Overview of the CSNS Linac LLRF and operational experiences during beam commissioning
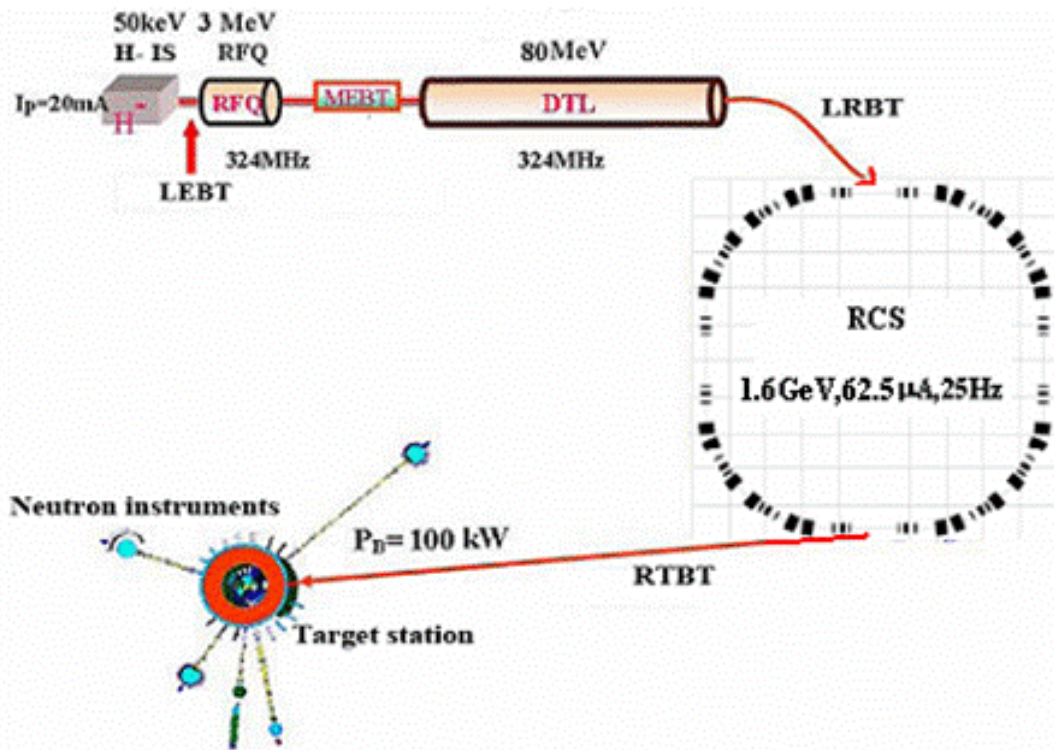
Zhencheng Mu
Chinese Spallation Neutron
Source (CSNS), Dongguan, China

Outline

❑ **Introduction of CSNS Linac RF System**

❑ **Digital LLRF Control System**

❑ **Summary**

Chinese Spallation Neutron Source (CSNS)

❑ **Pulse Repetitive frequency : 25Hz**
Linac beam energy: 80MeV
RCS beam energy: 1.6GeV
Beam Power to Target:100kW

❑ **Linac is comprised of**
1 RFQ
2 Buncher Cavities
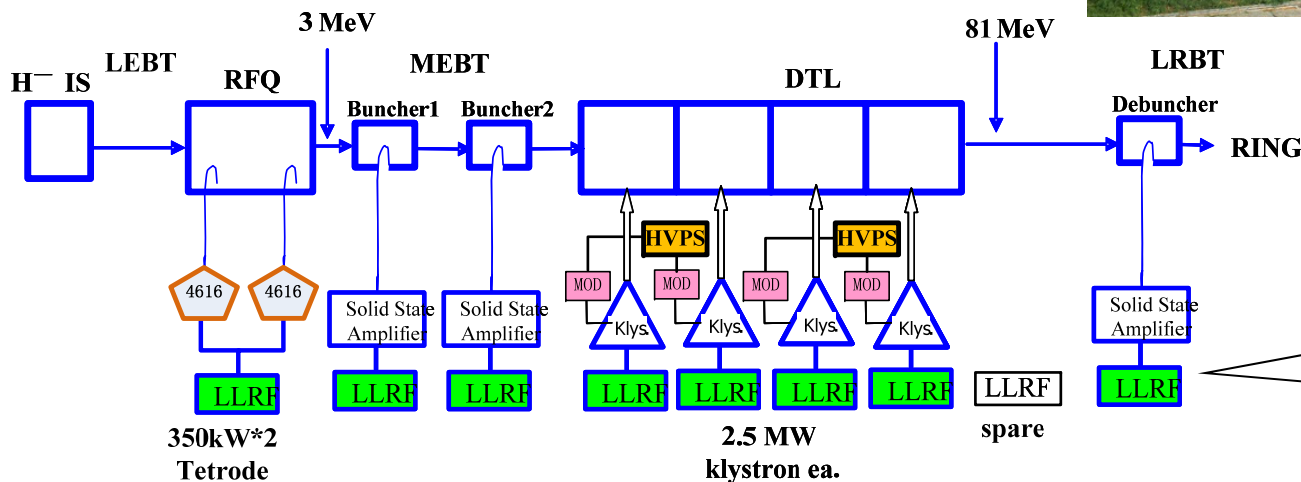**4 DTL Accelerators**
1 Debuncher Cavity

Introduction of CSNS Linac RF System

❏ **Linac RF system owns three types of power sources**

——**RFQ: two 350kW 4616 tetrodes**

——**Bunchers/Debuncher Cavities: three 25kW solid state amplifiers**

——**4 DTLs: four 3MW klystrons**

**The Linac RF power sources hall**

Overview of the Linac RF system

3 MeV

81 MeV

H⁻ IS LEBT RFQ MEBT Buncher1 Buncher2 DTL LRBT Debuncher RING

HVPS HVPS

MOD MOD MOD MOD

4616 4616

Klys Klys Klys Klys

Solid State Amplifier Solid State Amplifier Solid State Amplifier

LLRF LLRF LLRF LLRF LLRF LLRF LLRF LLRF LLRF

350kW*2 Tetrode

2.5 MW klystron ea.

spare

LLRF Low Level RF | 4616 Tetrode RF Amplifier | Klys Klystron | MOD Modulator | HVPS High Voltage Power Supply

Two Burle 4616 Tetrods Combined for RFQ

❏ **RF power requirements for RFQ:**

RF power	RF pulse width	Rep. rate	Duty factor
410 kW (cav. loss) +120 kW (beam loading) = **530 kW**	650μs	25pps	1.625%

❏ **Each 4616 tetrode can output 350kW, 2×350kW=700kW. The power source was used in the RFQ beam commissioning in 2015, it works well!**
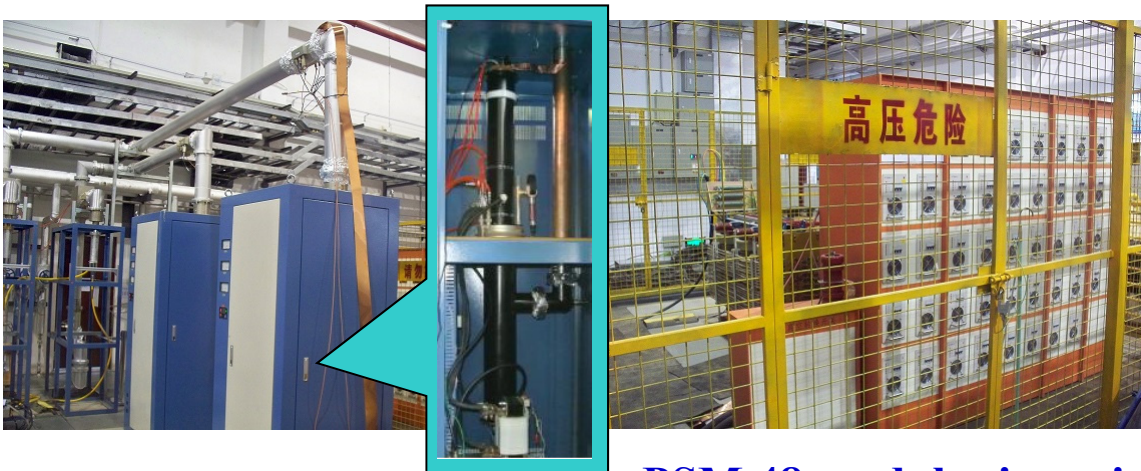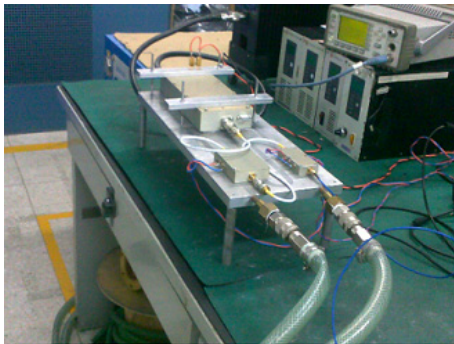

4616 tetrode final cabinet

PSM 48 modules in serial configuration

Two 4616 output 350kW

Three Solid State Amplifiers for Two MEBT Buncher Cavities, One LRBT Debuncher Cavity

❑ **Each solid state RF amplifier can output 25kW power, redundancy design, test results show that these amplifiers have excellent performance and stability.**

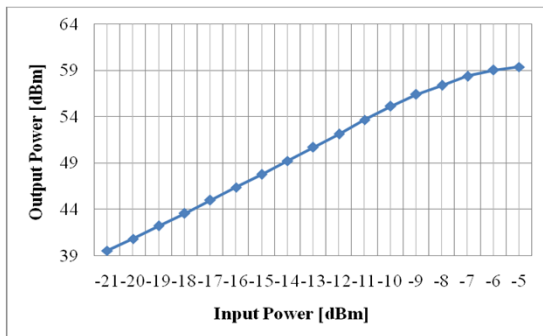

800W power amplification module
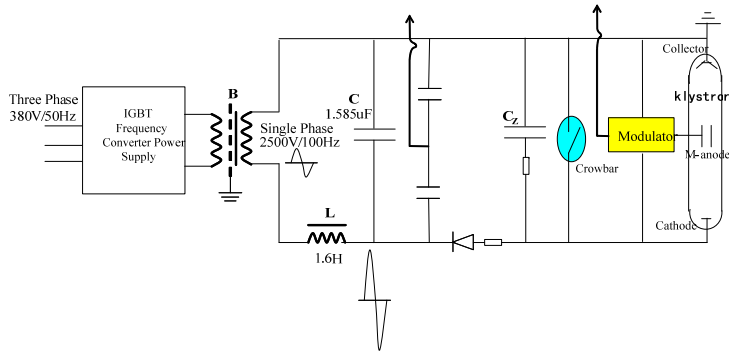

Three-stage power combiner

800W power module array

Two 25kW solid state amplifiers

input-output linearity of the 800W module

Four Klystrons for Four DTLs

❑ **CPI 324MHz pulsed klystron amplifier, Maximum output power: 3MW. The installation and commissioning of the first klystron power source have been finished.**
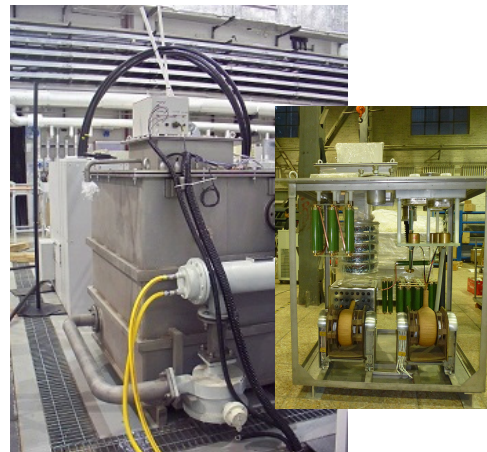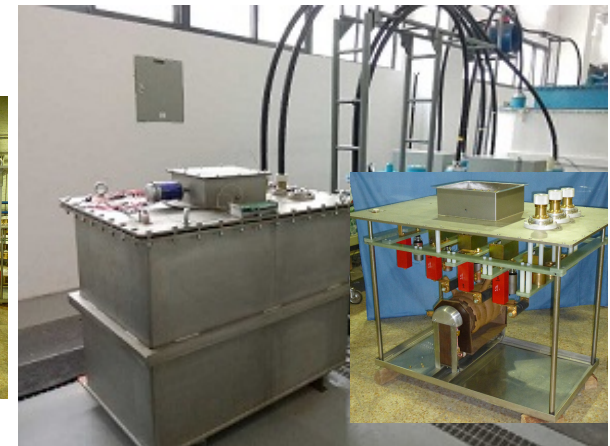

Block diagram of the klystron power source.

120kV serial resonant high voltage power supply


IGBT solid state switch modulator

Crowbar: ignitron as the energy relief device

Digital

LLRF Control System

❑ **Duties of the LLRF system**

— **±1% amplitude of the cavity field**

— **±1° phase of the cavity field**

— **Cavity resonant frequency control**

— **High Power protection**

The cabinet of the LLRF control system

324MHz RF reference line

AM (Analog Module), temperature stability

CDM (Clock Distribution Module), temperature stability

DCM(Digital Controller Module)

HPM(High Power Protection Module)

The 324MHz Reference Line

—The reference line is located in sub-tunnel, frequency of the reference signal is 324MHz

—the Andrew phase stable cable is wrapped in a constant temperature water jacket, the variation range of the water temperature limited within $\pm0.1°$.

—The reference signal is picked up through a Narda 3000 coupler, Andrew phase stable cable to each station.
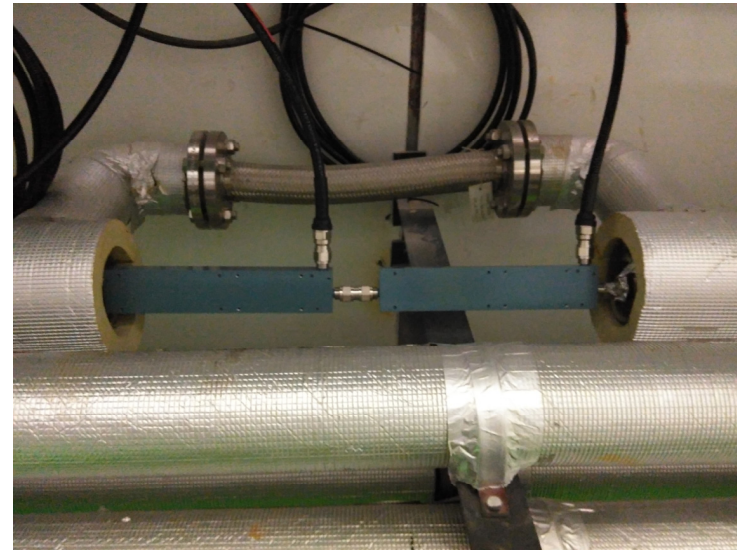
The Analog Module

❑ **The analog module consisits of two units :**

—**The analog up-down conversion unit: RF 324MHz, LO 360MHz, IF 36MHz.**

4×down conversion channels

2×up conversion channels

—**The clock generation unit**

144MHz, 36MHz, 72MHz

❑ **Put two units into a temperature stabilizing chamber, air cooling semi-condutor refrigeration, the temperature variation range is kept within ±0.1°.**

The Digital Field Control Module

❑ **Hardware**

—1×**FPGA: Altera Stratix II family EP2S90F1020**

—2×**ADCs with 4 sampling channels: Linear LTC2156, 170Msps 14-bit, DDR LVDS output to FPGA.**

—2×**DSPs: TI C6713**

❑ **ADCs Sampling frequency 144MHz, IF 36MHz, quadruple frequency sampling gets I, Q, -I, -Q……**

—**3 IF signals are sampled by ADCs: cavity field, forward , previous cavity field.**

—**Phase difference between the forward signal and the cavity field is used in the tuning system.**

—**Previous cavity field is used to recover the working point if something changed in the previous RF system.**

The Digital Field Control Module

□ **Software: IQ Demodulation → Feedback PI Controller → Feedforward Table → Numerically Controlled Oscillator (NCO).**

    —**Feedback Loop: Suppress various disturbances (power sources noises, high voltage drop, beam loading, etc).**

    —**Feedforward: It compensates the beam loading, triggered by beam gate, fixed value table.**

    —**NCO: Output 36MHz IF, digital frequency conversion technology.**

□ **In June 2015, good stability of the RF field has been achieved about ±0.4% in amplitude and ±0.5° in phase during the RFQ beam commissioning, the pulse width of the RF is 700μs, beam width 500μs, beam intensity 10mA.**
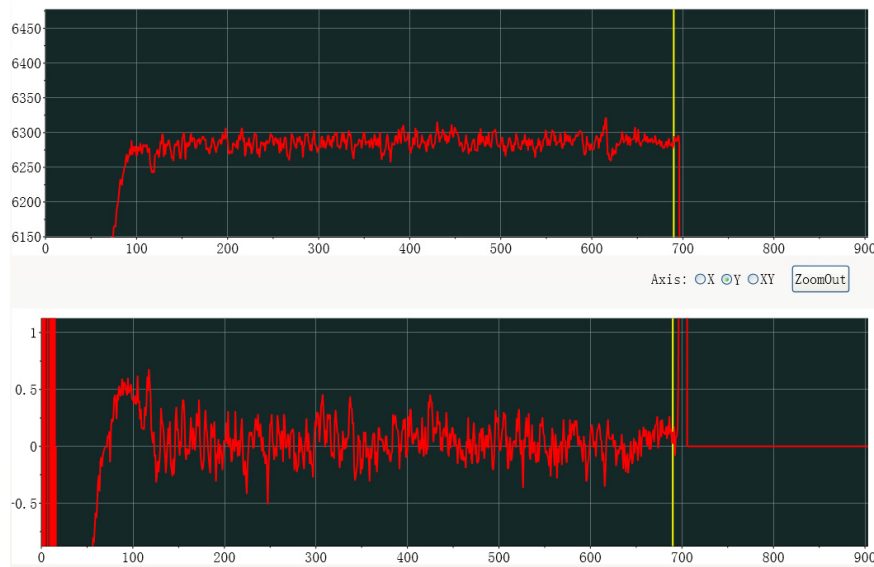
□ **Owing to the beam dump limitation, DTL just ran with low beam duty, maximum repetitive frequency 5Hz, and the beam pulse width 200us.**
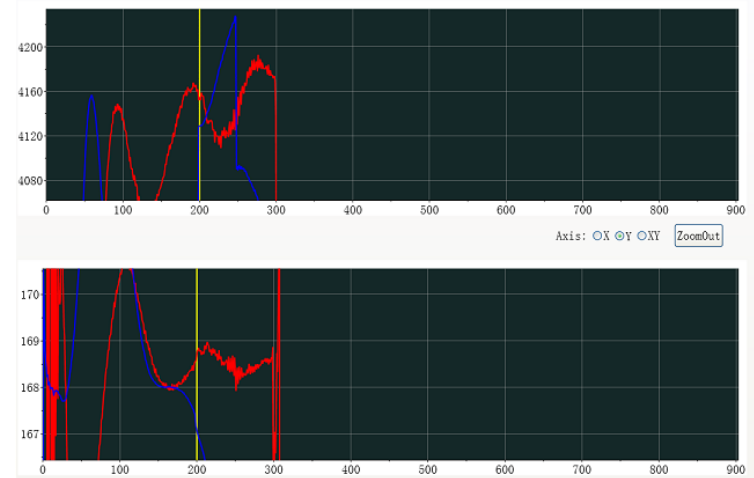
The Digital Frequency Conversion Technology
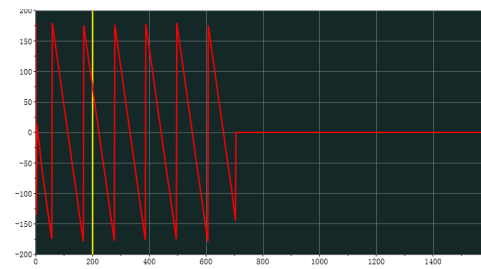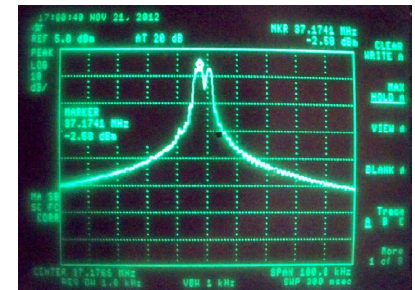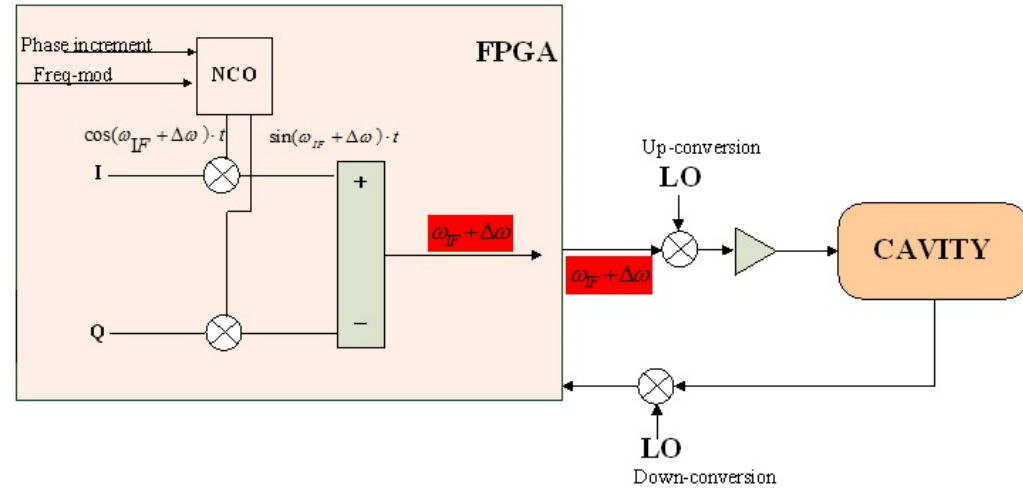
❑ **Digital Frequency Conversion Technology**

　　—**Target: the power source output frequency automatically tracks cold cavity resonant frequency, less reflected power.**

　　—**Actuator: NCO**

❑ **Two mode can be selected**

　　—**Manual mode**

　　—**Auto mode: the detuning frequency** $\Delta\omega$ **from the operating frequency of the cavity by the phase curve of the cavity field during the field decay.**
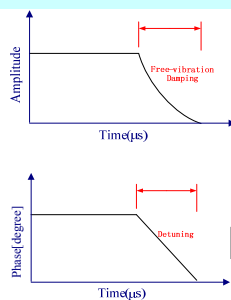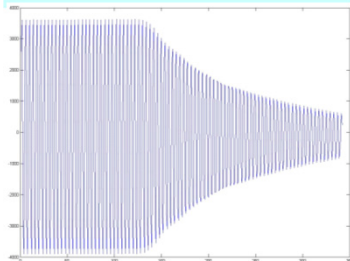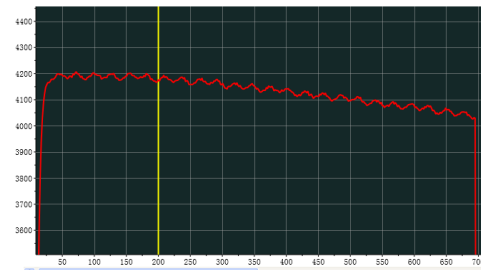
$$\Delta\omega = \frac{d\theta}{dt}$$

**Frequency sweeping dynamic range is about ±1MHz.**

The Tunner Loop

❑ **Two methods to judge whether the cavity is close to resonant state or not.**

—**The phase difference between the cavity input and output signal.**

—**The detuning frequency $\Delta\omega$ which is directly calculated from the phase curve of the cavity field during the field decay.**

❑ **Actuator**

—**RFQ: Cooling water, regulate the input cooling water valve**
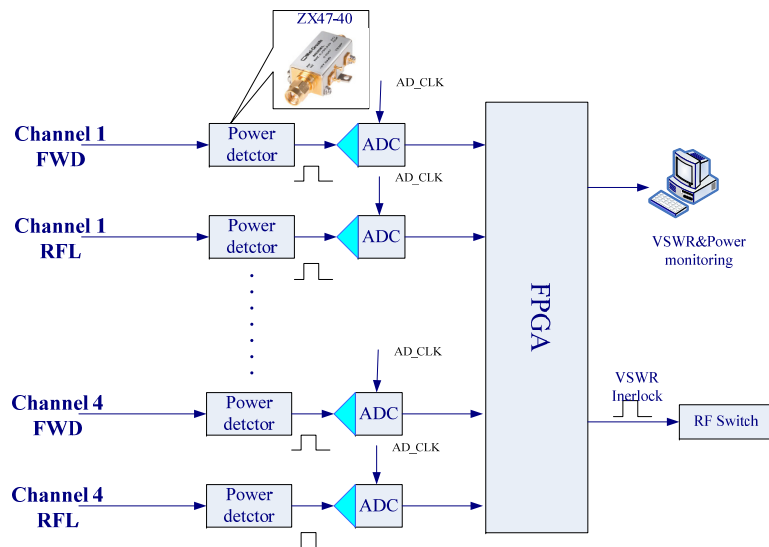
—**Buncher/Debuncher cavities and DTL: Tunner**
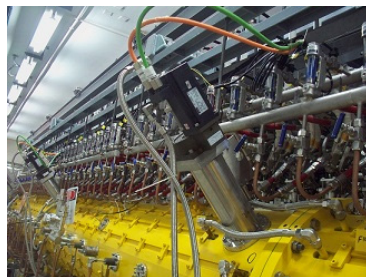
❑ **We use the detuning frequency $\Delta\omega$ to operating the actuator, higher precision.**
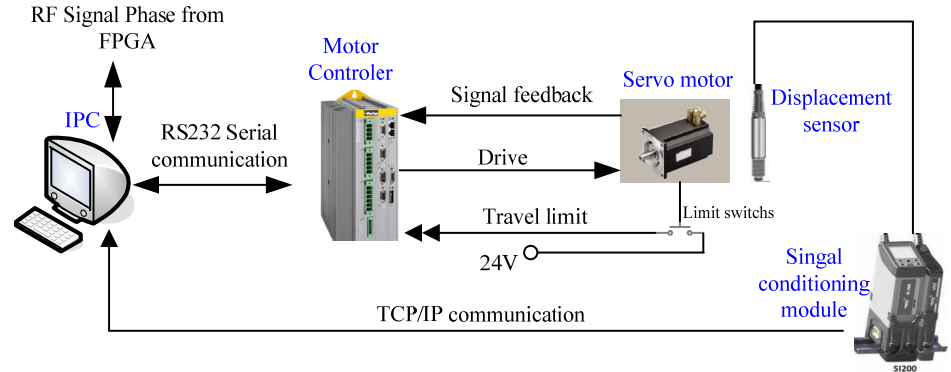
—**The servo motor moves to maintain the cavity resonant.**
—**Displacement sensor sends turner displacement information to IPC using TCP/IP protocol.**

Servomotor

Displacement sensor
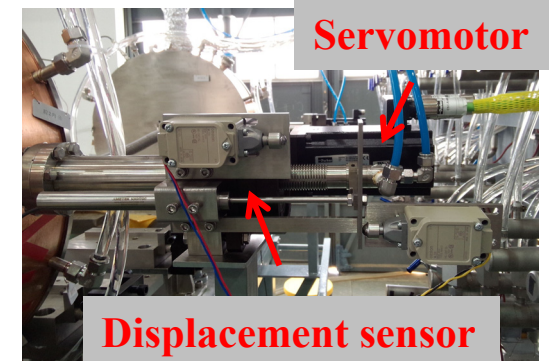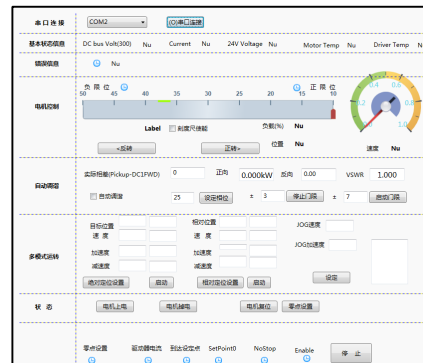
The High Power Protection

—**Power monitor**

—**Eight channels ADCs**

—**VSWR, count the VSWR protection number.**

—**Test result shows the RF shutdown time is less than 460ns once VSWR protection.**
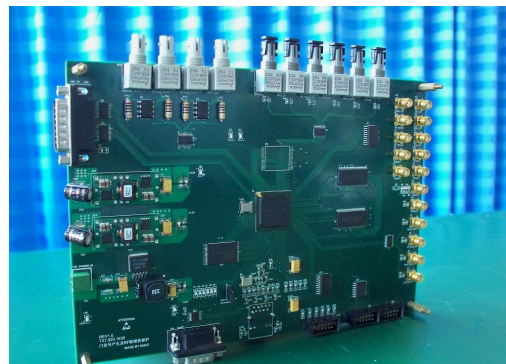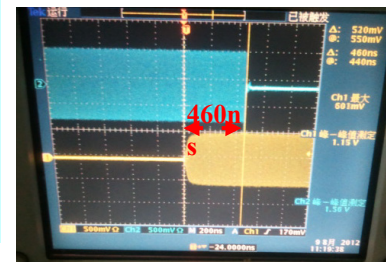
—**AFT ARC sensor and the sentry.**

—**Klystron output window, Circulator, Cavities, etc…**

—**Count ARC number**
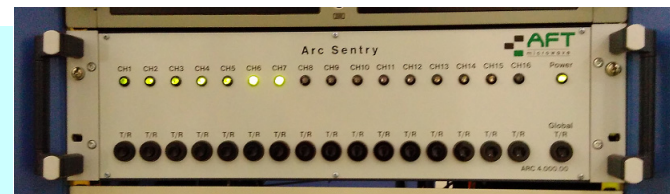
Summary

—**Two linear power supplies of the LLRF cabinet are ever broken, we need more time to decide if we should change them all.**

—**Long term stability of the LLRF system need time to test.**

—**In the future, we want to improve this system with chassis and CPU, maybe cPCI, vxworks OS.**

Thank you!!