Commissioning and operating of high power SSA of 25MeV SC proton Linac

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Outline

1、Introduction of 25MeV SC proton Linac

2、High power solid-state amplifiers

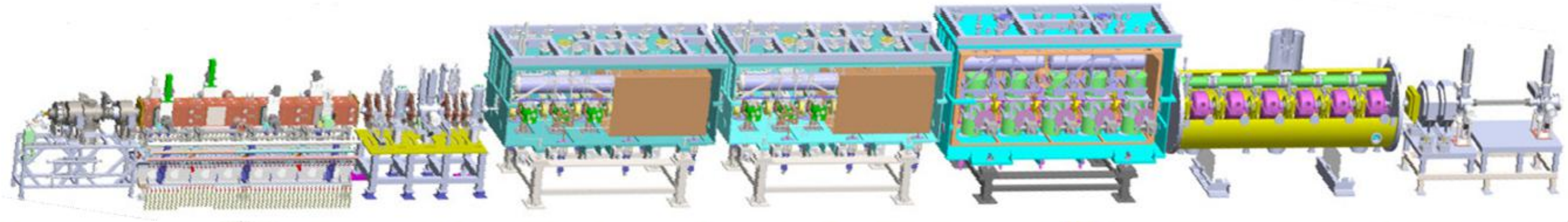
3、Failure modes and operating experiences

4、Summary and Future Plan

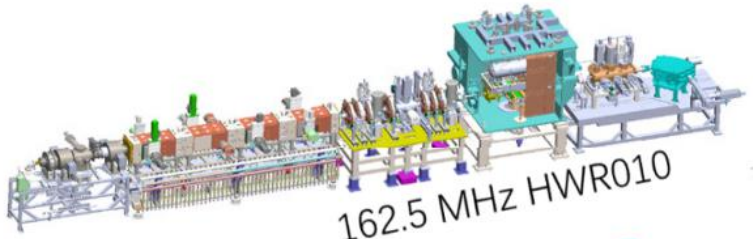
25MeV SC proton Linac

ECRIS + RFQ + CM1 + CM2 + CM3 + CM4
Energy is ~25 MeV
First beam June 5th, 2017

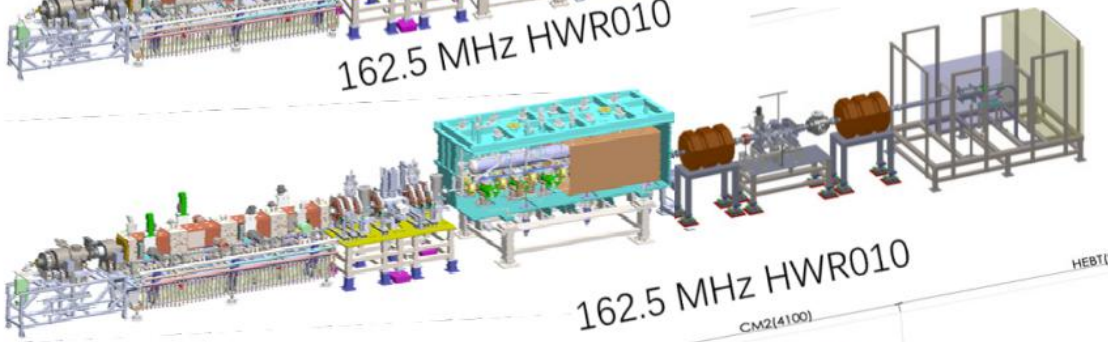
	CM1/IMP	CM2/IMP	CM3/IMP	CM4/IHEP
Frequency	162.5 MHz	162.5 MHz	162.5 MHz	325 MHz
Energy	6 MeV	11 MeV	18.6 MeV	26.2 MeV
Type	HWR010	HWR010	HWR015	Spoke021
Number	6	6	5	6



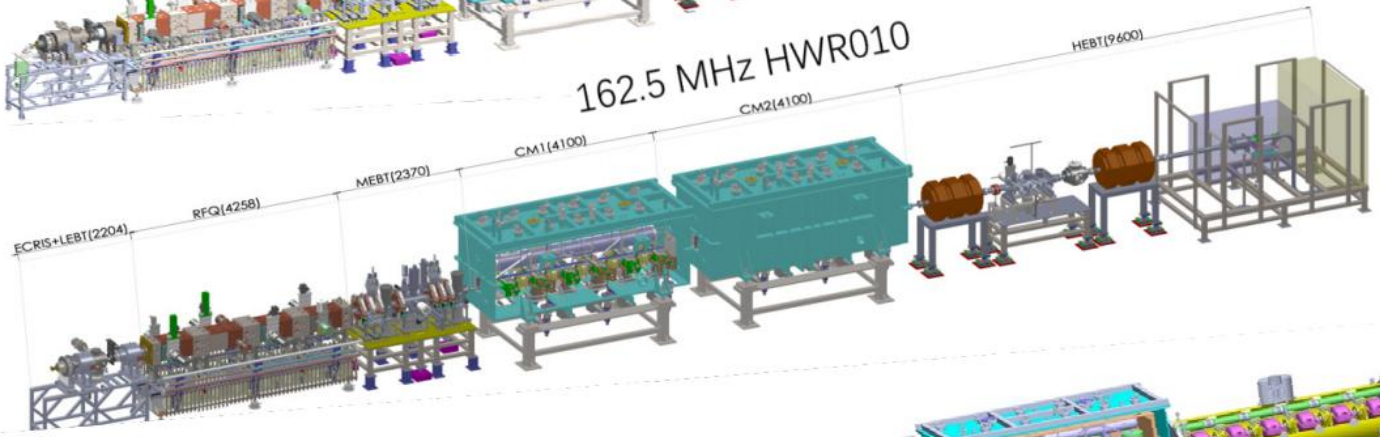
Commissioning Stages since 2014



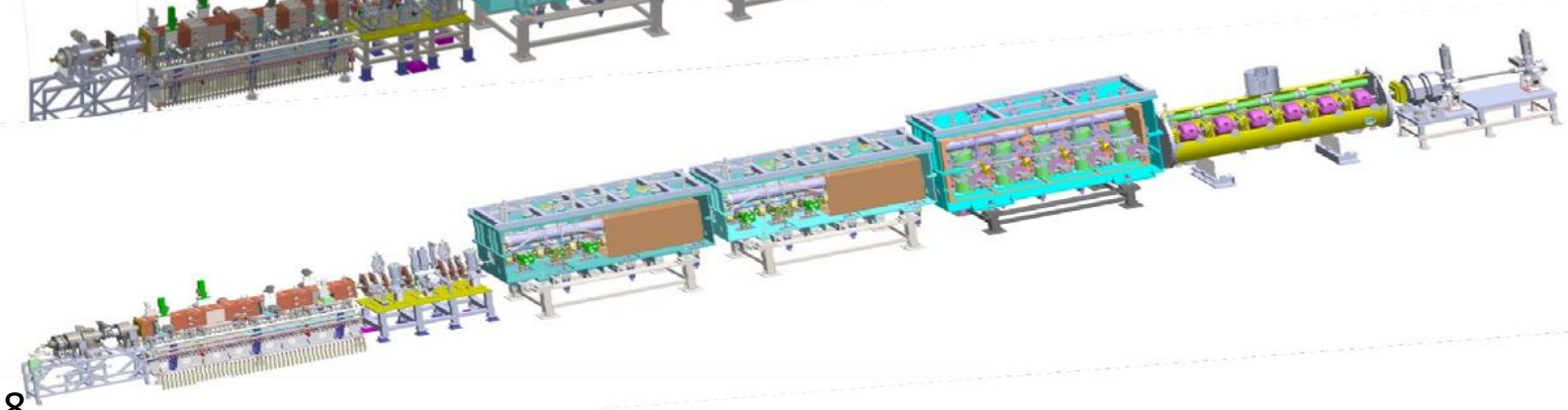
- ECRIS + RFQ + MEBT + TCM1 (single HWR)
- Energy is ~2.5 MeV
- First beam October 1st, 2014



- ECRIS + RFQ + TCM6
- Energy is ~5 MeV
- First beam June 6th, 2015



- ECRIS + RFQ + CM1 + CM2
- Energy is ~10 MeV
- First beam September 15th, 2016

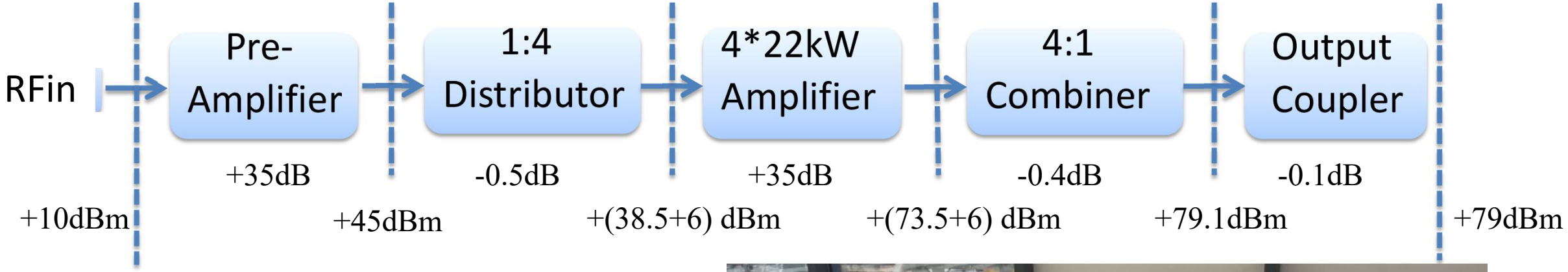


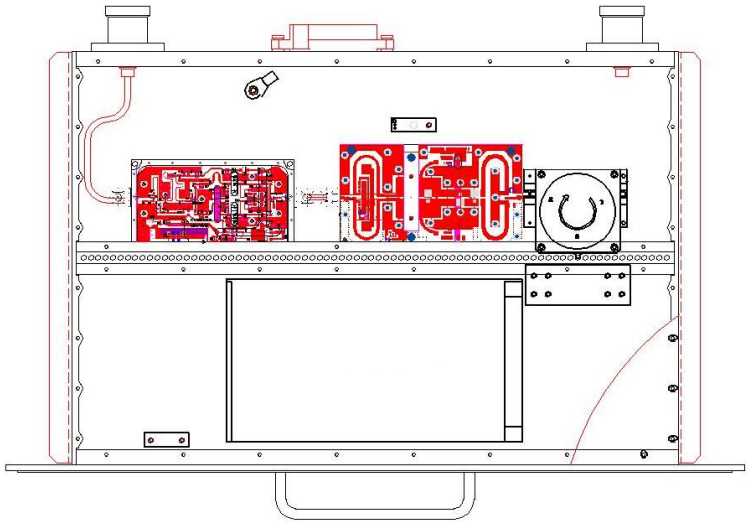
- ECRIS + RFQ + CM1 + CM2 + CM3 + CM4
- Energy is ~25 MeV
- First beam June 5th, 2017

Amplifier Specifications

	Parameter	Value
	Operating Center Frequency	162.5MHz / 325MHz
	RF Power Out	12kW / 20kW / 80kW
	Input Power	+10dBm
	3dB bandwidth	±2MHz
	Working Mode	CW
	RF Input Connector	N-type (female)
	RF Output Connector	EIA coax connection 3 1/8"@12kW 4 1/2" @20kW 6 1/8"@80kW
	Output Voltage Stability	< ±1%
	Output Phase Stability	<±1°
	Continuous power operation with a 100% mismatched load	Full power
	Harmonic Power Output	< -30 dBc
	Spurious Power Output	< -60 dBc

Amplifier Design @ 162.5MHz / 80kW

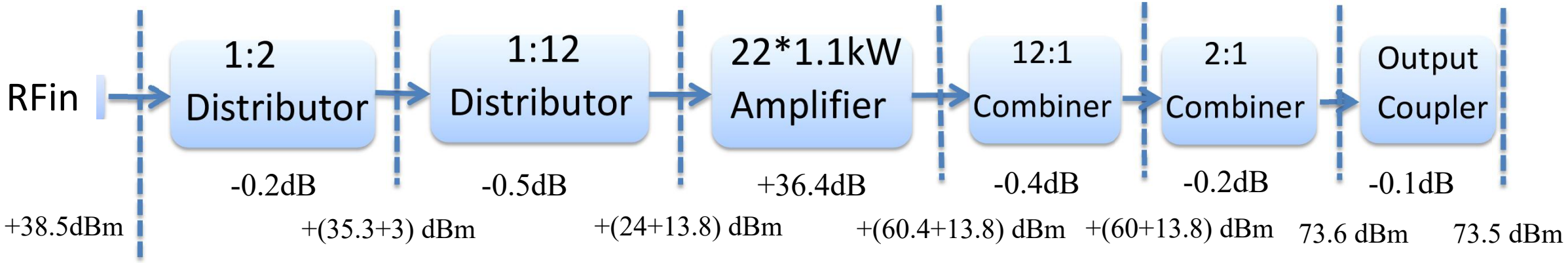


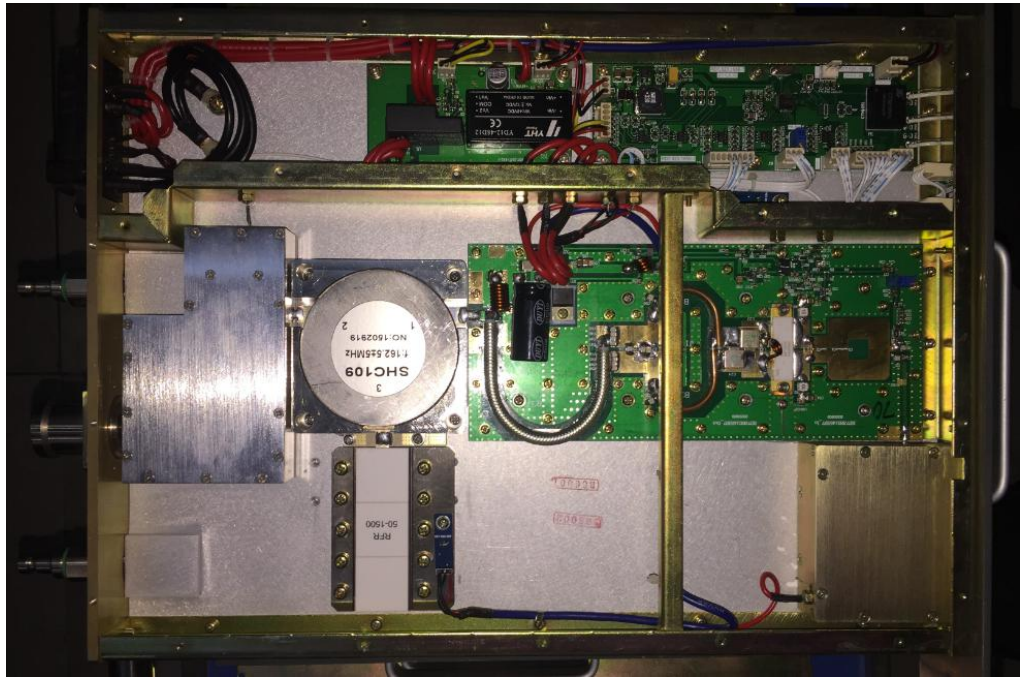


Pre-Amplifier

Combiner

Amplifier Design @ 162.5MHz / 20kW





1.1kW Module

Combiner

Redundant Design

Pre-amp redundant design

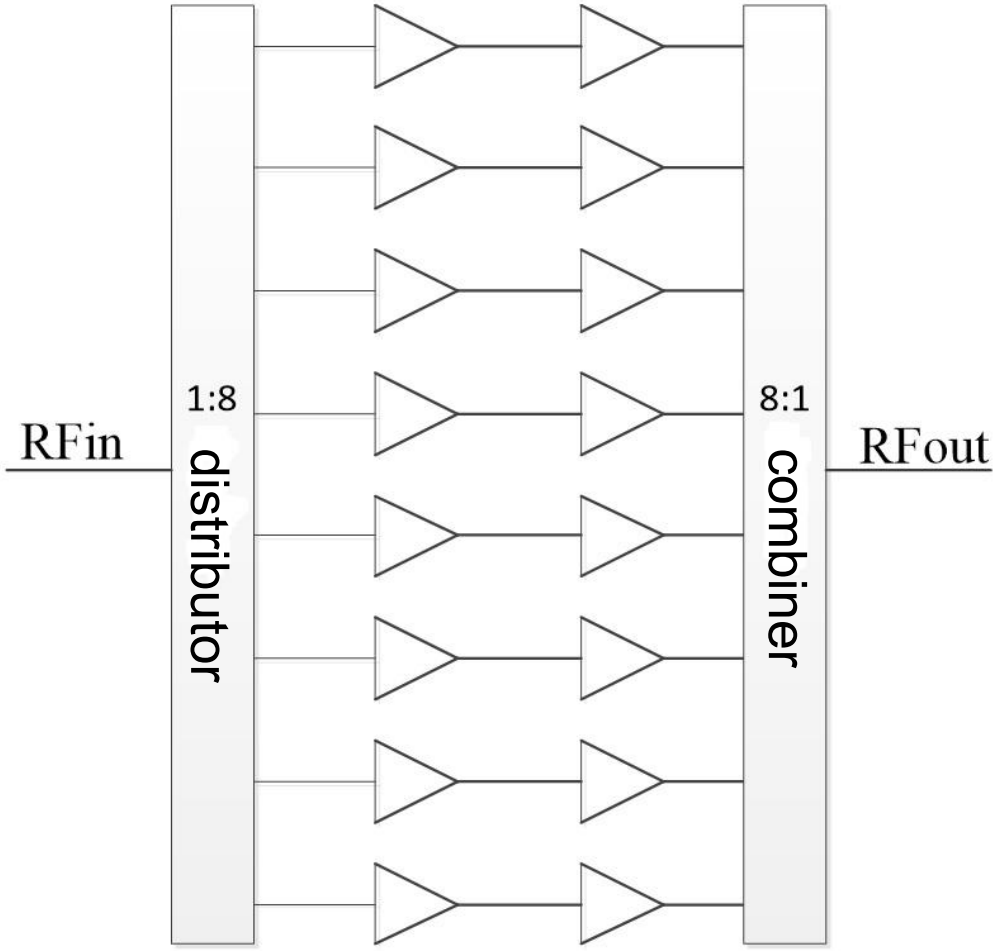
Redundant low-power amplifiers are used in the pre-amplifier system to improve the system reliability. Eight 36W amplifiers are combined into about 180W output power.

When one of the low-power amplifiers fail, the pre-amplifier system can still ensure the 180W output power.

Limiter is also uesd in the pre-amp system to limit the output power and guarantee safety.

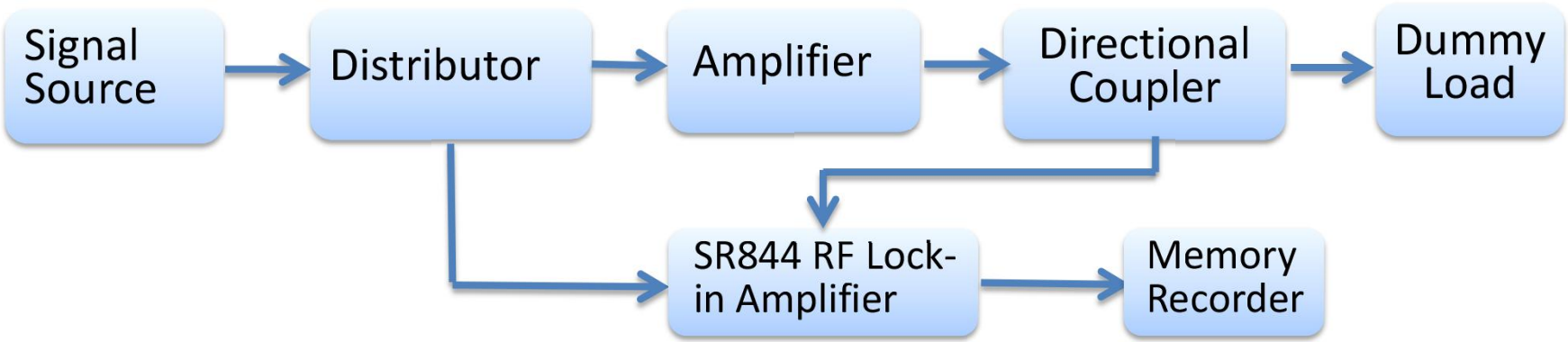
Module redundant design

One extra 1kW module is applied every 20kW to ensue full output power.

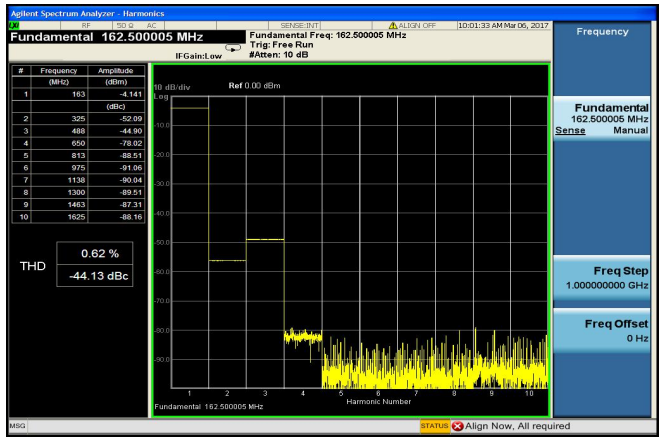


Pre-amp redundant design

Amplifier Tests

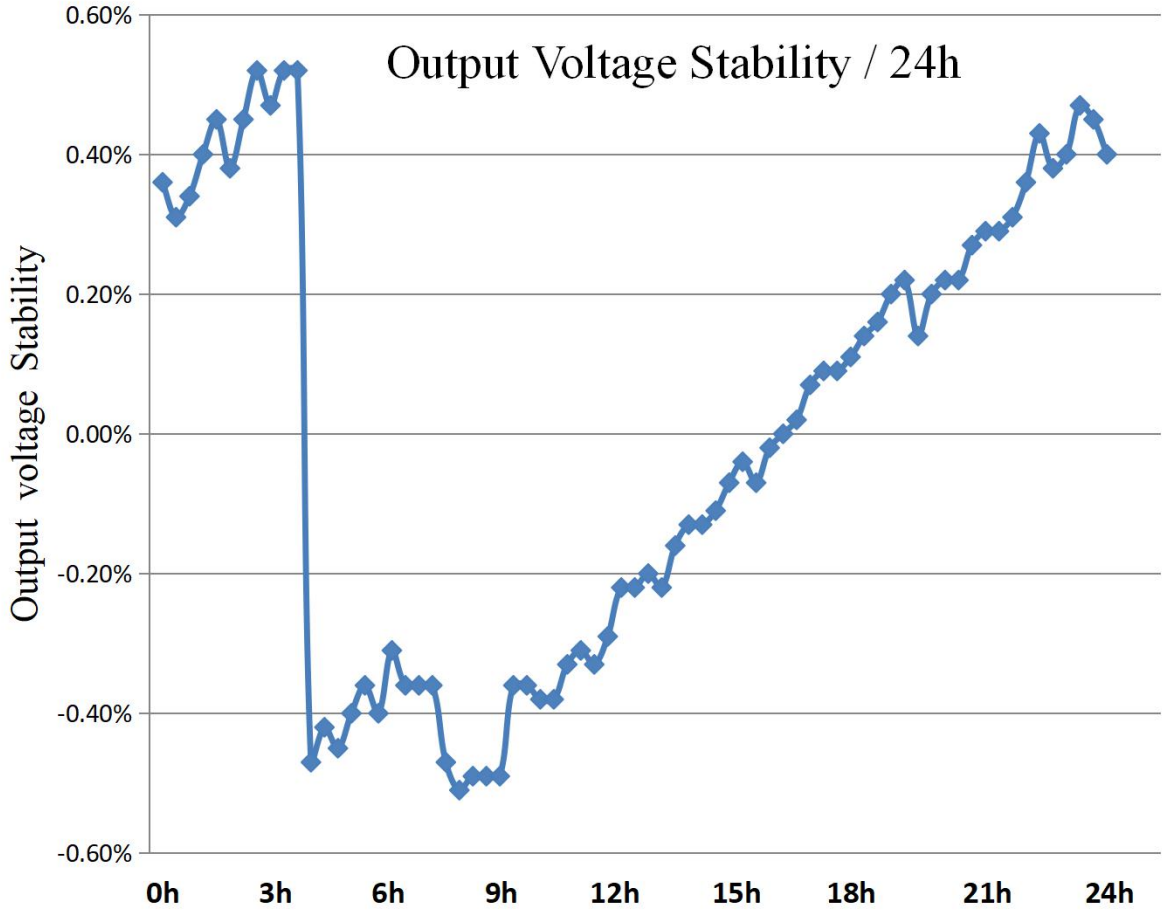


Amplifier Tests



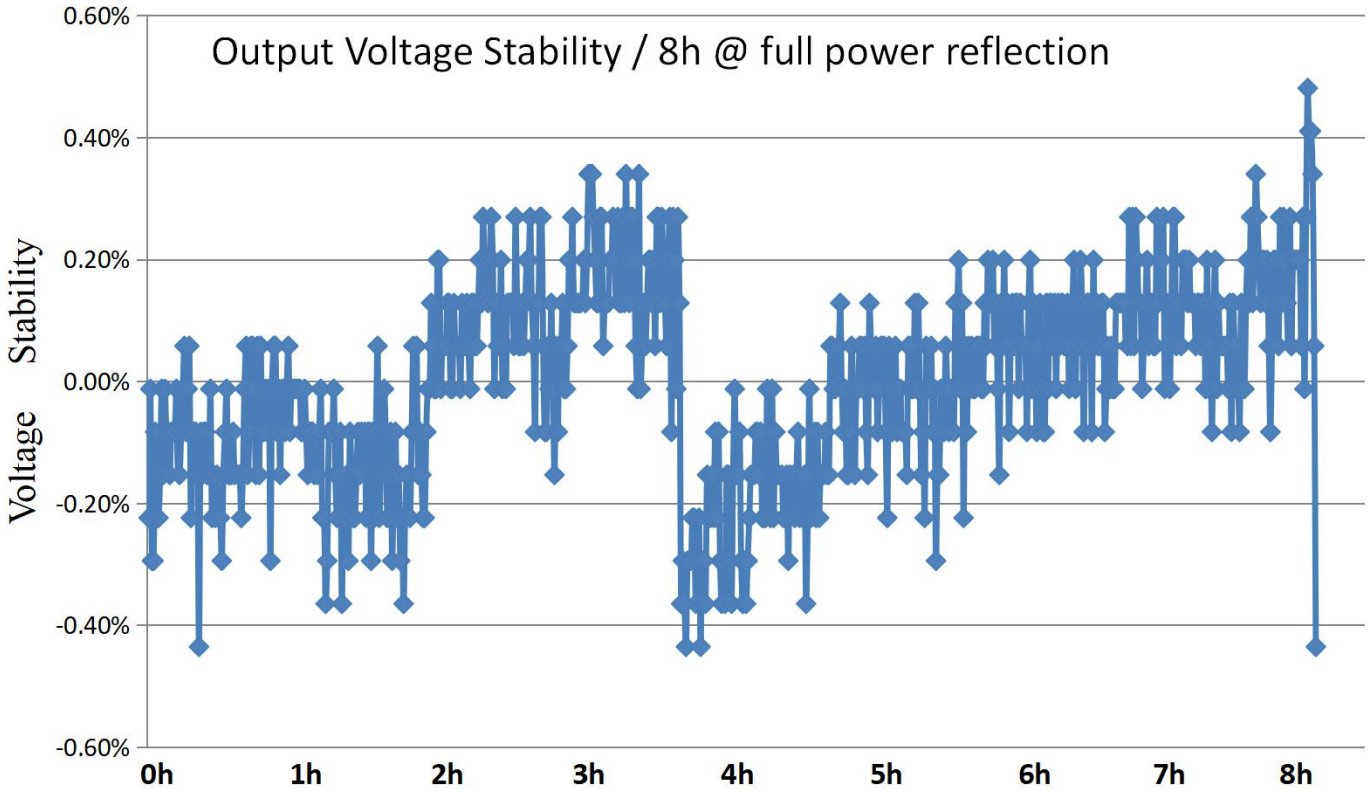
Harmonic Power Output ≤ -44dBc

Power Meter



Full power reflection Test

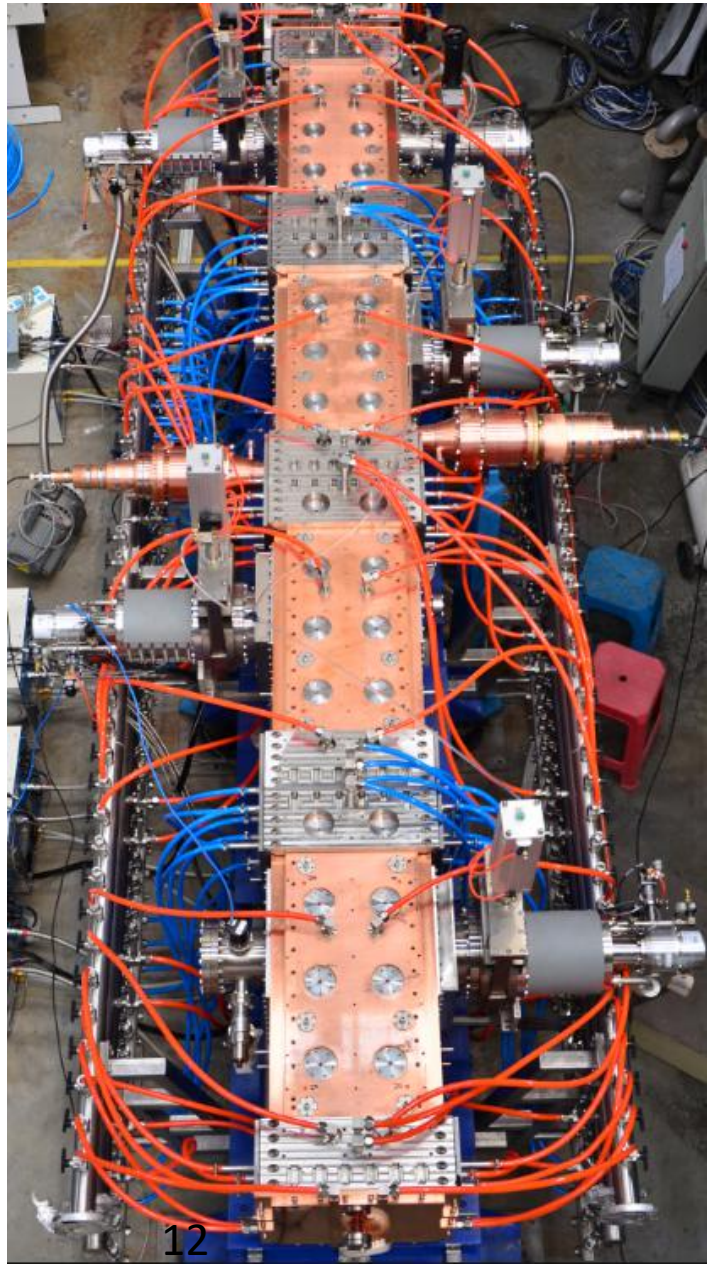
Eight hour 80kW full power reflection test is performed to verify the reliability of the amplifier under 100% mismatched load.



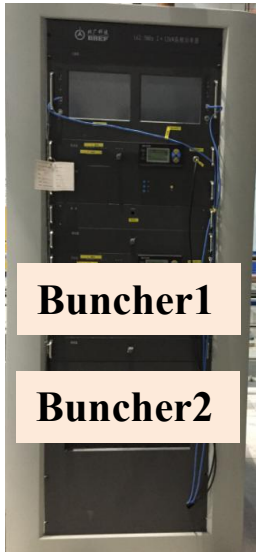
Two 80kW 162.5 MHz amplifiers for RFQ

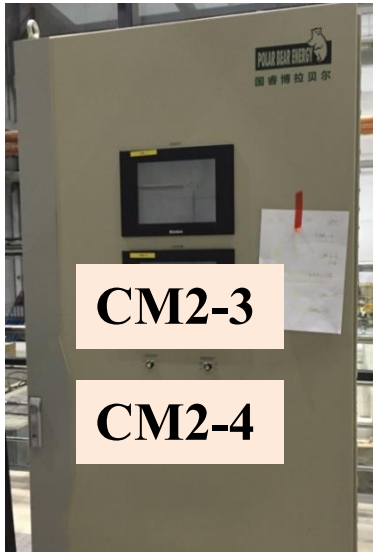
The RF system for RFQ cavity was two 80kW solid-state amplifiers with many small circulators inserted in power modules for feeding power to separate.

Two sets of SSAs both are consisted of four 20kW sections to integrate gradually for providing 50-60kW RF power for separate coupler at the same time, and due to the different output characteristics, LLRF has to adjust the offsets of output gain and phase in the beginning.



12*12kW 162.5 MHz amplifiers for buncher cavities and SC cavities



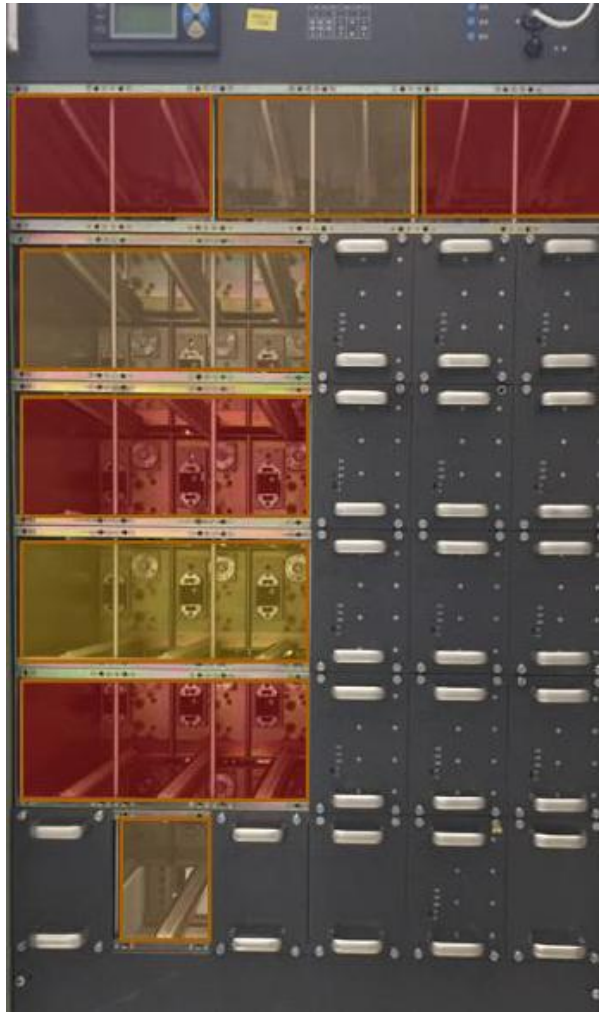


5* 20kW 162.5 MHz amplifiers and 6*25kW 325MHz amplifiers for SC cavities

One section of 80kW 162.5 MHz amplifiers failure

One important reason for accident is too sensitive of driving signal interlock in 3# section. Since the output power of 3# section was shut down during operation, other three sections were influenced in the same time due to the connection from combines of whole system. Thus, all transistors and sink loads were burnt.

Two factors lead to this accident, one is too high driving power due to the close loop operation of LLRF, the other is shutting down of 3# section resulted from its own amplitude interlock of input power (too sensitive to operate stably). Now, the logic of interlock and LLRF are both modified according to the analysis as above, and the abnormal increase of reflected power has never observed again. The new function of power balance was added to prevent from the big difference between two 80 kW amplifiers output during operation.



Cooling water problems

After a period of time of operation, the water flow decrease because of plug. Resin granule、solder、AL_2O_3(Aluminum oxide)、other impurities were found in the strainer.

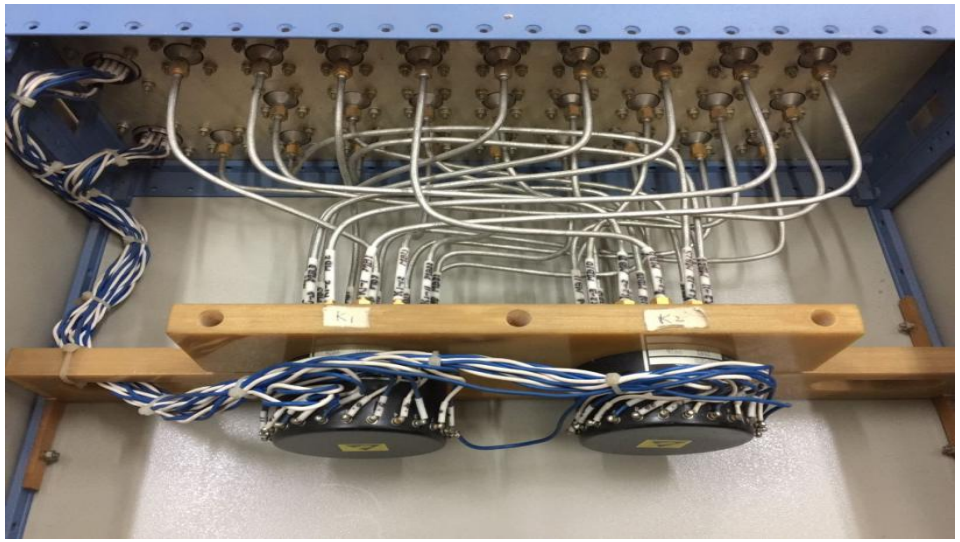
Water flow decrease may cause a series of damages to the amplifier including the module and power supply.

Cooling water and Aluminum cold plate is the main reason.
Independent cooling water supply would be helpful to solve the problem.

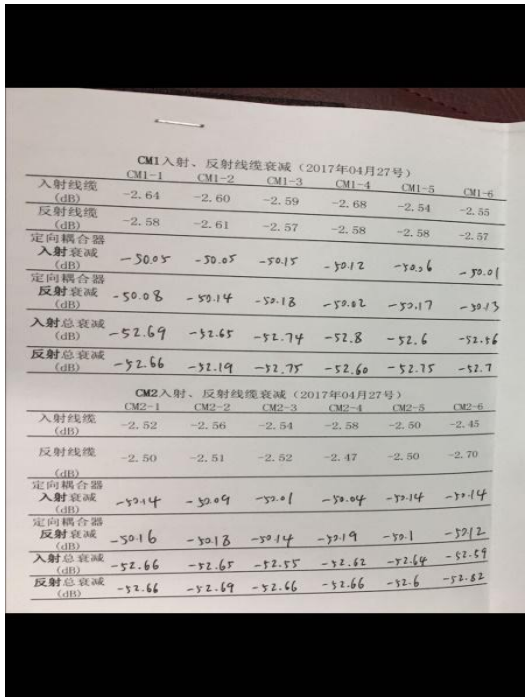
Experience: Build a glasshouse for SSA

A high power source room was built for amplifiers and power supply to provide clean environment. Precision air conditioning was also used to maintain constant temperature in the room. Each cabinet has independent power supply.

Power measurement



2*12 channels high-frequency switch



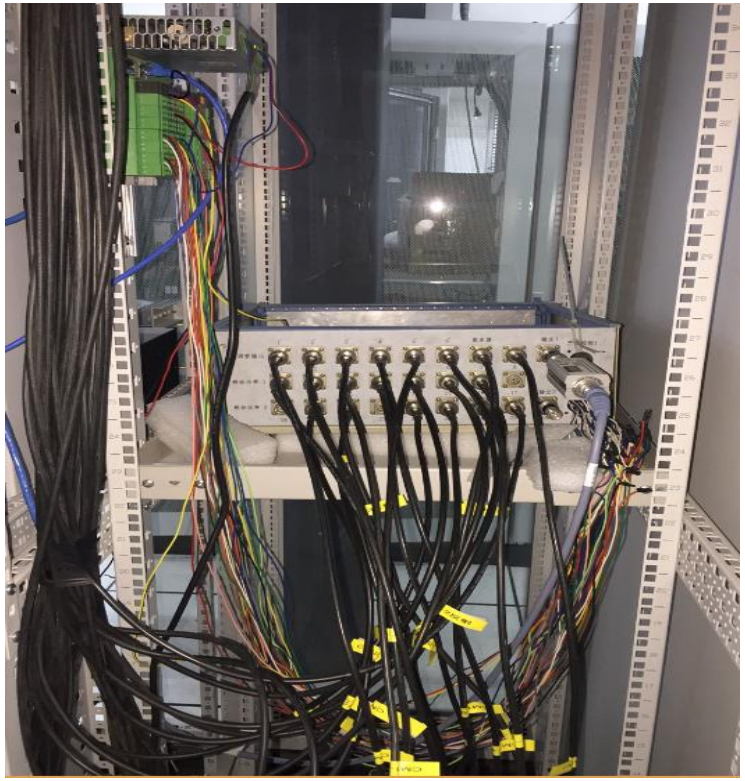
CM1入射、反射线缆衰减（2017年04月27号）

	CM1-1	CM1-2	CM1-3	CM1-4	CM1-5	CM1-6
入射线缆 (dB)	-2.64	-2.60	-2.59	-2.68	-2.54	-2.55
反射线缆 (dB)	-2.58	-2.61	-2.57	-2.58	-2.58	-2.57
定向耦合器 入射衰减 (dB)	-50.05	-50.05	-50.15	-50.12	-50.06	-50.01
定向耦合器 反射衰减 (dB)	-50.08	-50.14	-50.18	-50.02	-50.17	-50.13
入射总衰减 (dB)	-52.69	-52.65	-52.74	-52.8	-52.6	-52.56
反射总衰减 (dB)	-52.66	-52.19	-52.75	-52.60	-52.75	-52.7

CM2入射、反射线缆衰减（2017年04月27号）

	CM2-1	CM2-2	CM2-3	CM2-4	CM2-5	CM2-6
入射线缆 (dB)	-2.52	-2.56	-2.54	-2.58	-2.50	-2.45
反射线缆 (dB)	-2.50	-2.51	-2.52	-2.47	-2.50	-2.70
定向耦合器 入射衰减 (dB)	-50.14	-50.09	-50.01	-50.04	-50.14	-50.14
定向耦合器 反射衰减 (dB)	-50.16	-50.18	-50.14	-50.19	-50.1	-50.12
入射总衰减 (dB)	-52.66	-52.65	-52.55	-52.62	-52.64	-52.59
反射总衰减 (dB)	-52.66	-52.69	-52.66	-52.66	-52.6	-52.62

CM1 & CM2 24 channels
Incident and reflected power offset



2*12channels coaxial cable connection with switch

Using 2 peak power sensors to achieve 2*12 channels power measurement.

Summary and future plan

Summary

All solid state amplifier were used in the RF system and generally working well. Failure modes have been observed and improvement has been made for better performance.

Future Plan

Independent cooling water supply
Better protection for both cavities and amplifiers
Standardized design for SSA to reduce the cost and improve the reliability

Thank you for your attention!