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Using A 1.3GHz 20kW Solid State Amplifier As RF Power Supply For DC-SRF Photo-injector

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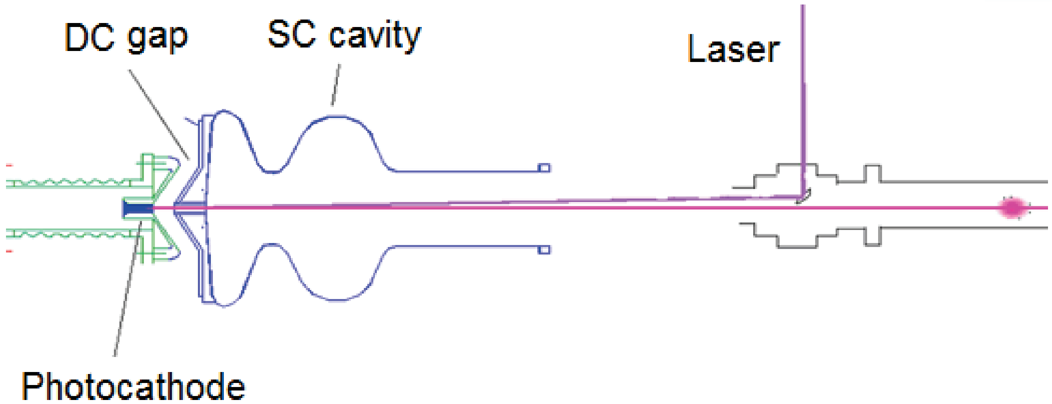
Outline

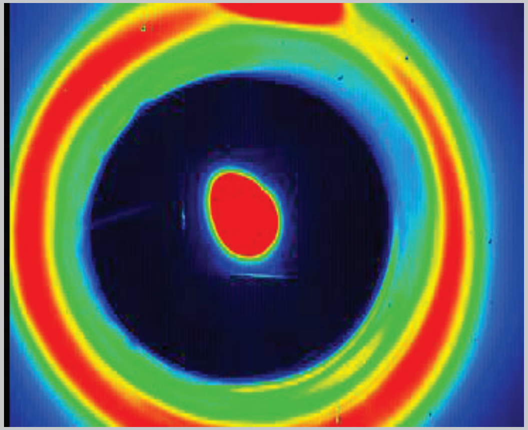
- DC-SRF Photo-injector
- Structure & Test Results of SSA
- Performances
- Summary

DC-SRF Photo-injector



- Pierce structure + SRF cavity

- **The prototype of DC-SRF injector with a 1.3GHz 1.5-cell superconducting cavity**



- **Electron beam spot after RF acceleration**

- In 2001, we first proposed DC-SRF photo-injector
- In 2004, preliminary experiments at 4.2K demonstrated the feasibility of DC-SRF photo-injector

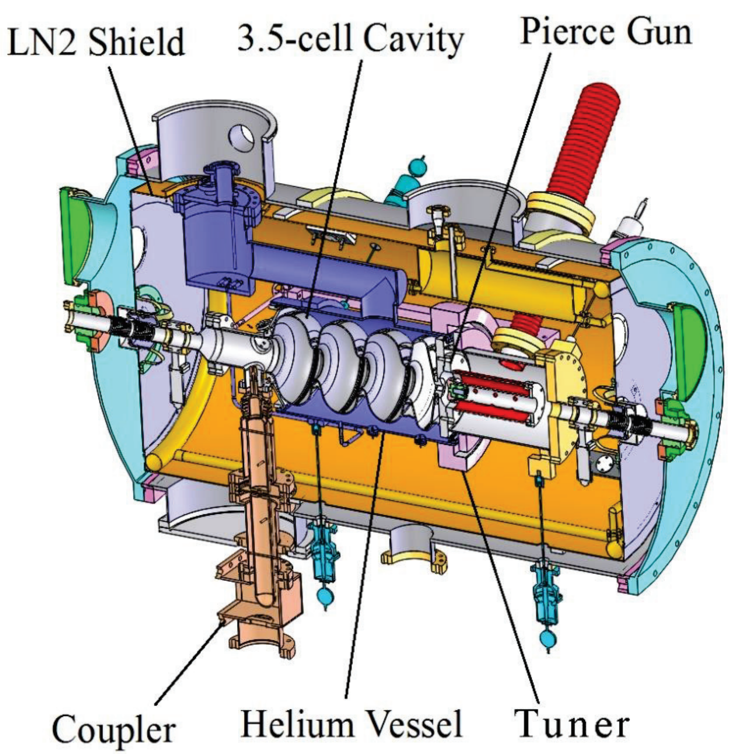
Power Amplifier of the Prototype Injector

- 3.5 KW solid state power amplifier at 1.3GHz

- It is combined by 8×600 W unit modules and a dummy load.
- Each module includes 4×150 W transistors.

Upgraded Injector

- Upgraded DC-SRF photo-injector



- Design parameters of the injector

pulse length	8 ps
spot radius	3.0 mm
repetition rate	26 MHz
bunch shape	transverse uniform, longitude gaussian distribution
accelerating gradient	13 MV/m
charge/bunch	100 pC
energy	5.0 MeV
emittance (rms)	1.2 µm
longitudinal emittance (rms)	14 deg·keV
bunch length	5.6 ps
rms beam size	0.4 mm
energy spread	~0.5%

A 1.3GHz 20kW CW RF amplifier was demanded in 2009.

Technical Specification of 1.3GHz/20kW Power Amplifier

Parameter	Required
Frequency Range	1300±0.05MHz
CW & Pulsed Output Power (1dB Compression)	≥ 20 kW
Linear Gain	≥73dB
Output Harmonics 2^{nd} Order	≤-30 dBc
Output Harmonics 3^{rd} Order	≤-30 dBc
RF Phase Shift vs. Output	≤10 degree
Gain Change vs. Output	≤2.0 dB
Efficiency at 20kW output	≥40%

Possible RF amplifiers for the DC-SRF Injector

Applications of 1.3GHz CW Amplifiers in 2009

Facility	Type	Power
ELBE at Rossendorf	Klystron	4×10 kW from CPI
Cornell ERL injector	Klystron	5×120 kW from e2v
Cornell ERL injector	IOT	1×16 kW from Thales
ALICE at Daresbury Lab	IOT	5 IOTs from three manufactories (e2v 16kW, CPI 30kW, Thales 16kW)
DC-SRF Prototype Injector at PKU	**SSA**	1×3.5 kW

Type Choose

Vacuum tubes:
Klystron
IOT

- MIT X-Ray Laser Project in proposed
- 24×15 kW CW amplifiers at 1.3GHz
- IOT has a number of advantages

Solid state amplifier

Solid state amplifier:

- Modularity
- Reliability
- No HV, no X-Ray
- No high power circulator
- Simple start-up procedures
- Low maintenance cost

- ➢ Transistors with CW output power more than 200 W at 1.3GHz are available from industry.
- ➢ We incorporate with BBEF (Beijing) to manufacture a SSA.

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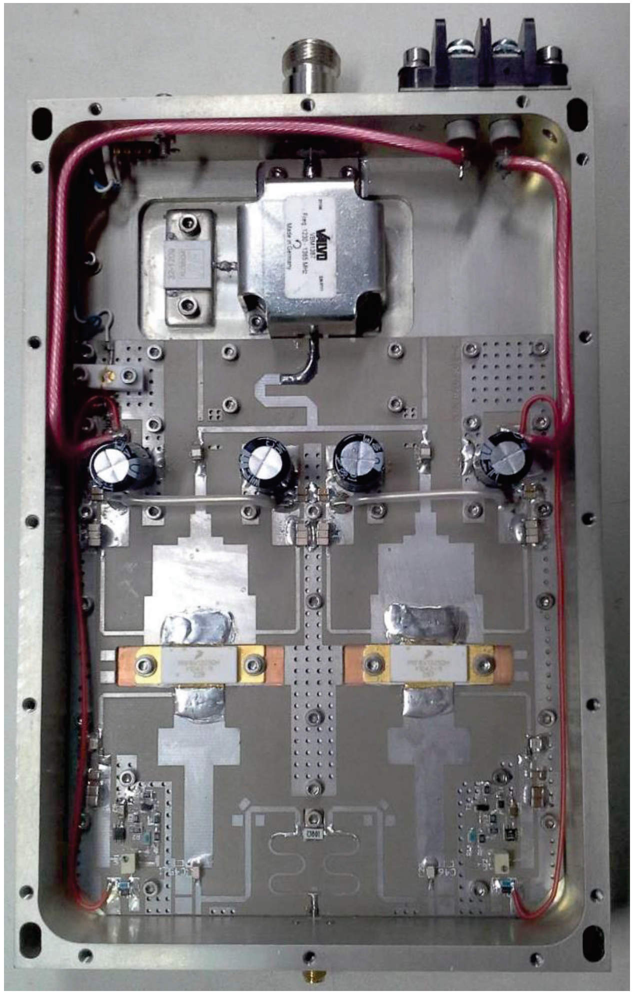
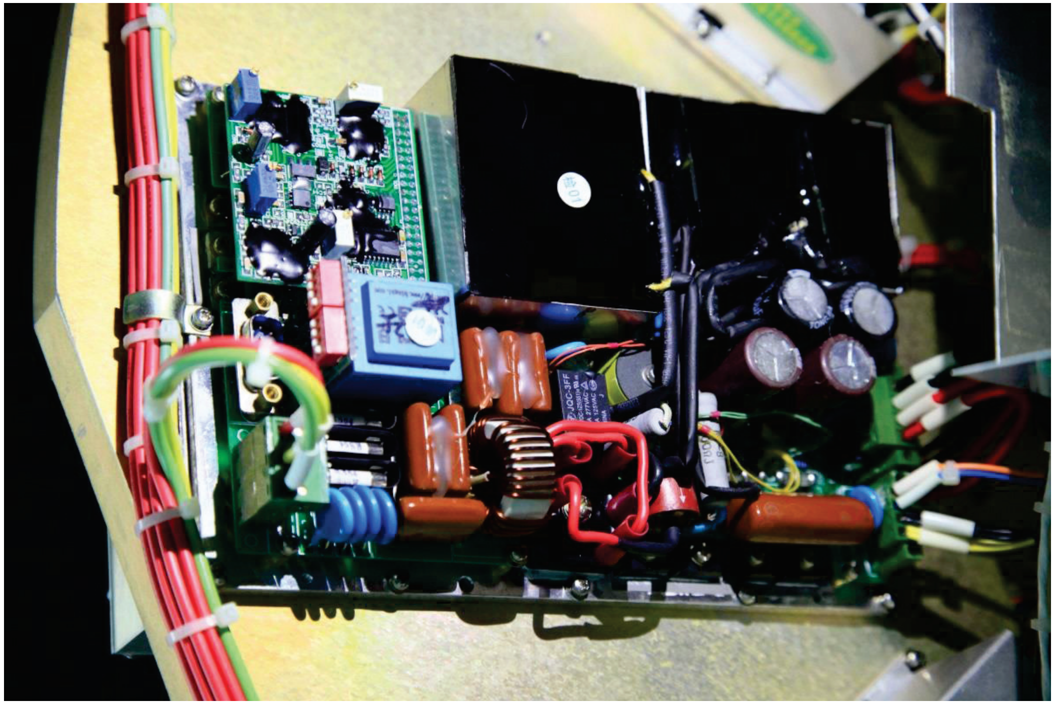
Structure-Amplifier Modules



each module can deliver up to CW 350W

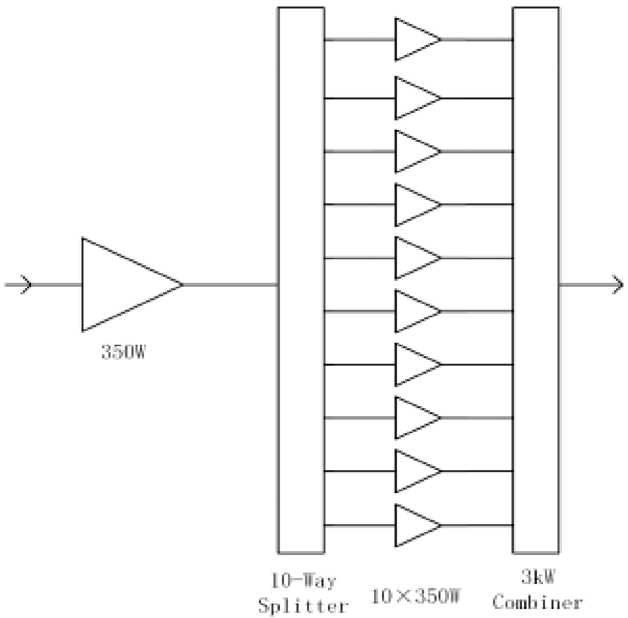
- Two FETs
  - MRF6V13250H from freescale
  - 230 W CW output at 1.3GHz
  - operating voltage of 50V
  - gain of 18dB
  - drain efficiency of 55% in CW mode
- One circulator
  - VBM1387 from VALVO
  - Frequency:1230…1365MHz
  - Isolation: min 25 dB (@centre)
  - Insertion loss: max 0.25dB
  - Retrun loss: min 25 dB (@centre)
  - Power: 400 W cw, 100% reflection allowed
- One terminal
  - Series 32-1209 from Florida RF Labs
  - Power: 500 W
  - Frequency: 2 GHz
  - VSWR: max 1.25

Structure-Power Source of the Amplifier

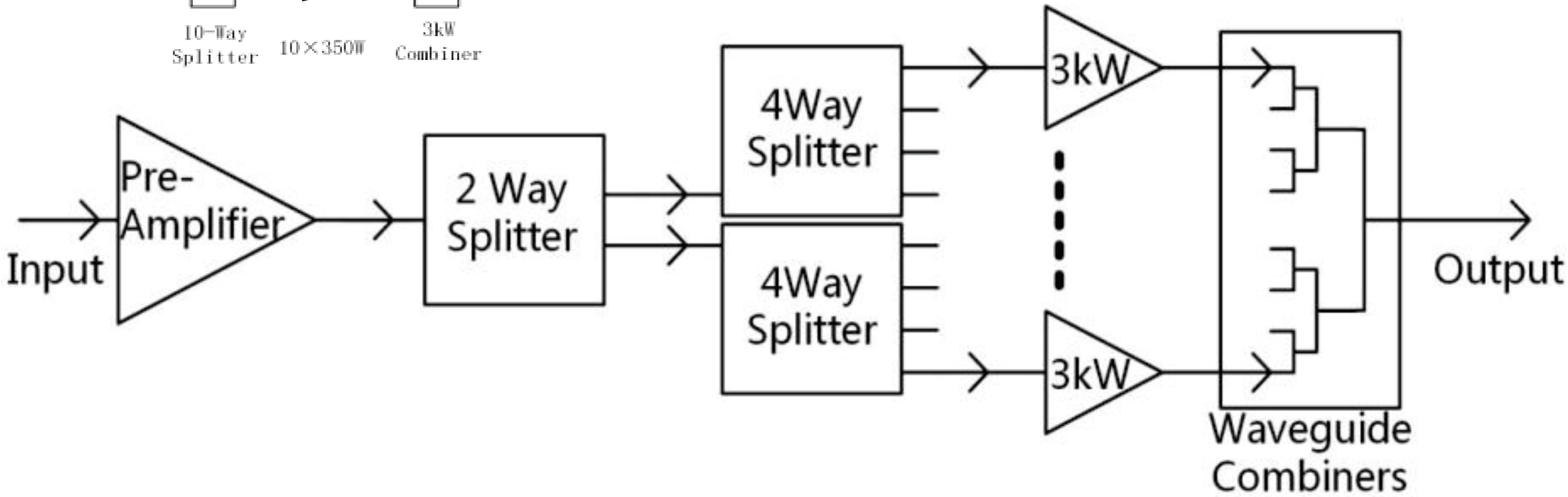


- AC/DC Convertor, the designed efficiency is 92%
- Each module is driven by its own power source
- Output voltage is 50 V, and the current is up to 14 A

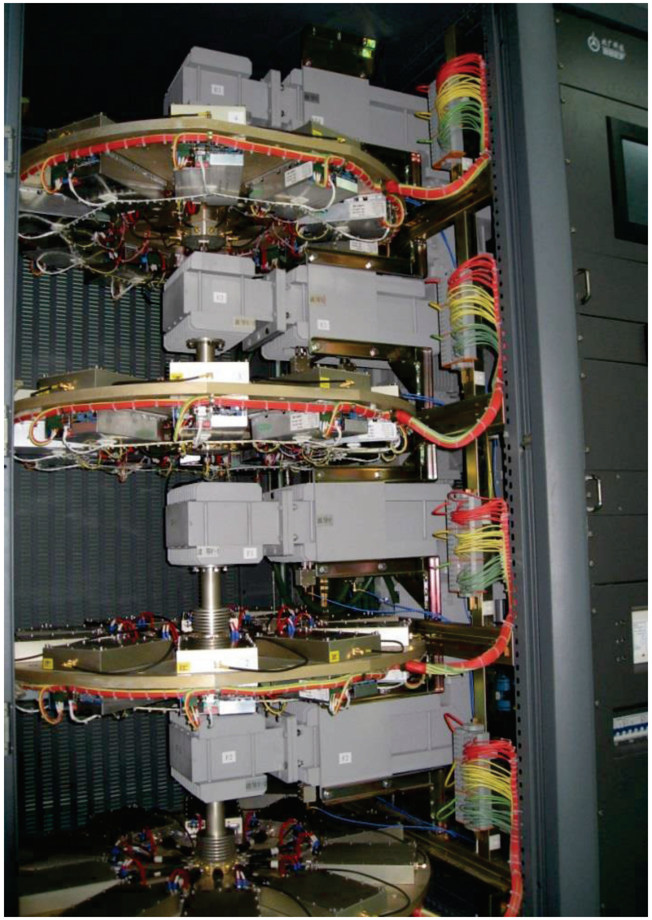
Structure-the Amplifier



- 88 unit modules
- 8 one to ten coaxial dividers
- 8 ten to one coaxial combiners
- 8 coaxial-waveguide transitions
- 7 waveguide combiners



Structure



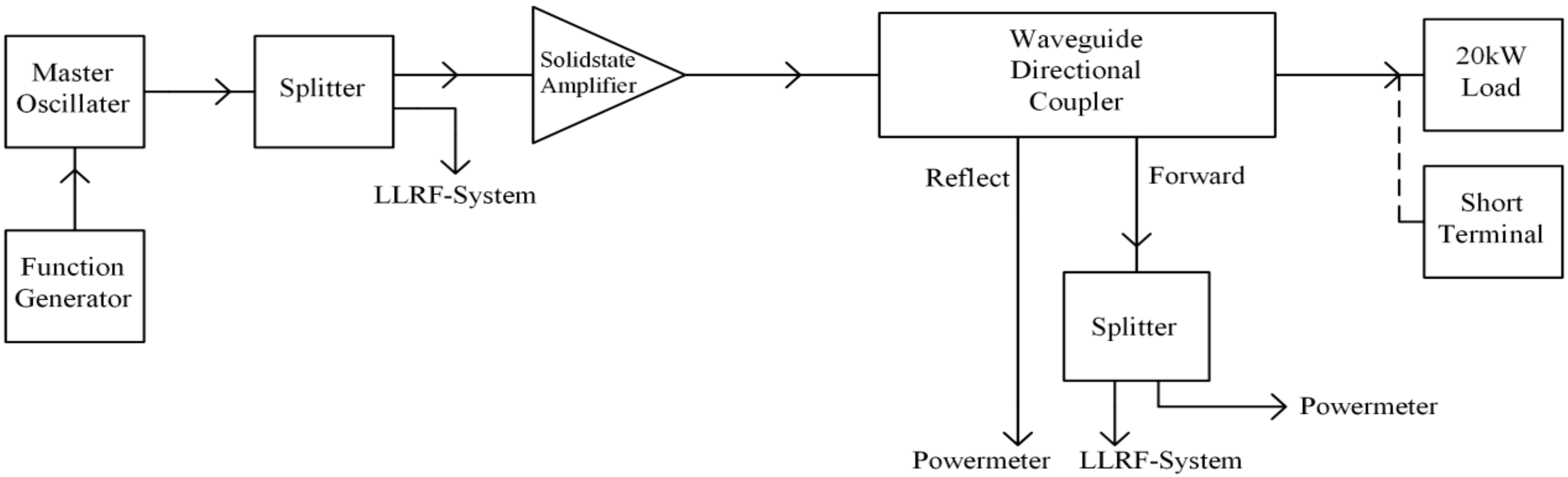
Dimensions: 2.9 m × 1.2 m × 2.1 m

The Human Machine Interface

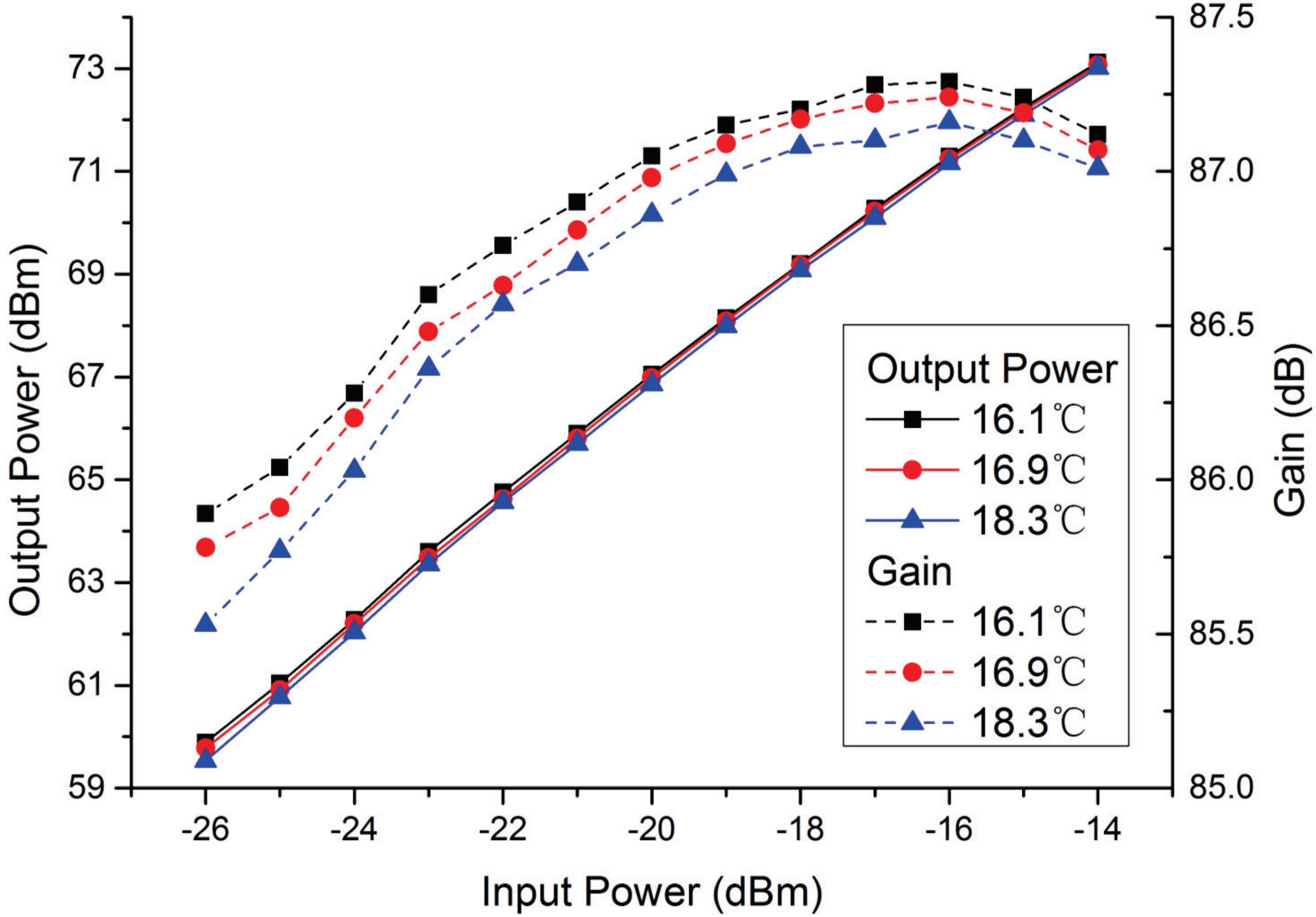
We plan to bring it to the existing EPICS system

- **Status**
  - Safety Interlock
  - Eight banks
  - Each module
  - Long term monitor
  - Log file
- **Power display**
- **Cooling water**
  Flow: 4.9m^3/h
  Pressure: 3 bar
- **Remote operation**

- Technical Specifications
  - Output power, gain, bandwidth, output stability etc.
- Long term performance with dummy load
  - With the help of the LLRF system
- The performance in pulse mode
- In full CW reflection with short terminal

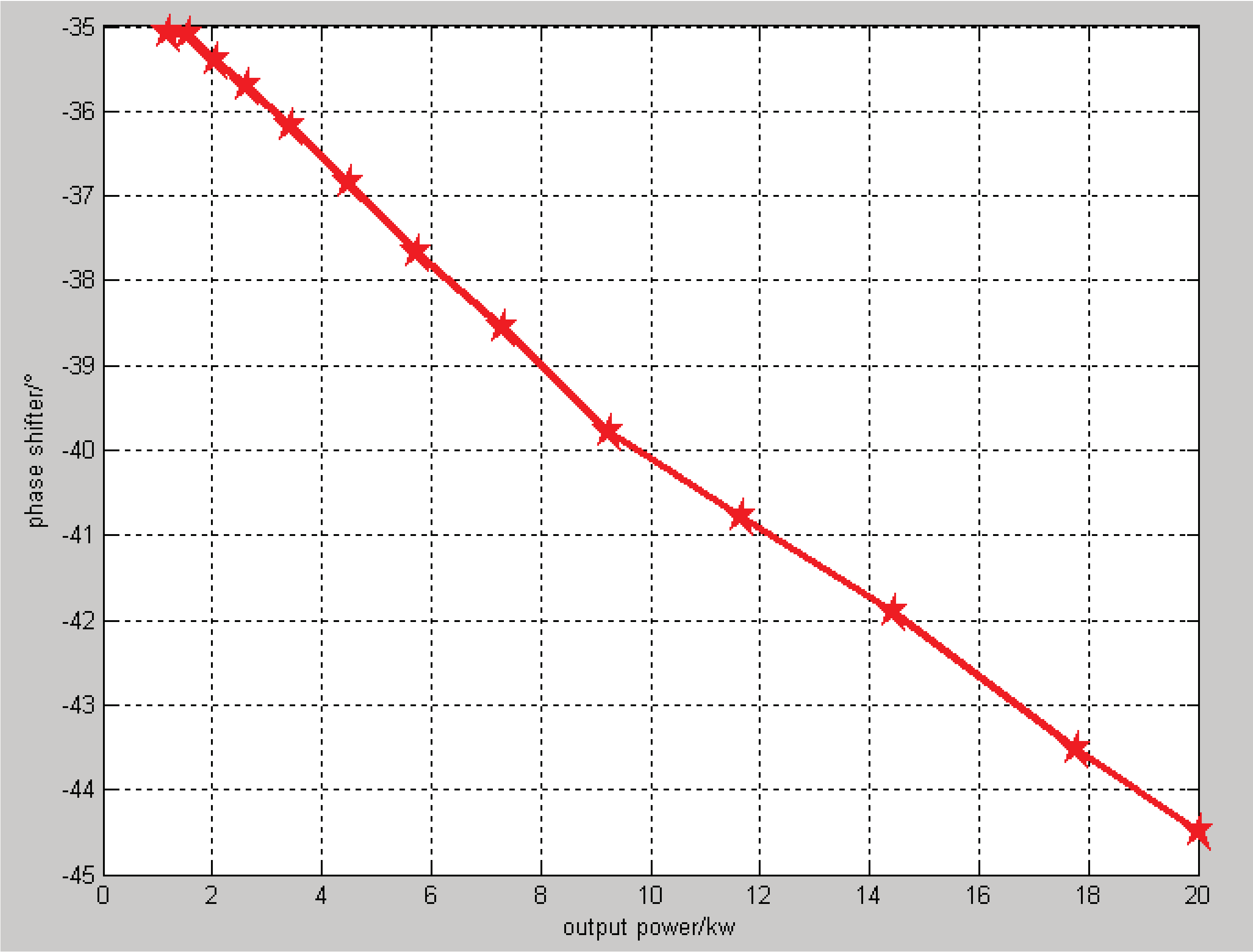


Tests-Gain



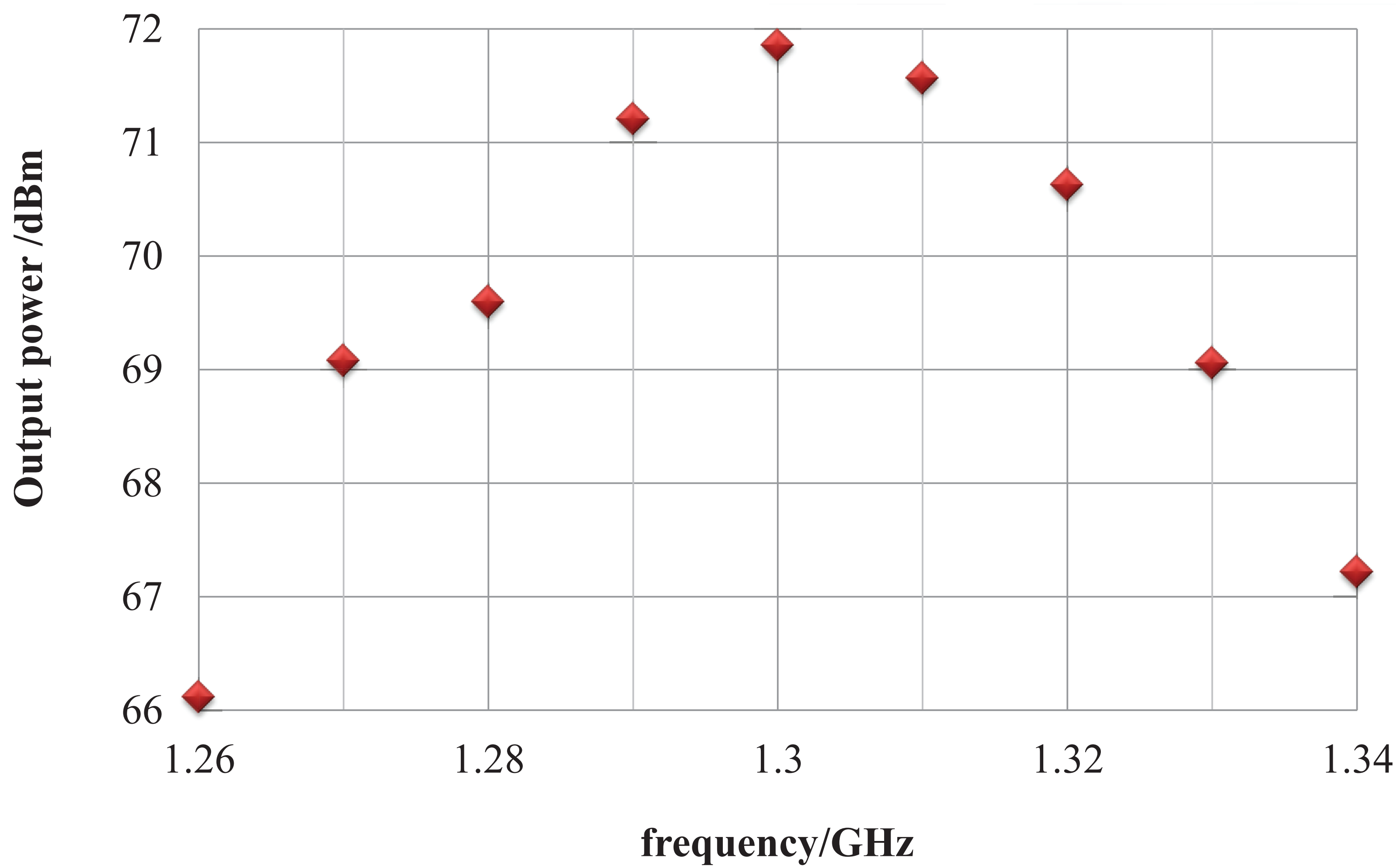
- ➢ Gain > 85 dB
- ➢ Gain changes 1.6 dB from 1-20kW

Tests-Phase Shift



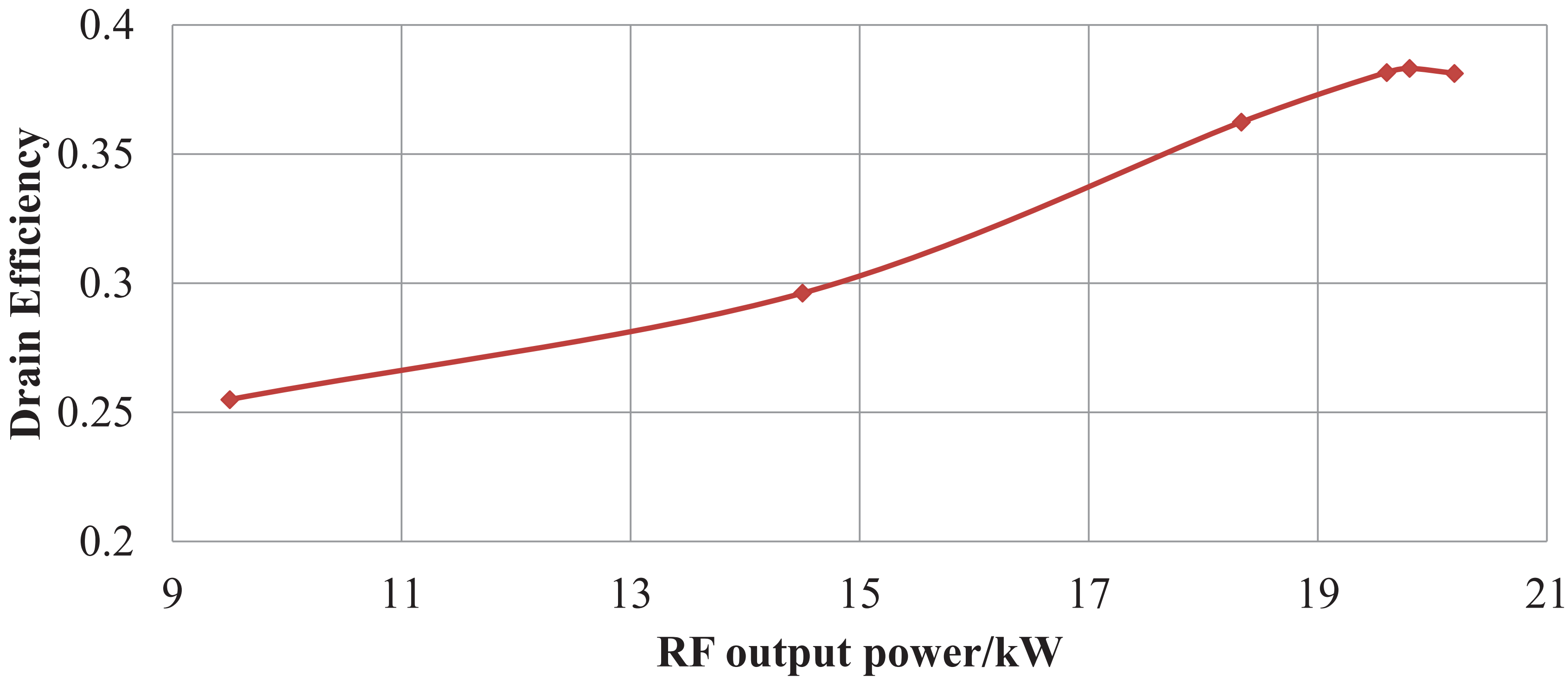
- Phase changes 9.5° from 1-20 kW

Tests-Bandwidth



- 3dB bandwidth is > ±30MHz

Tests-Efficiency



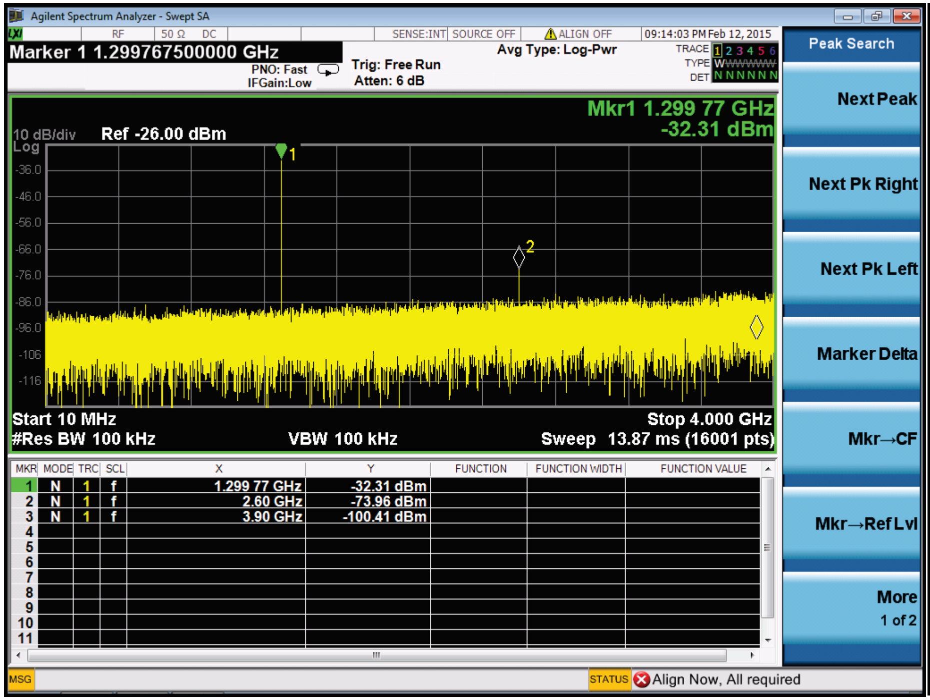
- Drain efficiency:

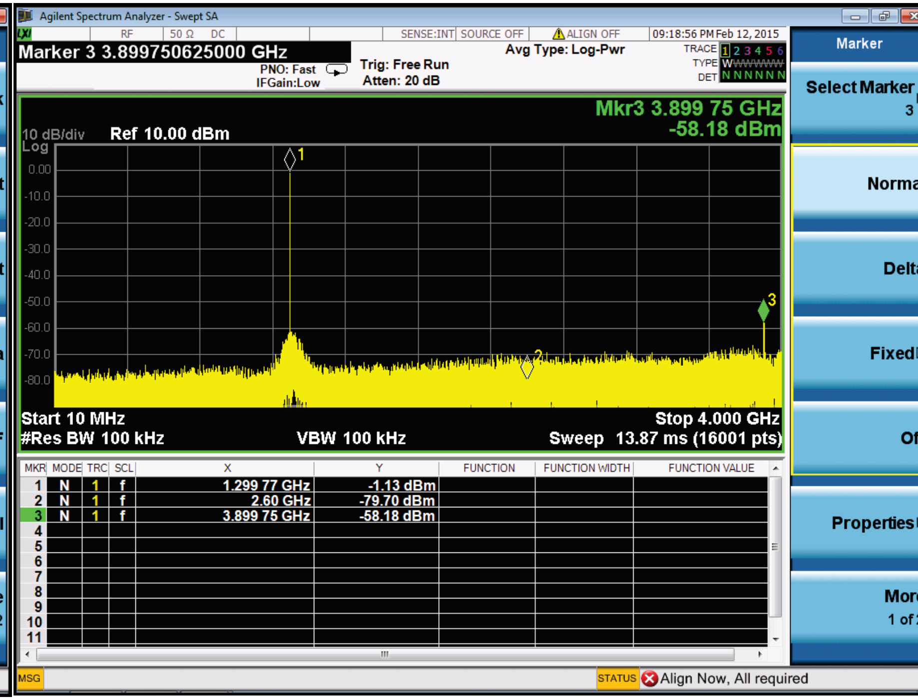
— 38% at 20 kW output, 25% at 9.5 kW output

- RF Power ratio to the wall-plug power:

— 34% at 20 kW output, 20% at 9.5 kW output

Tests-Harmonic

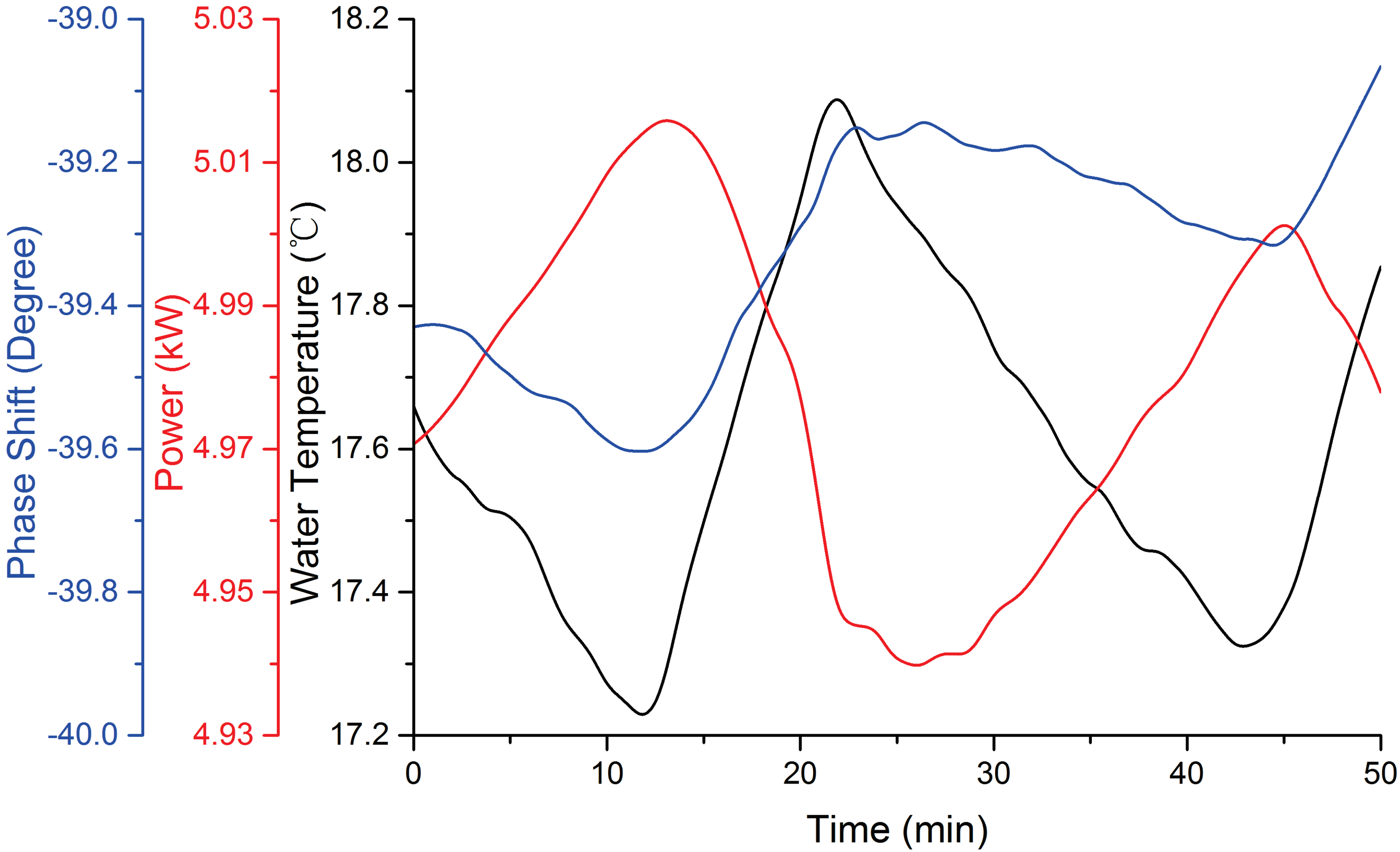




- Input signal
- Output signal

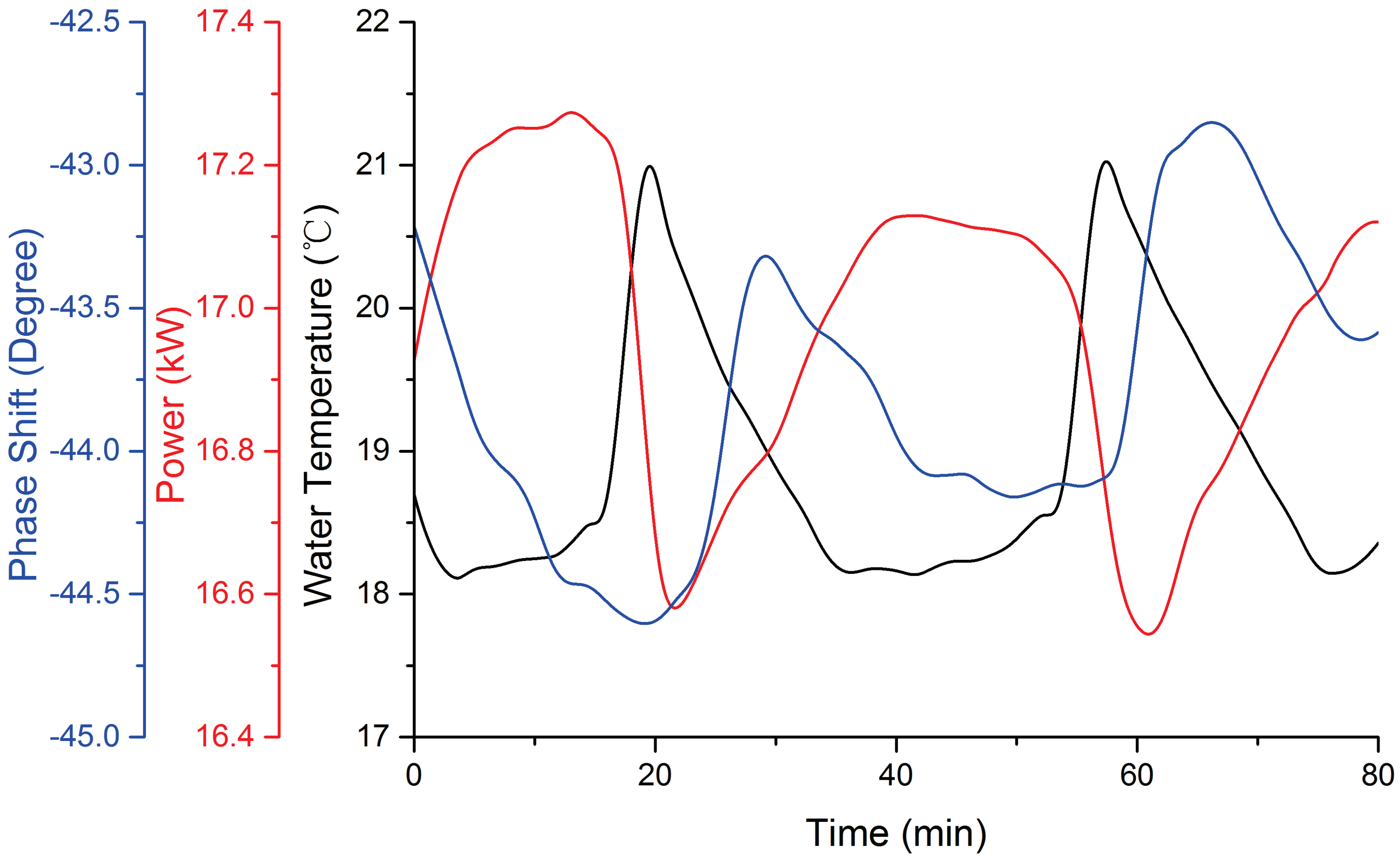
	input	harmonic	output	harmonic
1.3	-32.3		-1.1	
2.6	-74.0	**-41.7**	-70.0	**-68.9**
3.9	-82.0	**-49.7**	-58.2	**-57.1**

Tests-Temperature Gradient



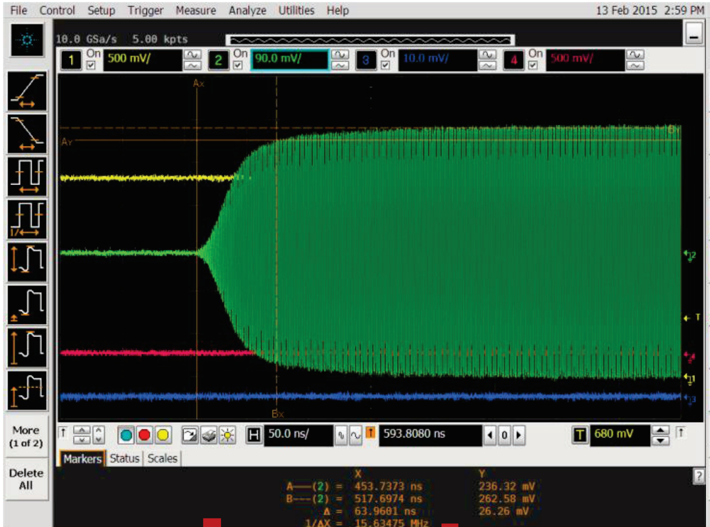
- Temperature Gradient： ±0.8% /℃

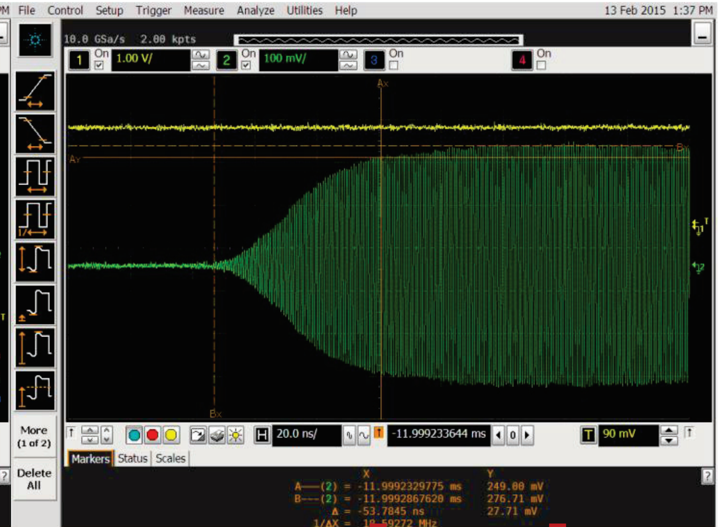
Tests-Temperature Gradient



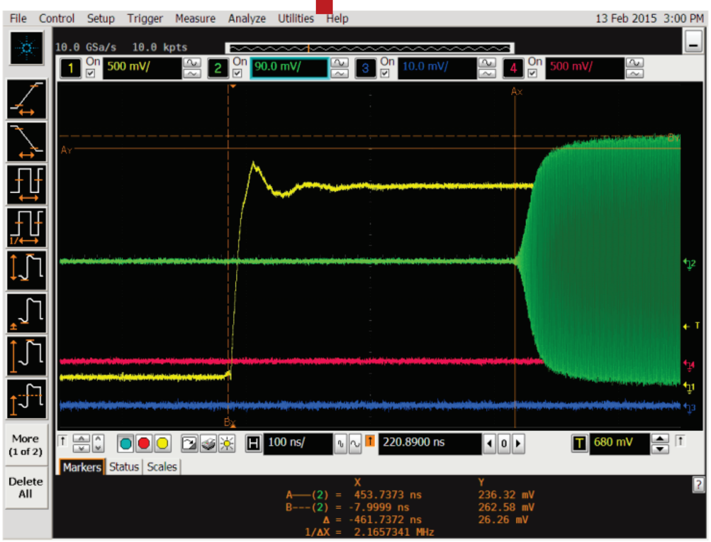
- Temperature Gradient： ±0.8% /℃

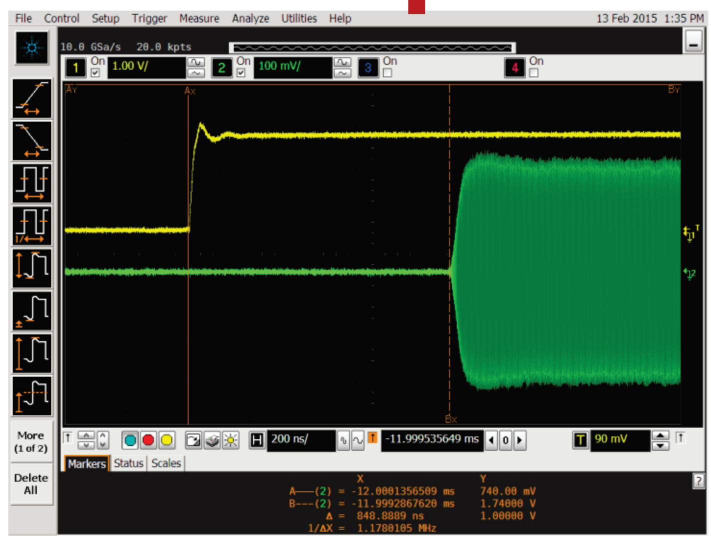
Tests-Rising Time and Delay





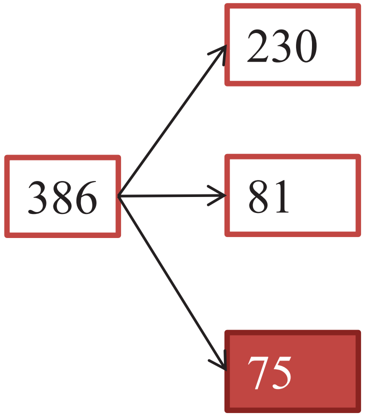
input **output**



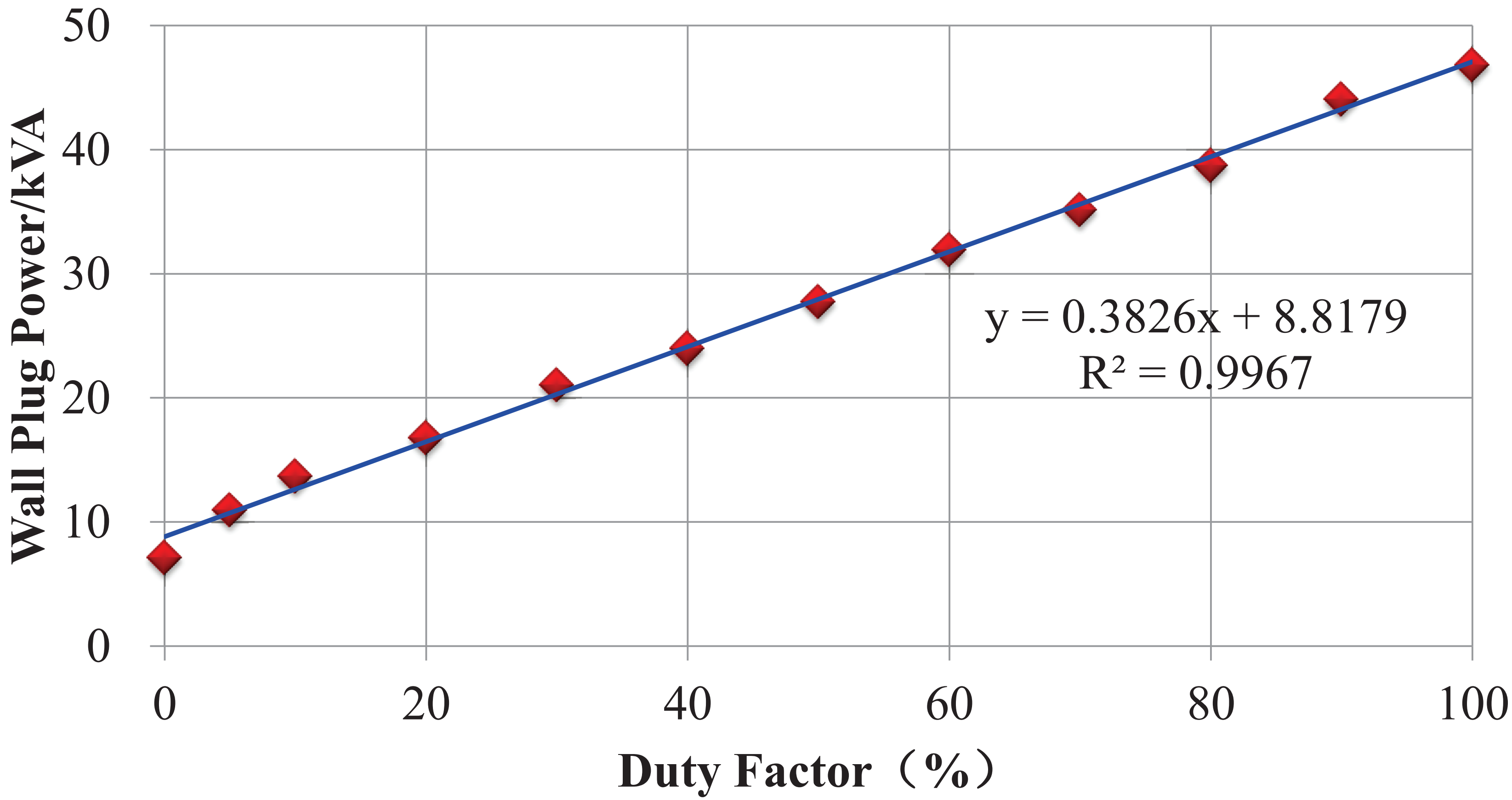


- **Rising time**
  from 0 to 90%
  Input ~54ns
  Output ~64ns

- **Delay**
  Input 462ns
  Output 848ns

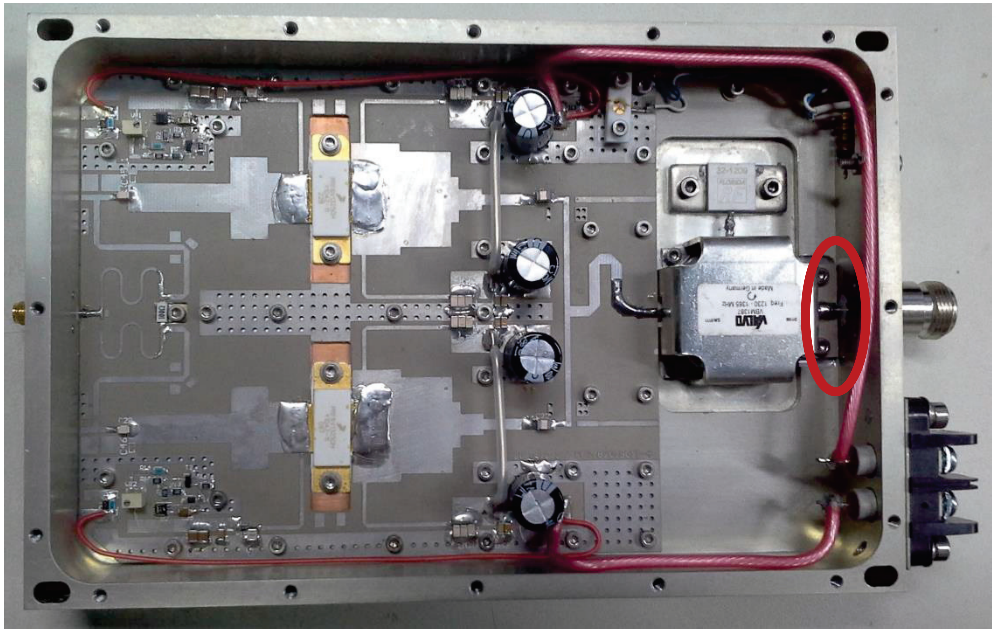


Tests-Power Consume in Pulsed Mode



- The wall-plug power of about 9 kW is consumed without input RF
- The quiescent power drain limits the efficiency

Tests with Full Reflection



- During the full reflection tests with forward power of 20 kW, one 3 kW bank had failure.
- The printed circuits near the output of the unit modules had cracked.
- Make the printed circuits thicker.

Result:
16 over 16 kW in cw for ten minutes without problem.

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Performance

DC-SRF Injector

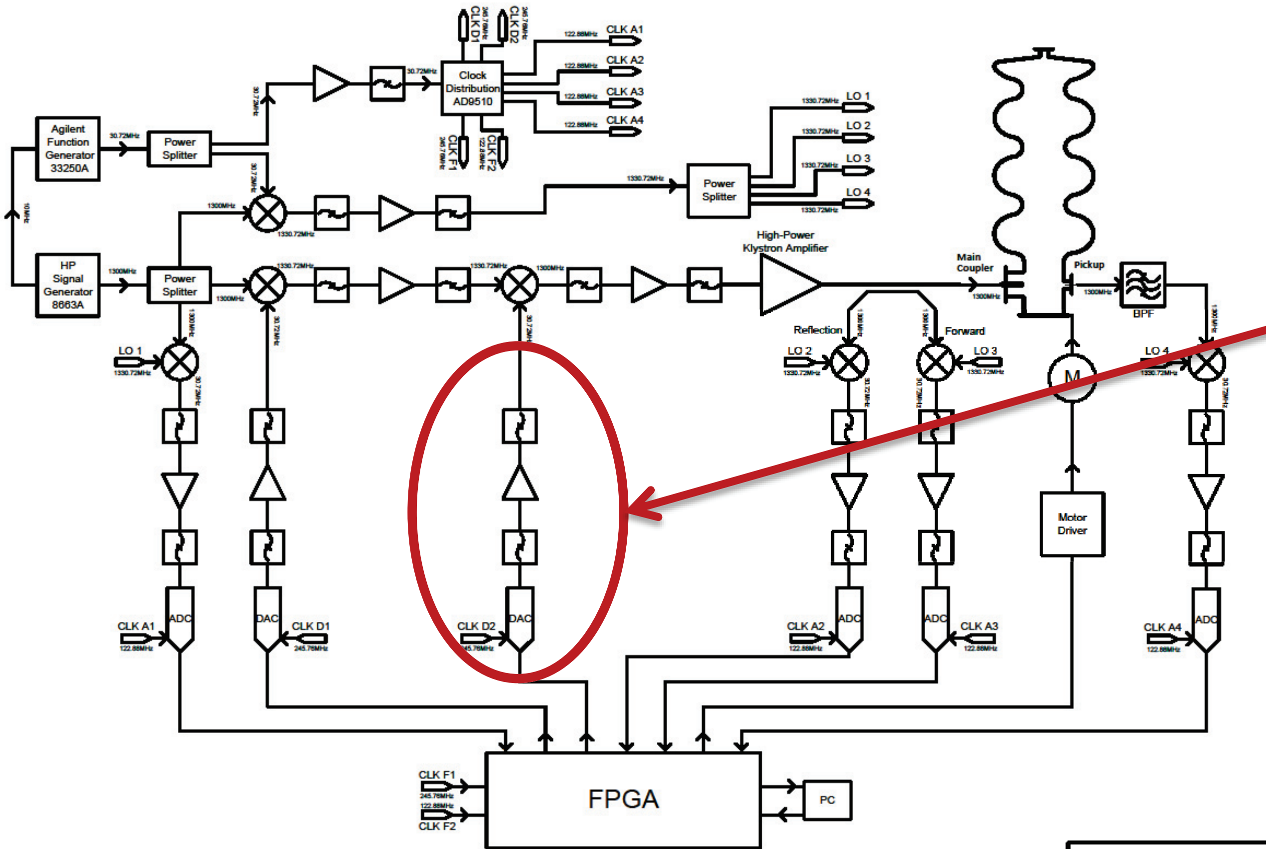
2K Box

The 3.5-cell DC-SRF photo injector and its diagnostic beam line

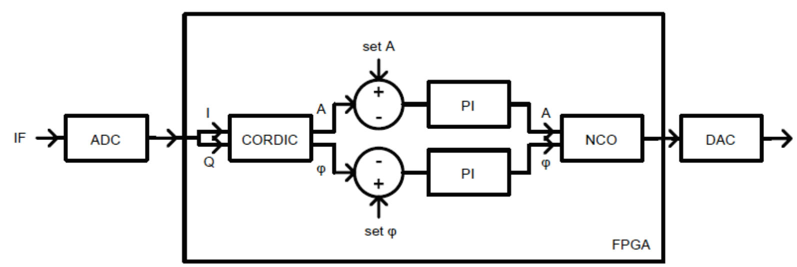
WR650 waveguide

Beam Line

Low Level Control System

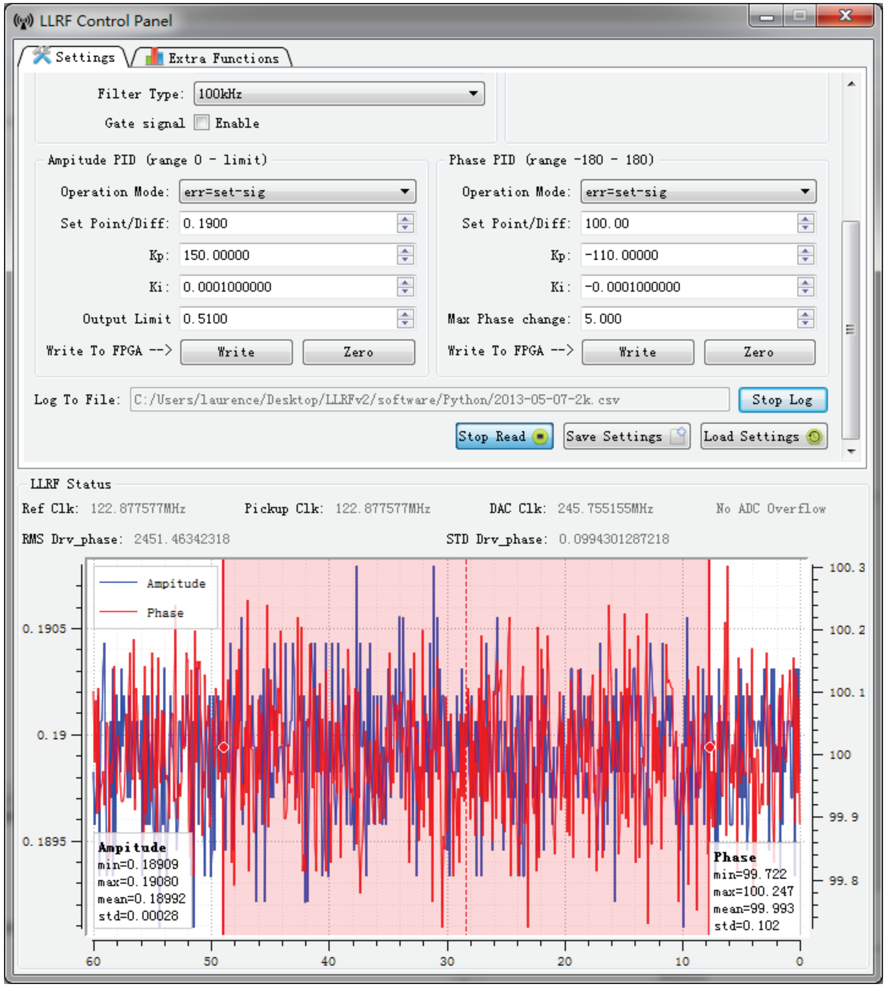


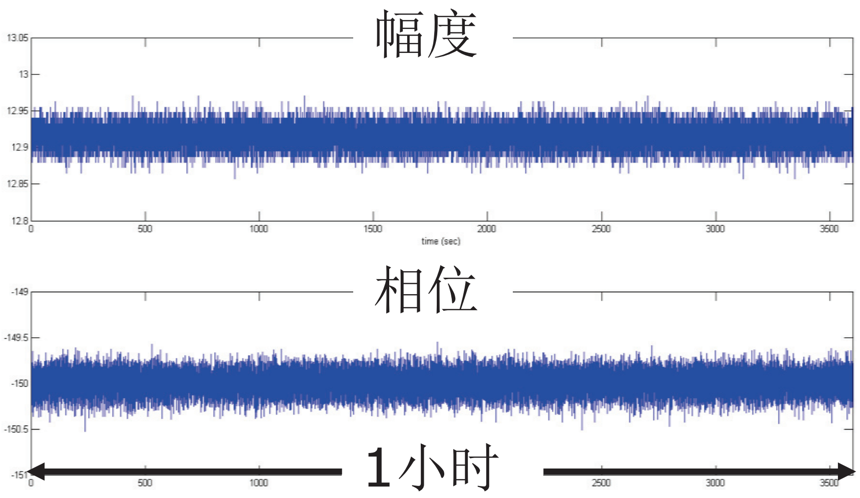
Amplitude & Phase control



Digital LLRF system based on FPGA

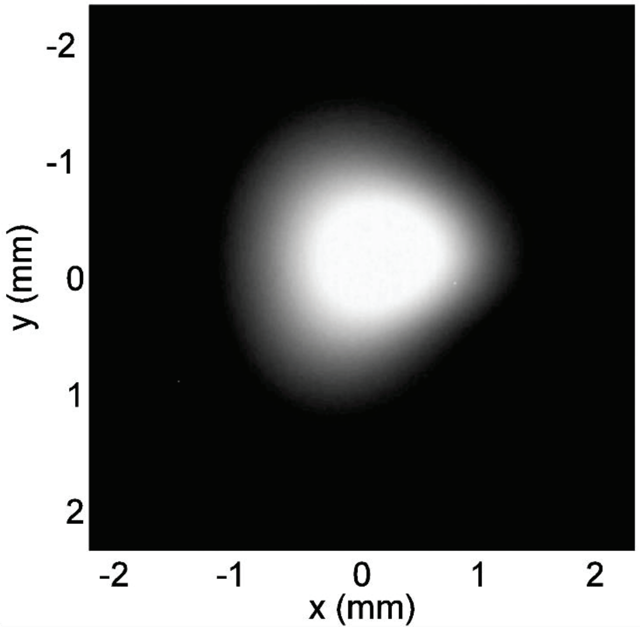
Results of LLRF System

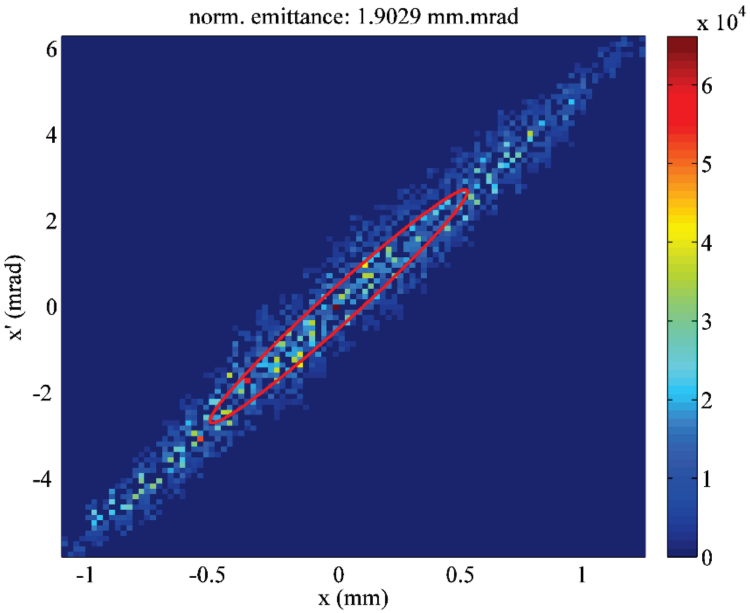


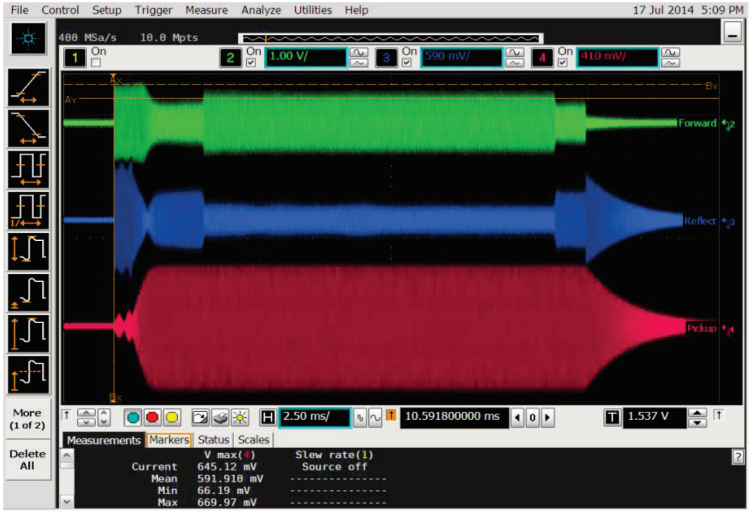


- **Amplitude Instability <0.1%**
- **Phase Instability <0.1°**

Performance







- E_{acc}: 8.5MV/m（pulse mode 17.5MV/m CW14.5MV/m)
- Energy: 3.4MeV
- Macro electron current ~1 mA, duty factor 7%
- Normalized emittance ~2mm·mrad
- Stable operation

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Summary

- A 1.3 GHz 20 kW CW solid state amplifier is developed under the cooperation between BBEF (Beijing) and Peking University. It is the first CW solid state amplifier more than 10kW in China.

- Test results shows the technical specifications are mostly achieved.

- It has been applied to the experiments of the DC-SRF photo-injector at Peking University since 2012 and works stably.

Thank you for your attention!