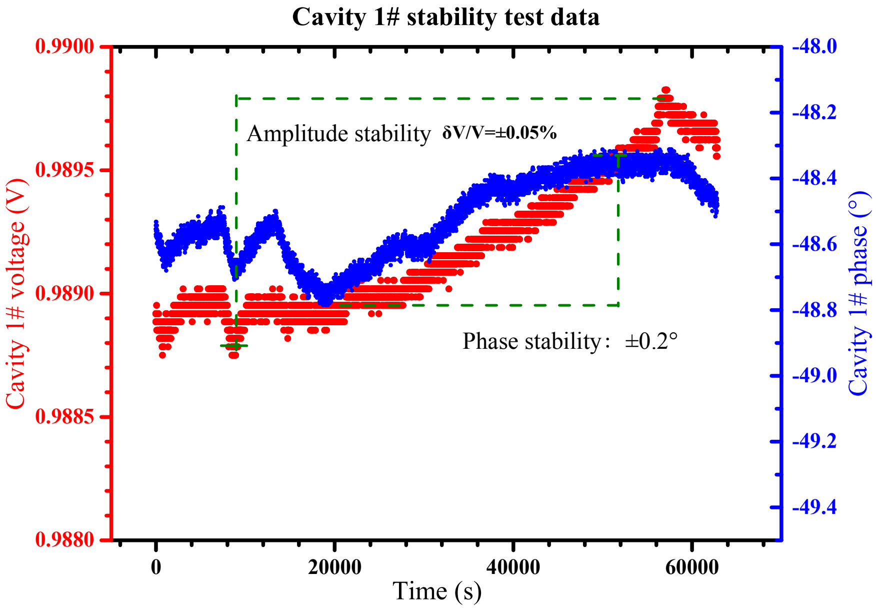


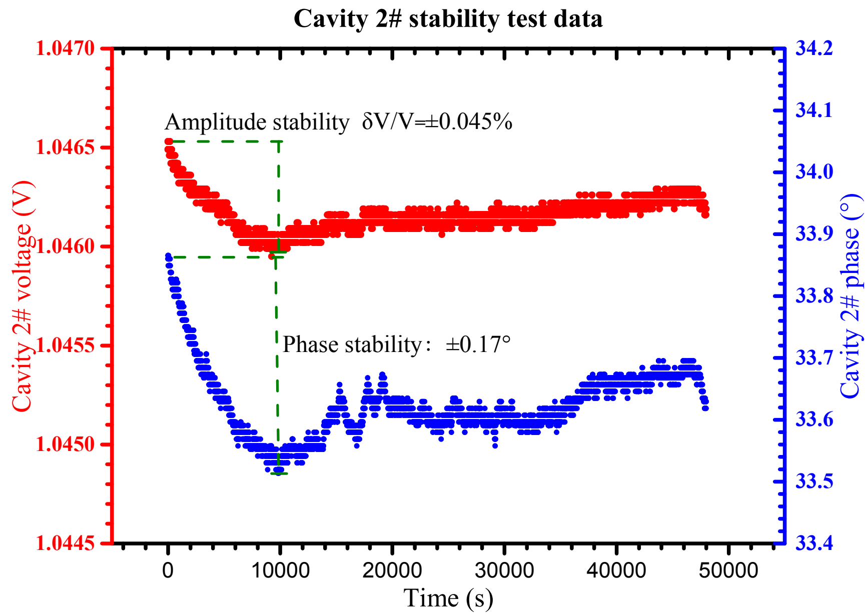
Monitoring system of rf and beam stability based on Lock-in Amp.

LLRF System for Cyclotrons

RF system parameter

Resonant Frequency	31.02MHz
Dee Voltage	60-80KV
Dee Angle	33°
Extraction Radius	750mm
Injection Radius	35mm
Phase Stability	≤±0.5°
Amplitude Stability	$\leq 1\times10^{-4}$
Frequency Stability	$\leq 1\times10^{-6}$
Magnet	
Magnet Coil	~300kAT
Maximum magnetic field	2.75T
Magnet Weight	~90 tons





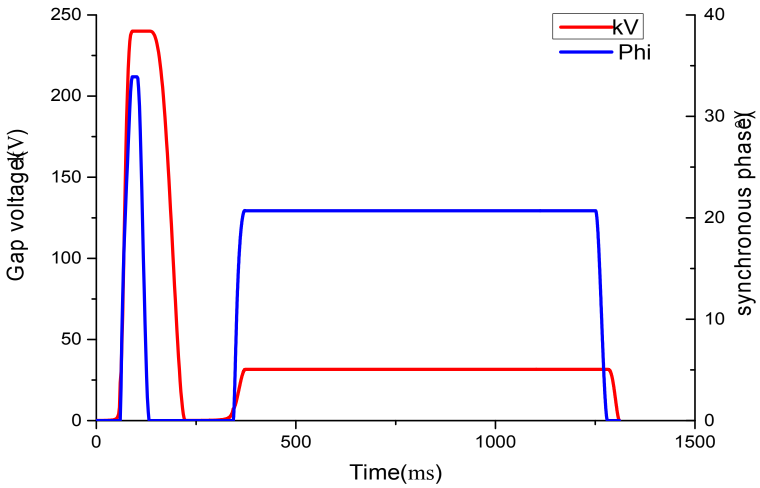
LLRF System for Synchrotrons

Requirements of the LLRF System

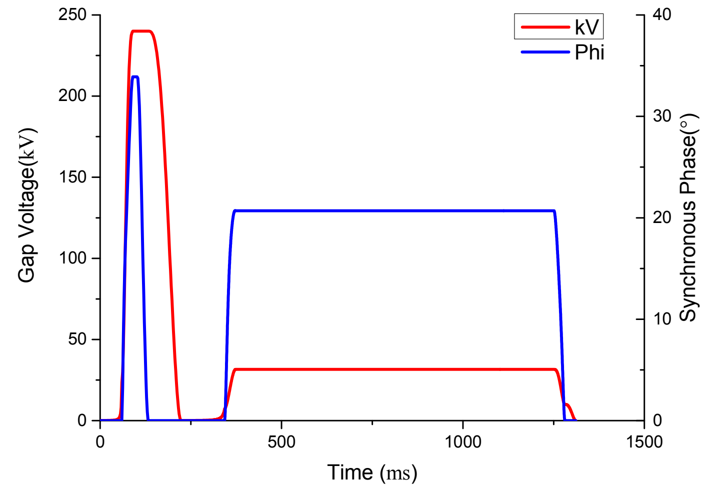
- Regulate the amplitude and phase
- Beam Loading Compensation
- Adjust phase between different cavities
- Synchronous phase control
- Adjust the working frequency according to BPM signal
- All digital system
- Base cPCI Bus

LLRF System for Synchrotrons

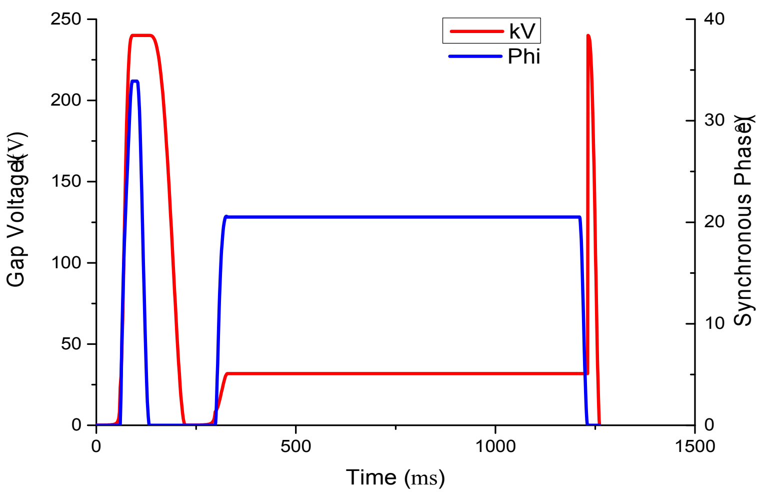
- **BRing-gap voltage waveform**



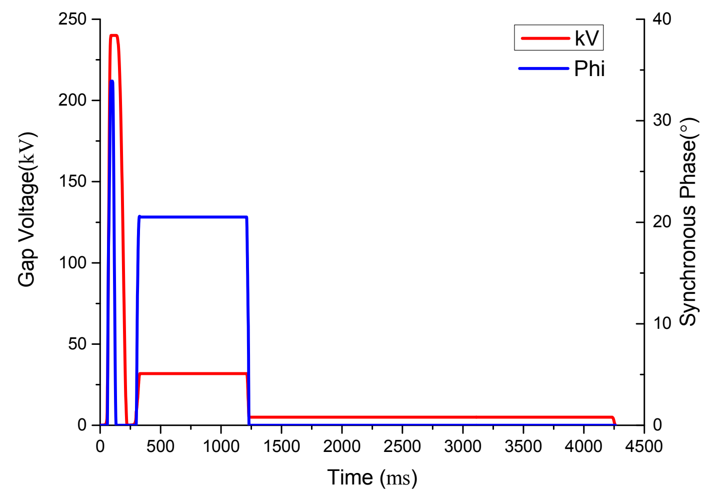
Conventional beam acceleration



Momentum spread adjustment



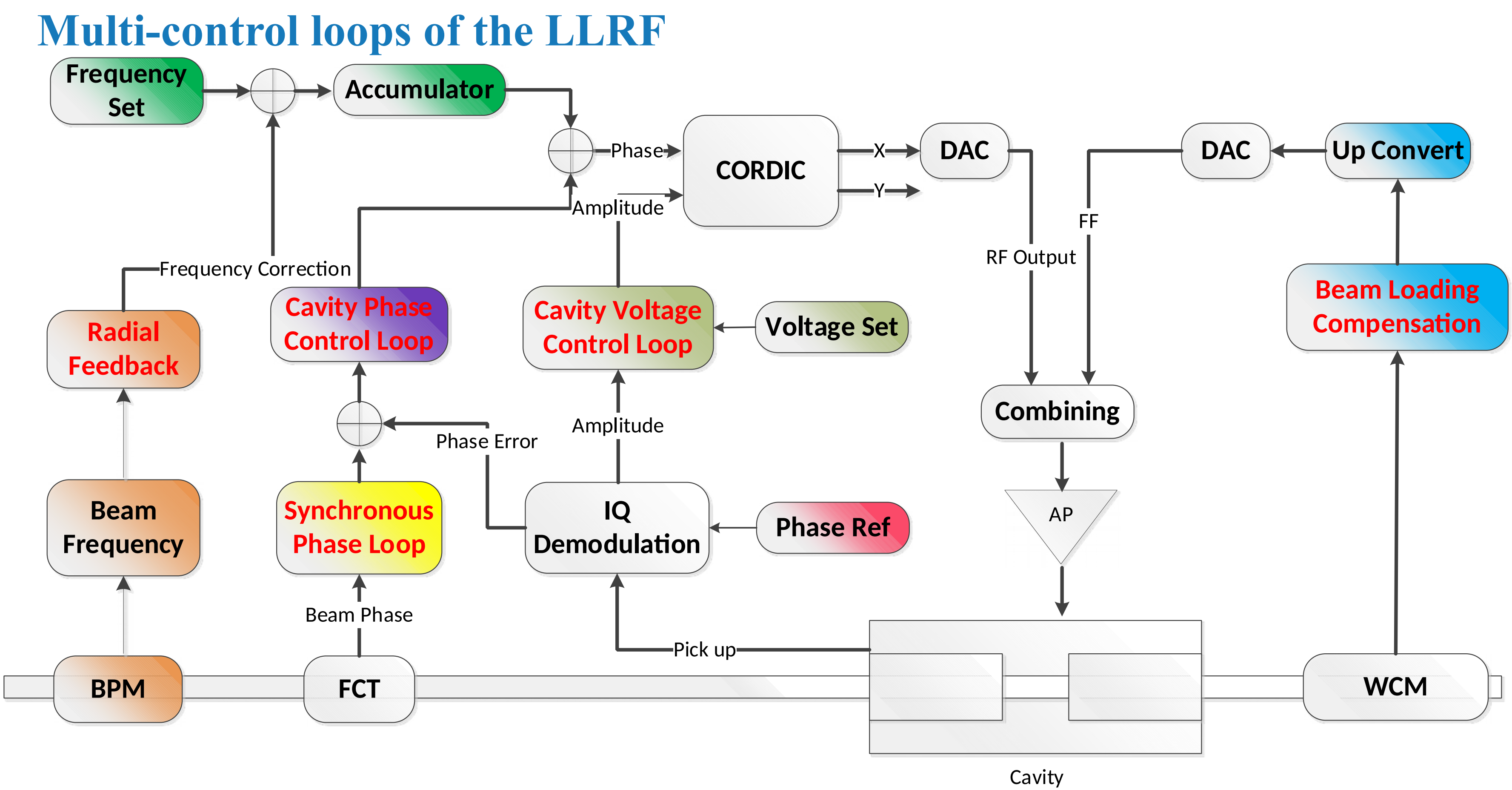
Bunch rotation



Bunch length manipulation

LLRF System for Synchrotrons

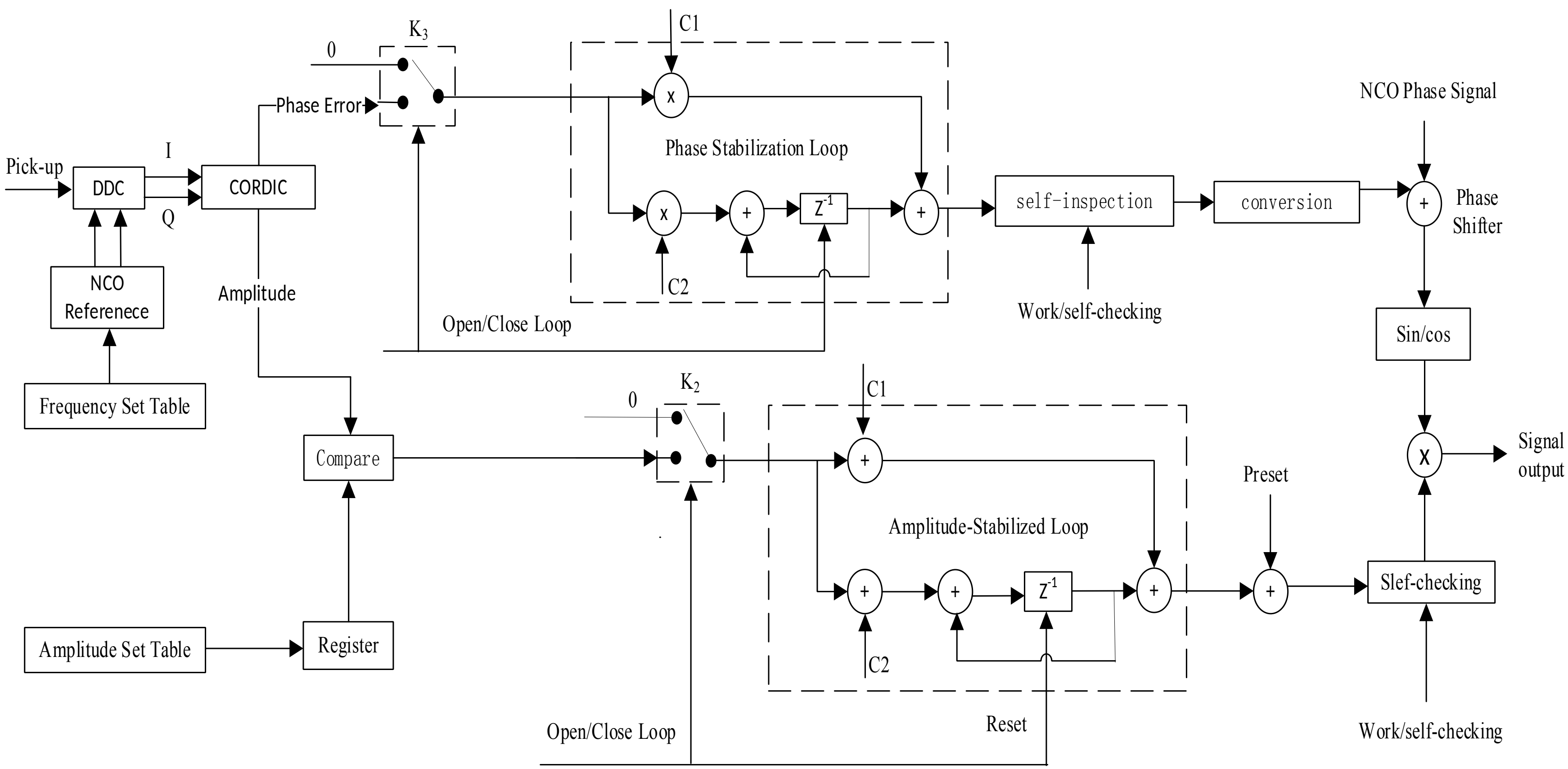
- **LLRF System of Sring and Bring**



Principle Diagram of the Multi-Control Loops

LLRF System for Synchrotrons

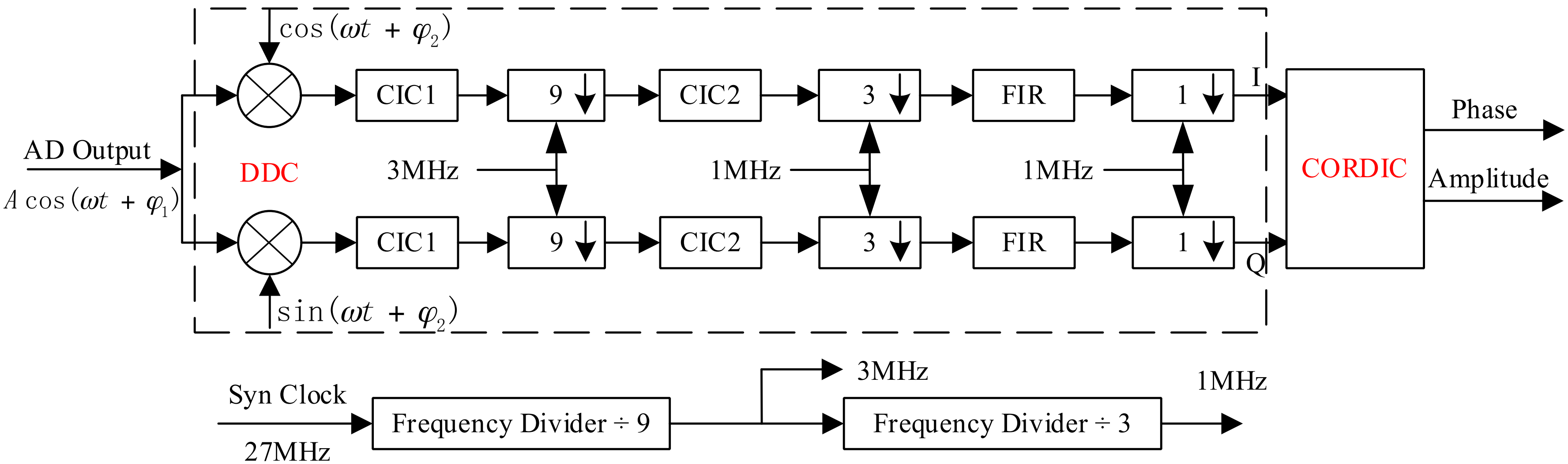
- **LLRF System of Sring and Bring**



Principle Diagram of Phase/Amplitude stabilization Loop

LLRF System for Synchrotrons

- **LLRF System of Sring and Bring**



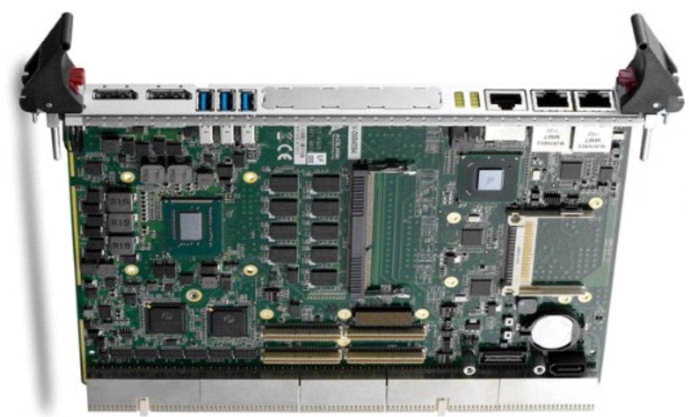
Principle Diagram of Demodulation and Digital Down Convert

LLRF System for Synchrotrons

- **LLRF System of Sring and Bring**

Hardware

- 6U 8-slot CompactPCI
- PICMG2.5 H.110 CT Bus
- PICMG2.1 Hot Swap compliant 64-bit
- backplane with P3 & P5 rear I/O
- Dual AC power inlets



cPCI-6520

- The 3rd generation Intel Core i7
- Dual channel DDR3 ECC memory
- Three independent displays
- USB 3.0 and PCI Express Gen3 support
- Remote management and optional TPM support

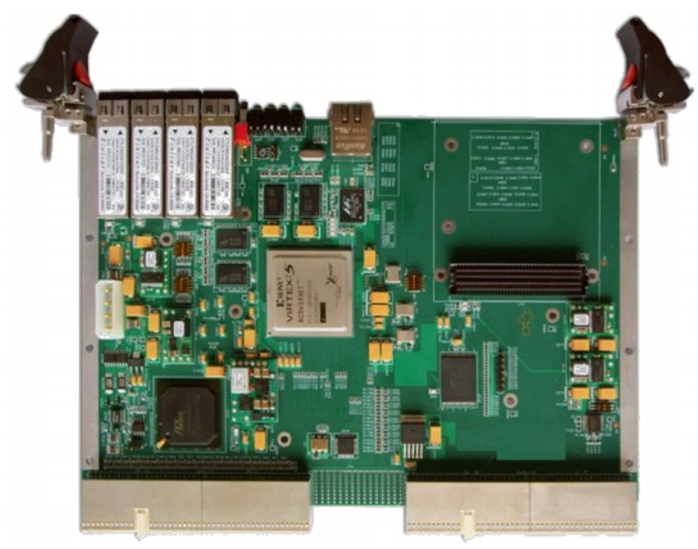
cPCIS-6418U

LLRF System for Synchrotrons

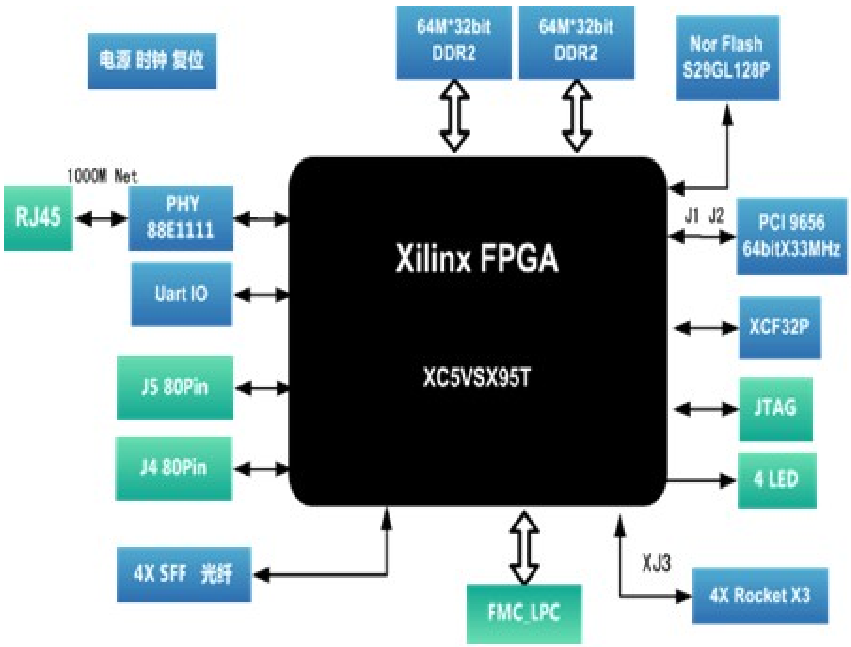
- **LLRF System of Sring and Bring**

Hardware

- Xilinx XC5VSX95T-1FF1136
- Configurable Logic Blocks 160 x 46
- Max Distributed RAM 1,520Kb
- DSP48E 640, CMT 6, IObank 20



Main Board



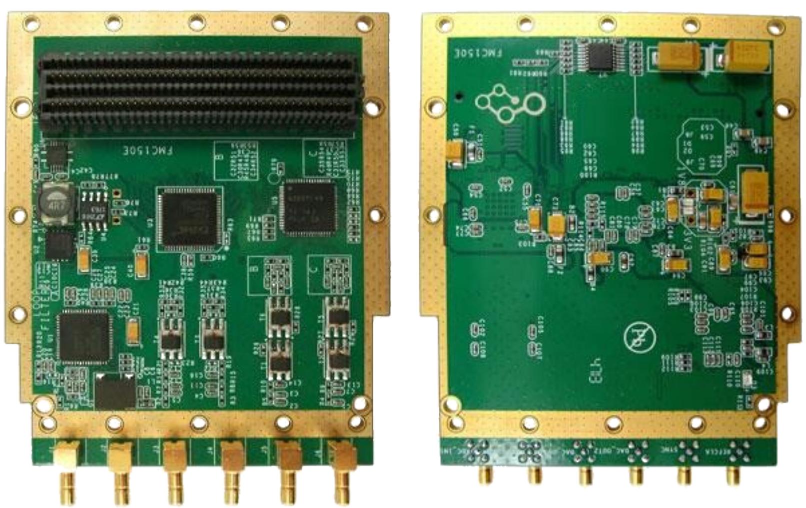
Main Board Block Diagram

LLRF System for Synchrotrons

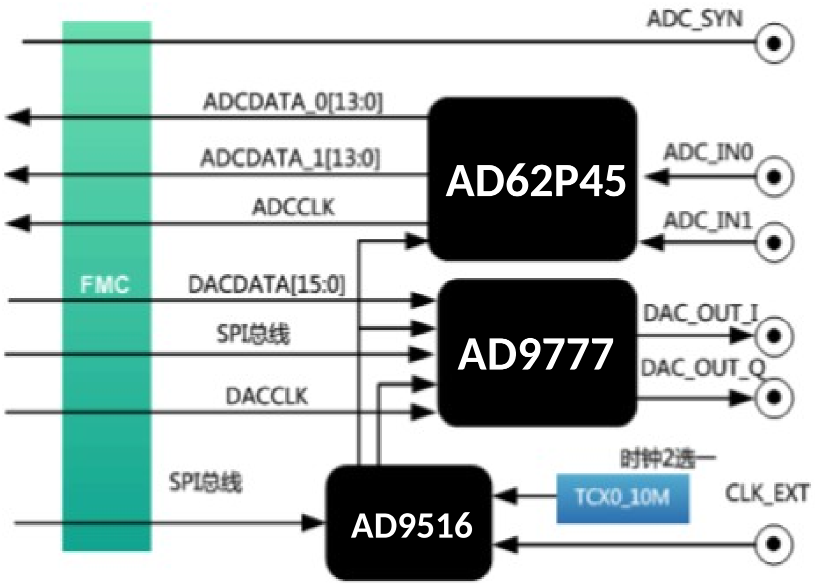
- **LLRF System of Sring and Bring**

Hardware

- FMC interface
- 2CH, 14bit, 125MSPS, AD62P45, ADC
- 2CH, 16bit, 160MSPS, AD9777, DAC
- AD9516 clock chip



ADC/DAC Board



ADC/DAC Block Diagram

LLRF System for Synchrotrons

LLRF System of Sring and Bring

Challenge

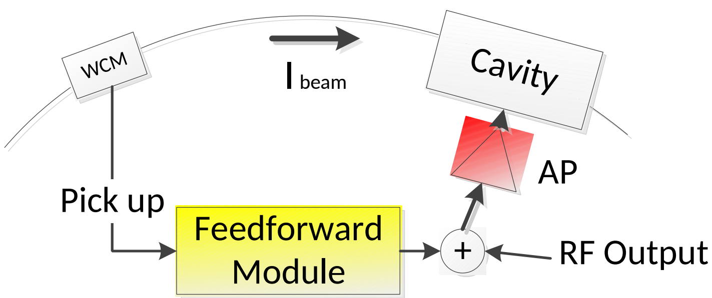
– Beam loading compensation

$$V_{cav}(t)=V_{cav,dr}(t)+V_{cav,wake}(t)+V_{cav,FF}(t)$$
$$=H_{dr}^{cav}(t)\cdot V_{dr}(t)+Z'_{cav}(t)\cdot I_{beam}(t)+Z_{FF}(t)\cdot I_{beam}(t)$$

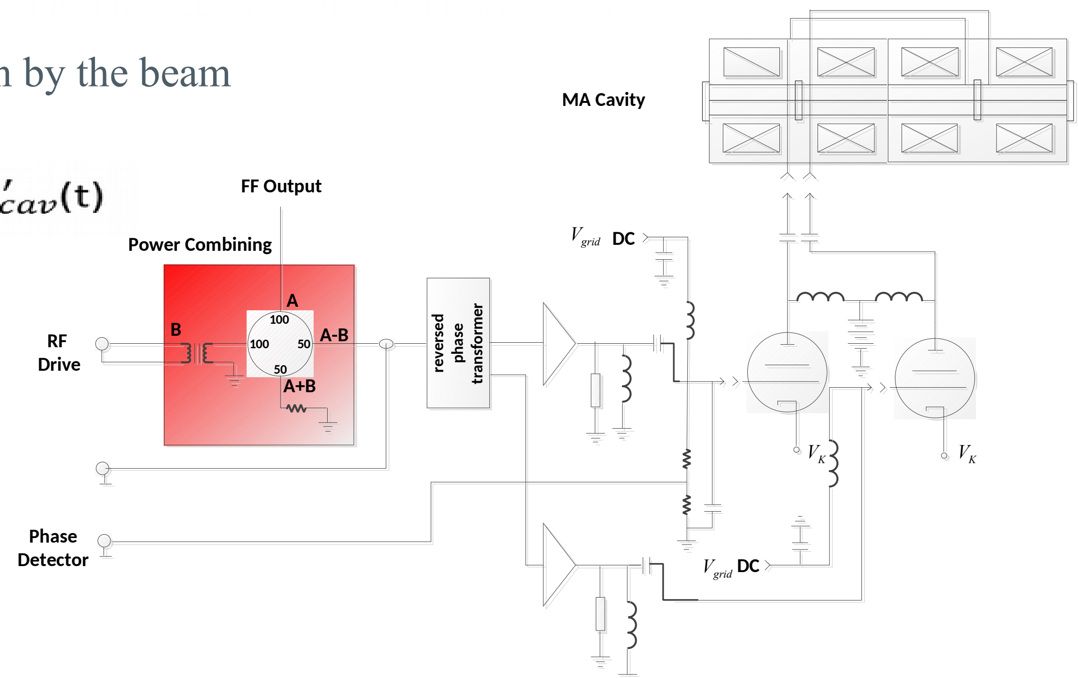
$Z'_{cav}(t)$ is the impdence seen by the beam

– Feed-forward

$$Z_{FF}(t) = -Z'_{cav}(t)$$



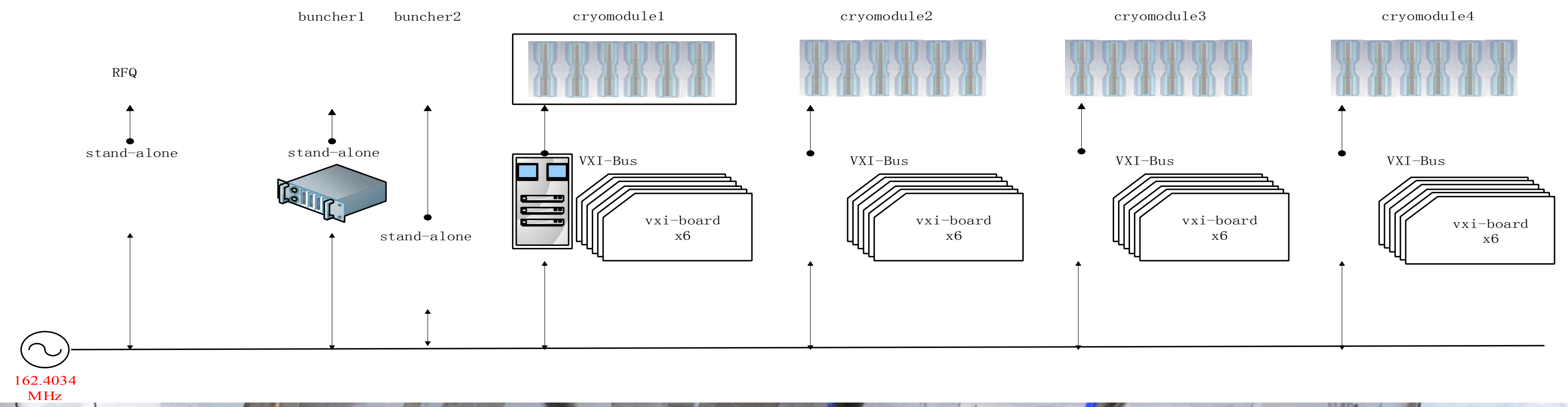
Principle Diagram of Feed-forward

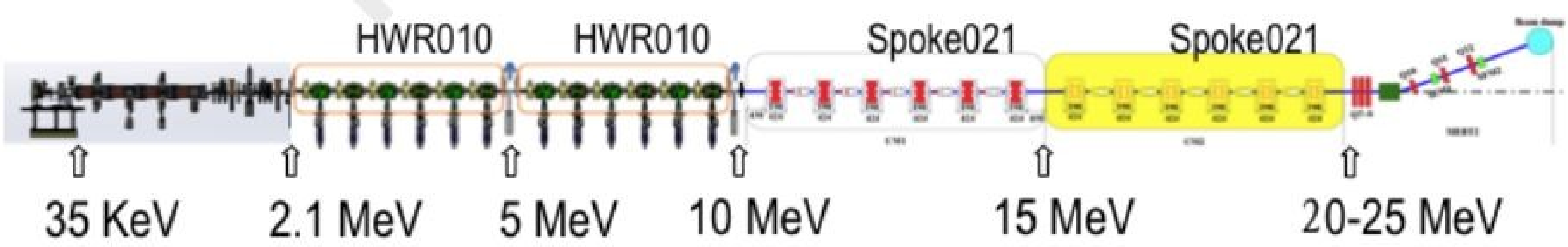


Schematic Diagram of transmitter

LLRF System for ADS

Injector Parameter **Extract enegy :25MeV Beam intensity 10mA@CW**





LLRF System for ADS

Required functions:

- Cavity field control
- Cavity resonance control
- RF reference generation and distribution
- HPRF protection

Table 1 : LLRF specifications

Frequency	**162.5**MHz
Operation mode	CW/Pulse
Amplitude stability	0.3%
Phase stability	0.3°
Tunning	±1°

LLRF System for ADS

- **work mode:**

normal mode: On the startup, work in Pulse mode to train the cavity, then switch to CW mode

commissioning mode: To avoid high radiation levels , during the commissioning of the machine, work in pulse mode

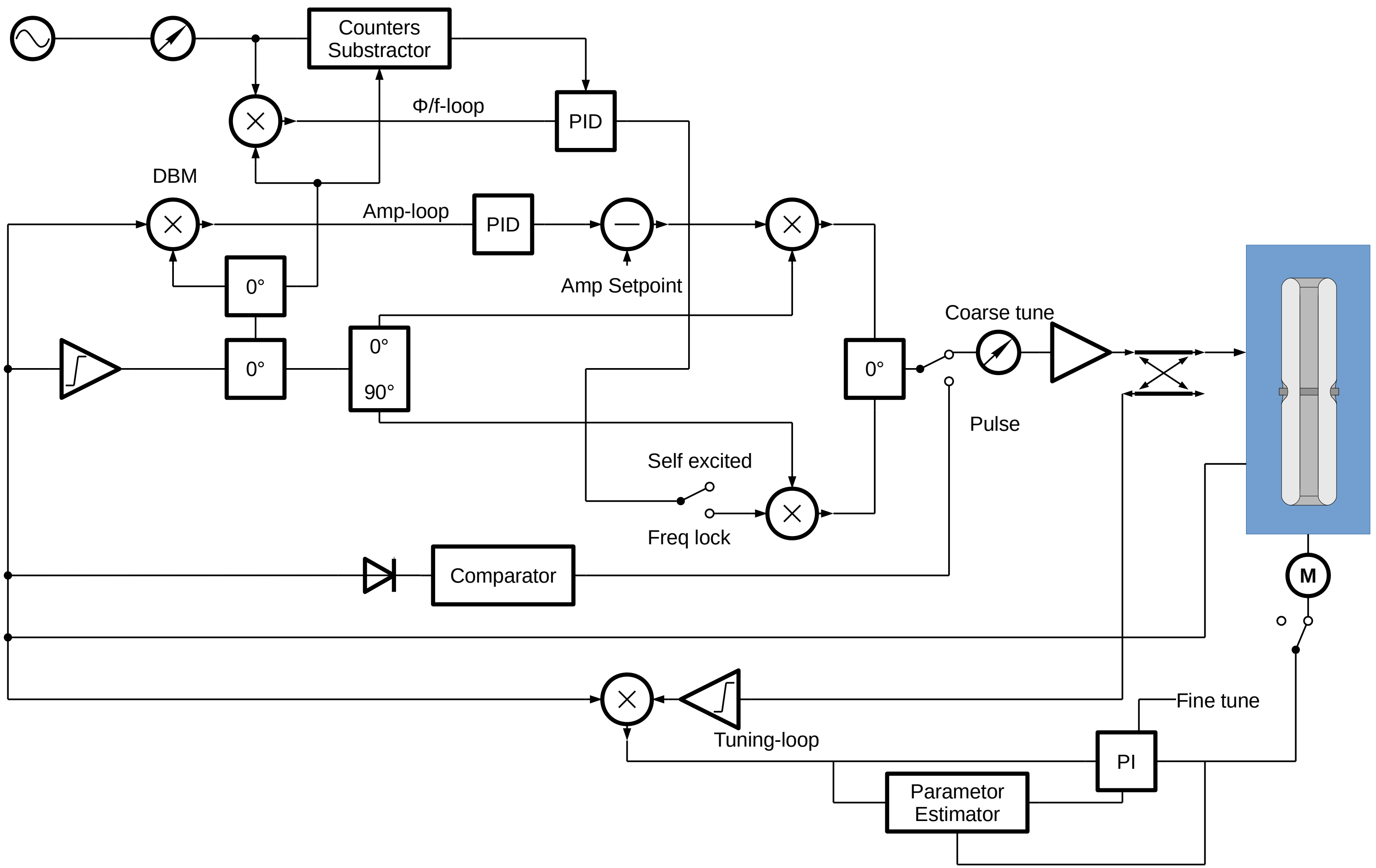
Self-Exited Loop

- **special for RFQ:**

Due to poor cooling system, heat detunes the cavity, On the startup LLRF takes self-exited loop to follow the resonance frequency of the cavity

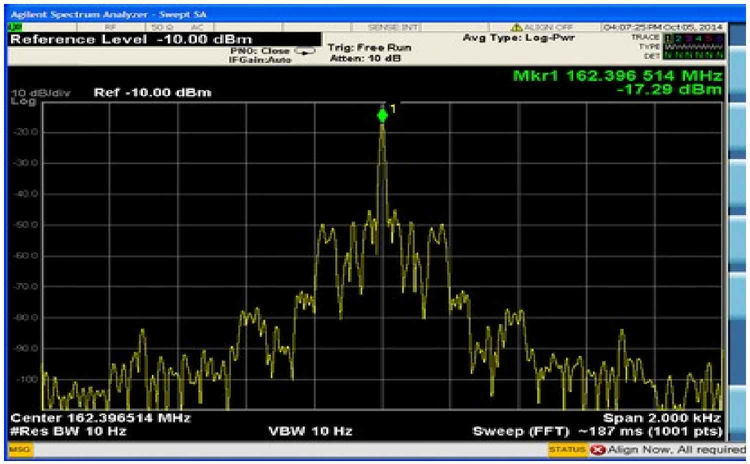
Once the RFQ has achieved steady operation, frequency change to MO (GDR)

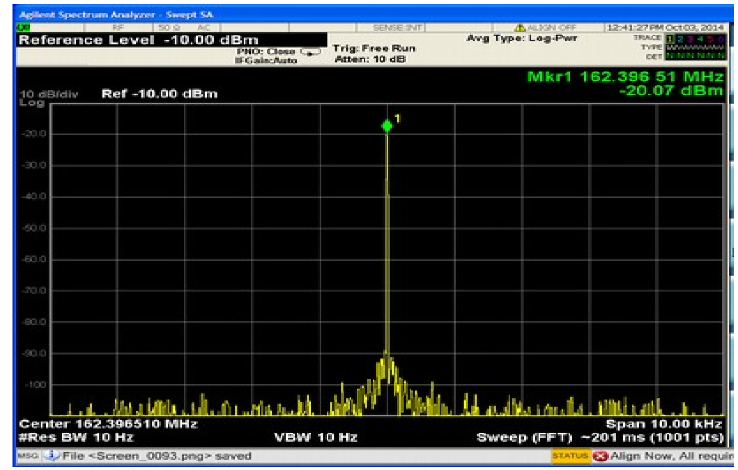
LLRF System for ADS

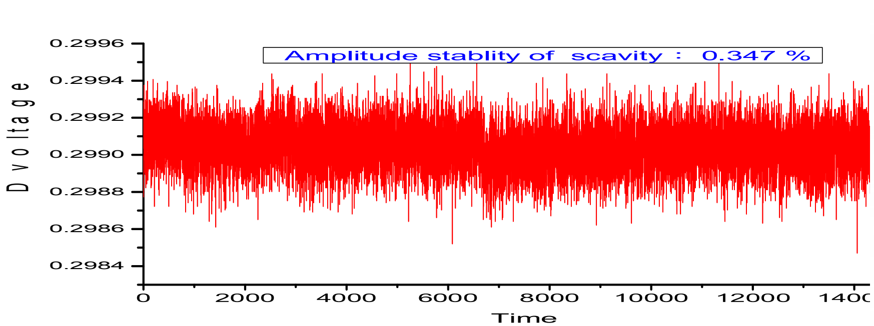


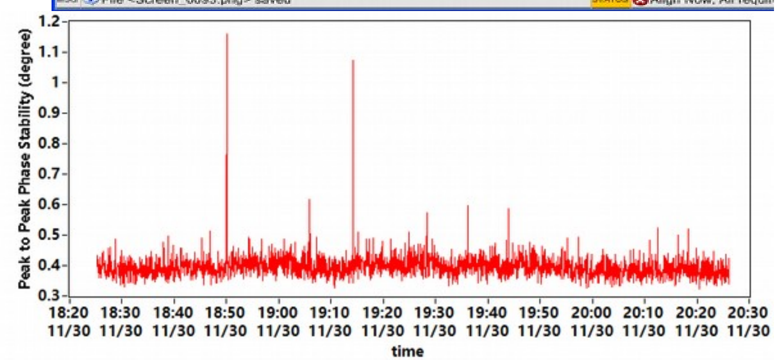
LLRF System for ADS

10MeV with beam test result:



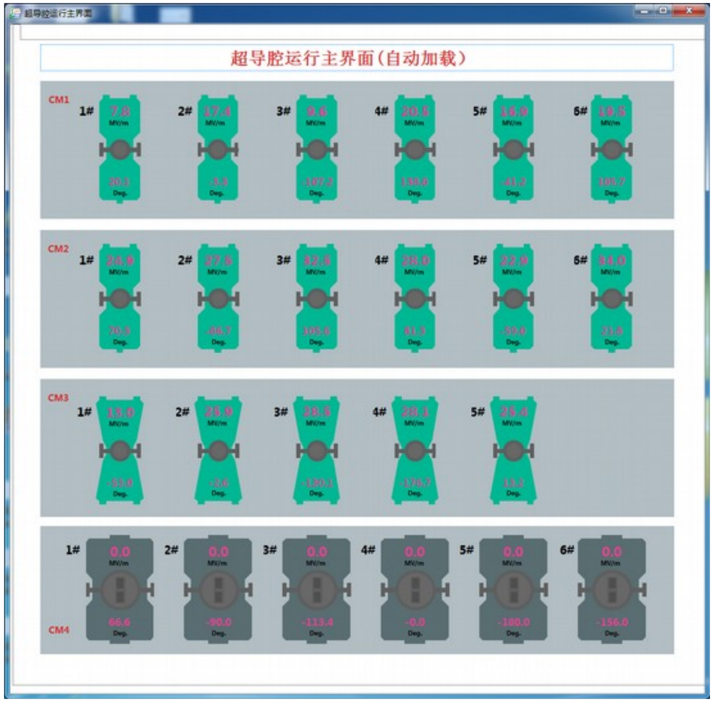


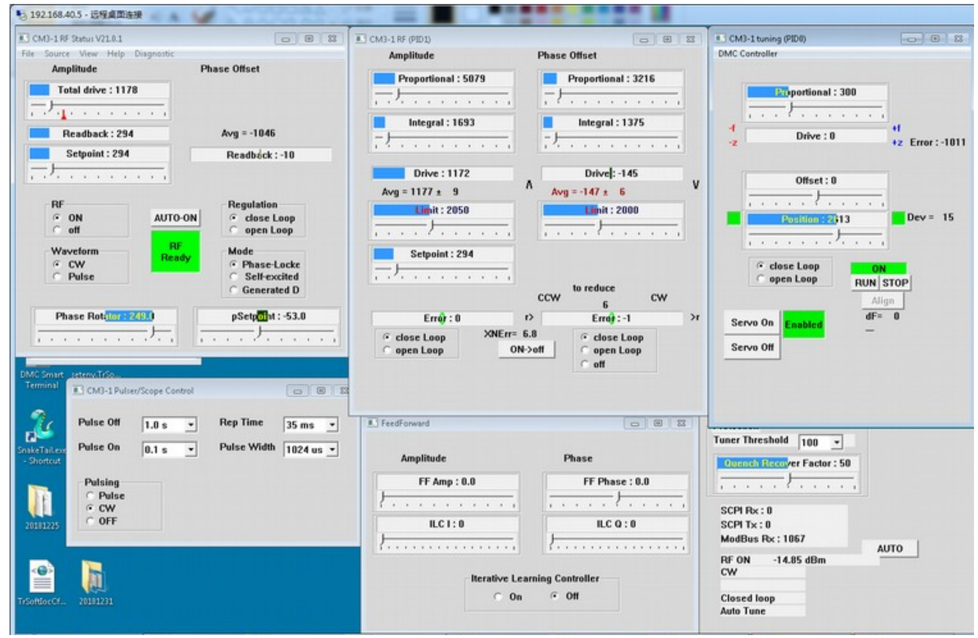


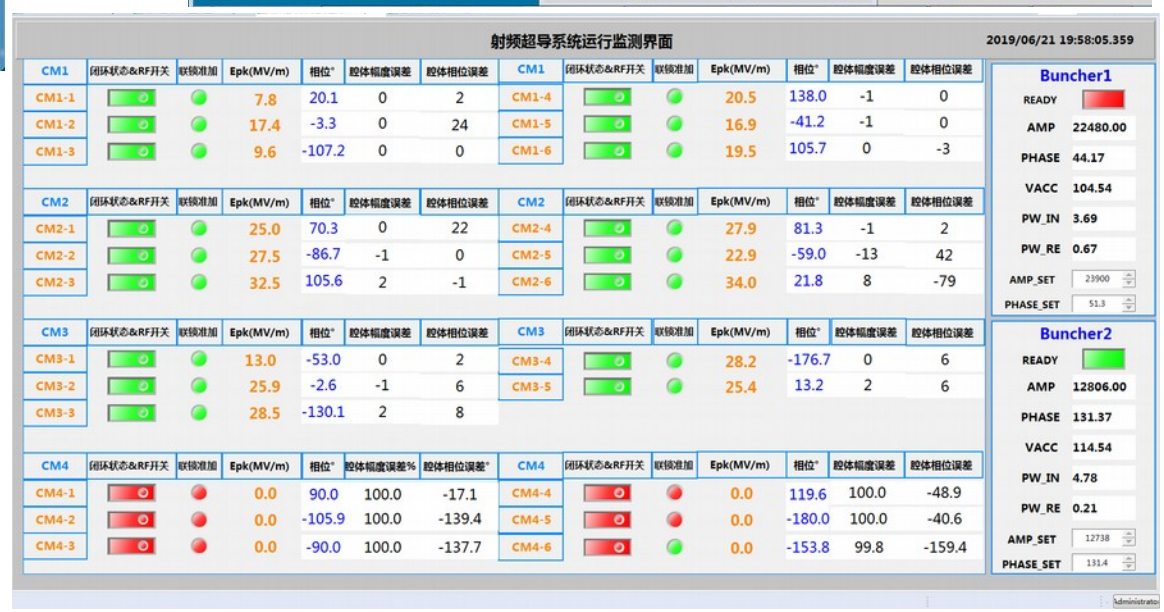


Test Results：Amplitude stability 3.5%，Phase stabiliy: ±0.4°。 ADS LLRF operating over 5000 Hs

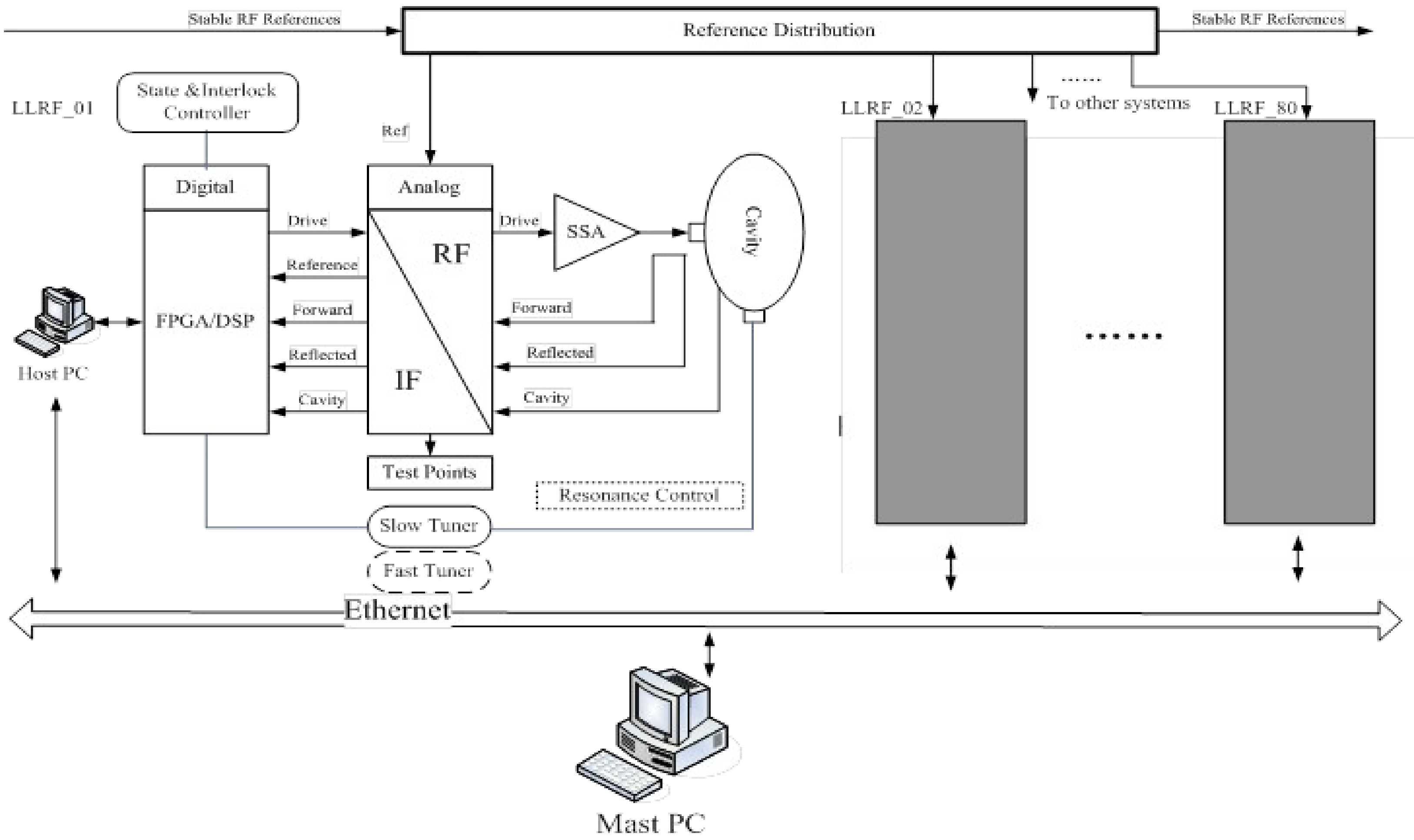
LLRF System for ADS







Prototype LLRF System



LLRF System for ADS

clocks distribution

RF 162.5MHz

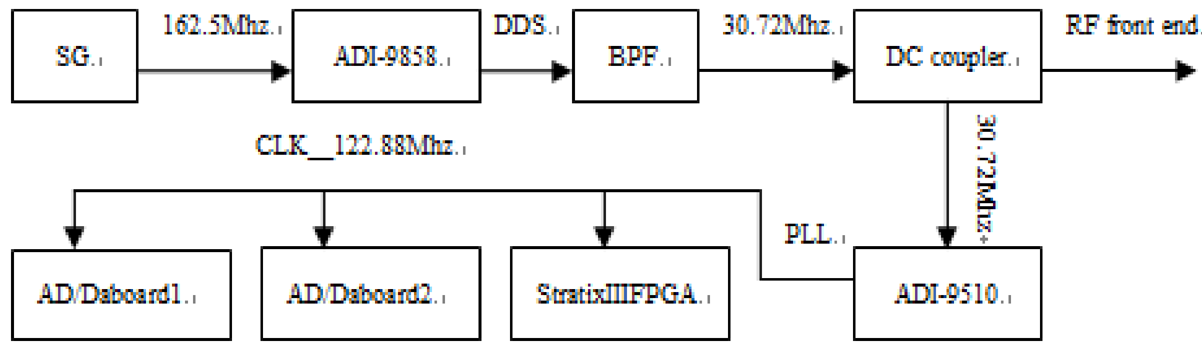
IF: 30.72MHz

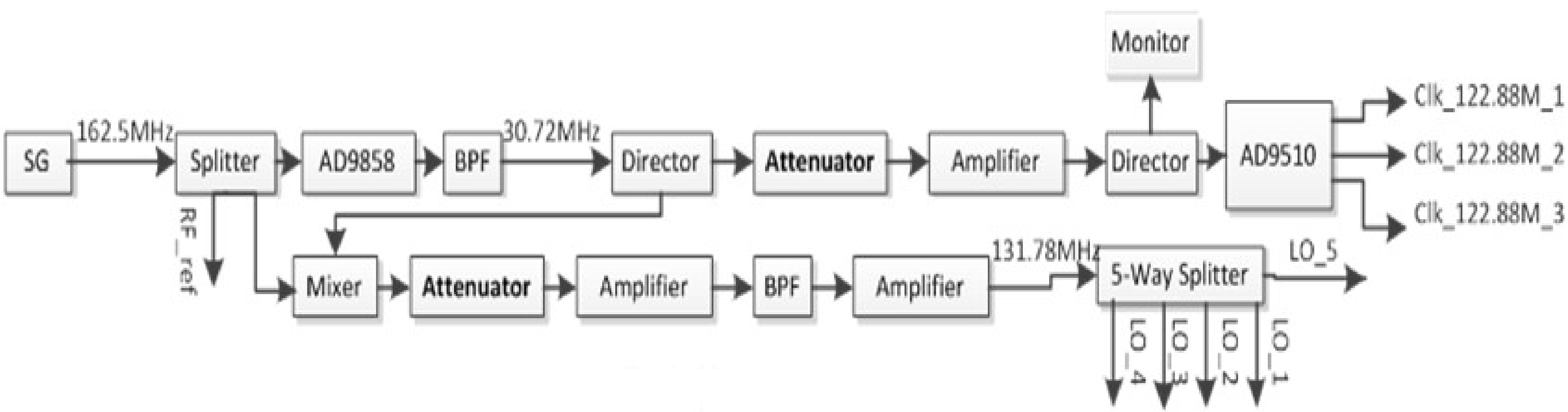
LO: 131.78MHz

ADC: 122.88MHz

DAC: 122.88MHz

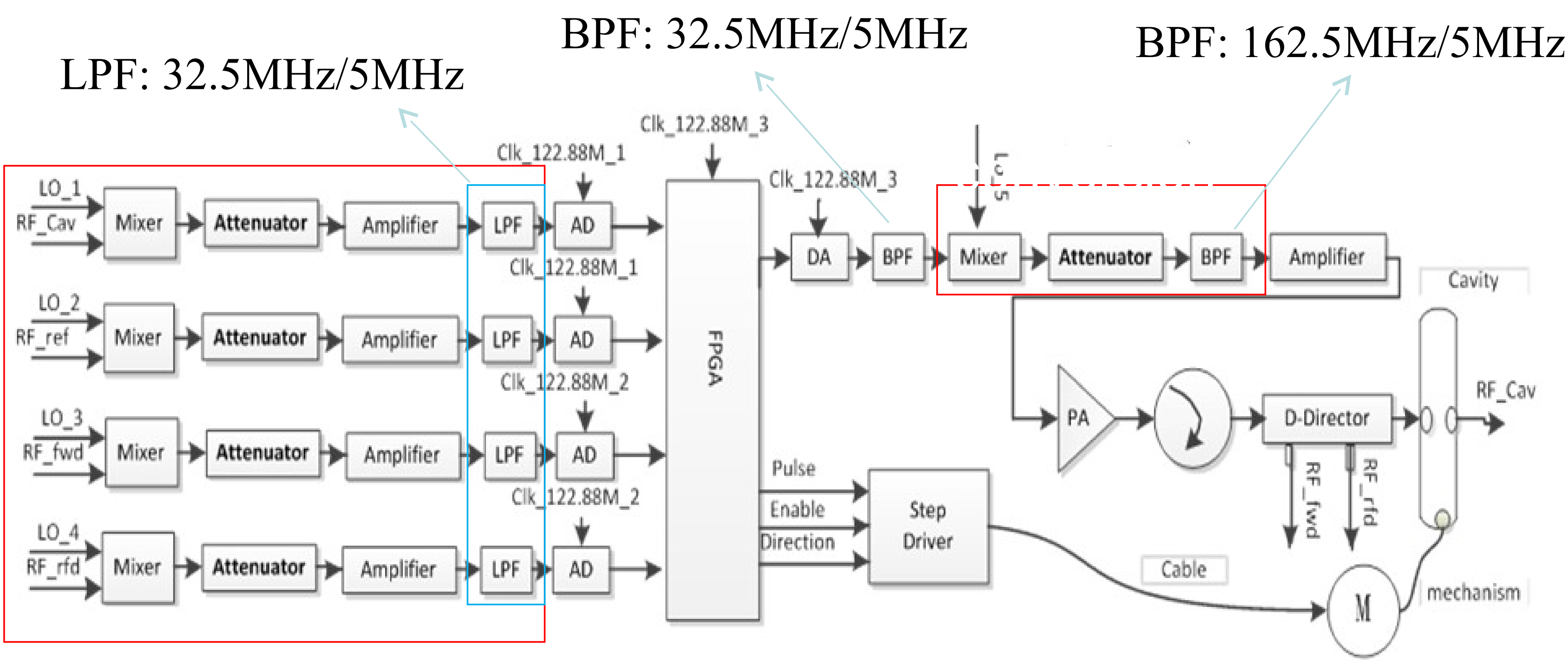
FPGA: 122.88MHz





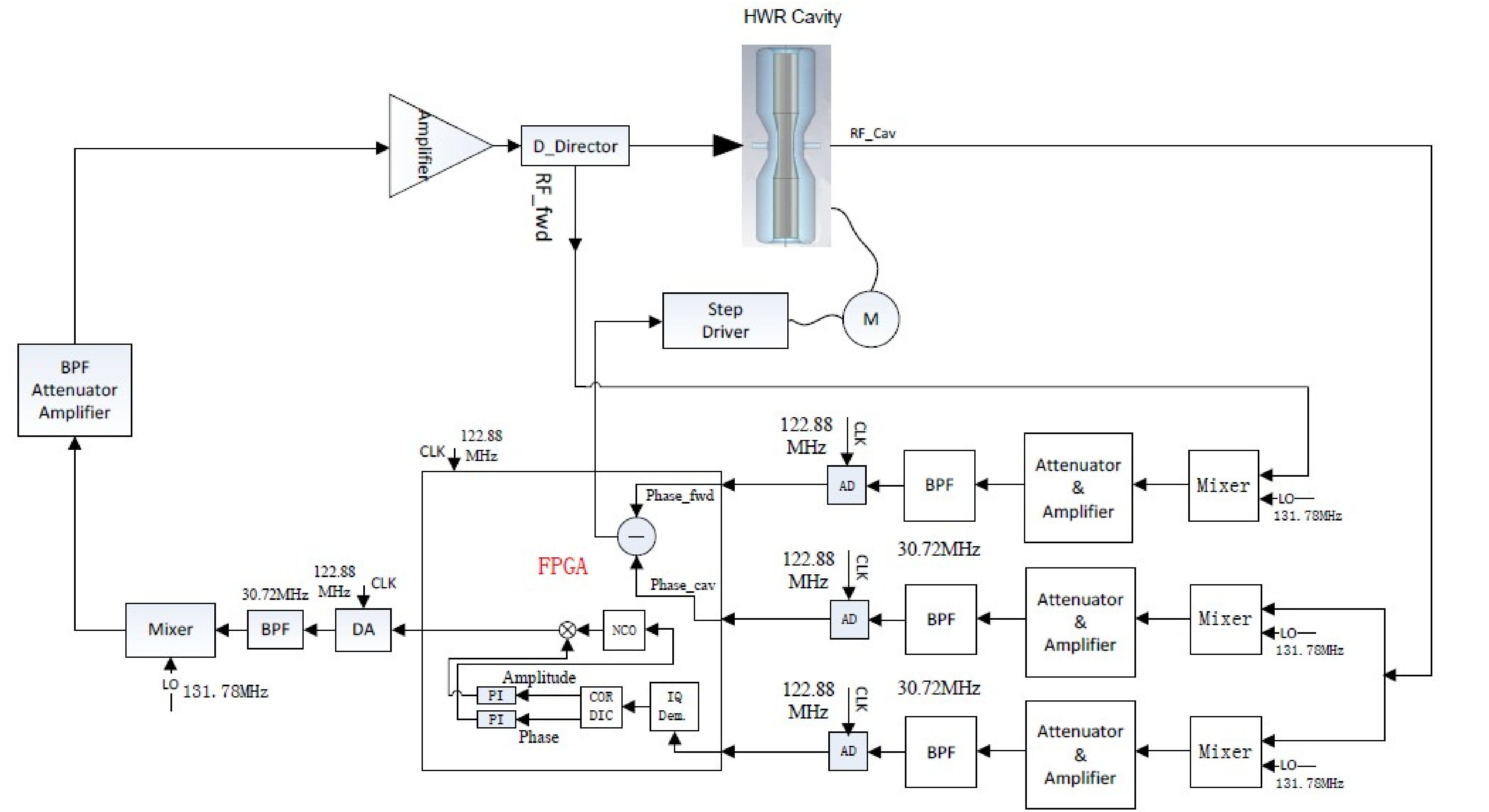
LLRF System for ADS

Frequency Conversion



Mixer: ZMY-2+ Mini-Circuit

LLRF System for ADS



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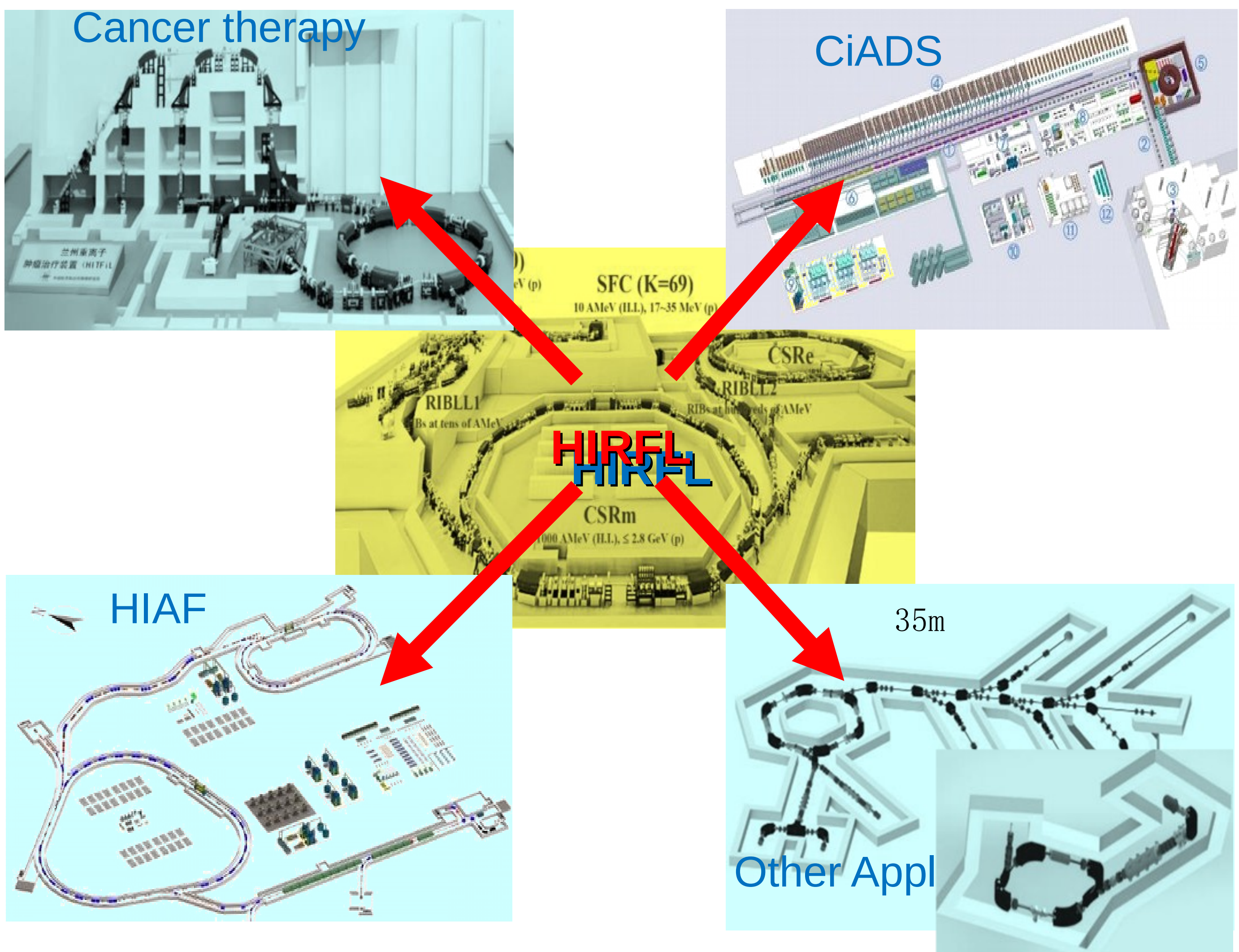
Future Projects

Recent and future projects based on HIRFL



Future Projects

- Universal Hardware
  - LLRF
  - Timing system
  - Beam diagnostic system
  - Data acquisition system
  - …
- Backplane bus standard
  - mTCA
  - PCIe
  - ...

Summary

- LLRF Activities in IMP:
- Cyclotrons LLRF (SFC, SSC)
  - Adopted analog circuit
  - consists of Phase stabilizer, amplitude controller and tuning controller.
- Synchrotrons LLRF (CSRm, CSRe)
  - The low level control system aims to realize the adjustment and stability of rf acceleration voltage, synchronization of acceleration voltage and beam phase, rf frequency correction, beam load feedforward and feedback and other control functions to ensure the stable operation of rf system in accordance with physical requirements.
- ADS linac LLRF
  - To control the cavity to work in the resonance state under the condition of large beam load and strong Lorentz force detuning to reducing the rolling fluctuation. The effects of temperature, cavity deformation and noise on the tuning process.

Thanks for your attention!