國家同步輻射研究中心
National Synchrotron Radiation Research Center

Construction and Installation of a 300kW Solid State Power Amplifier for Taiwan Photo Source

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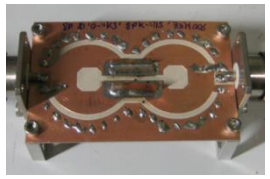
RF Group
NSRRC, Taiwan

Outline

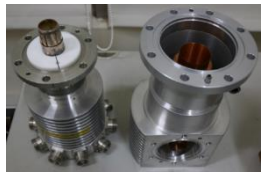
- Introduction
- Single 80 kW SSPA Tower
- SSPA and klystron power combine
- Performance of Each RF Tower
- 500 MHz 300 kW SSPA System
- Long-term Reliability Test
- Conclusion

The developing progress of SSPA technique



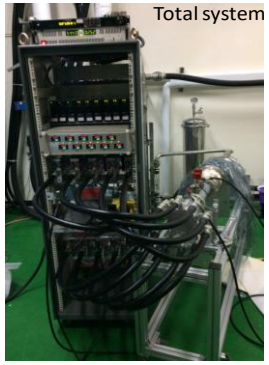
Planar balun

Power divider

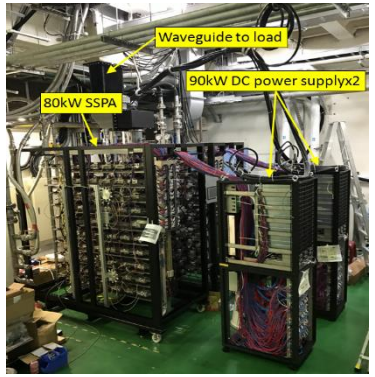


Power combiner

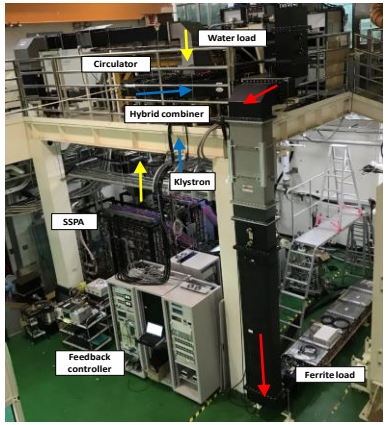
900W SSPA module



10-module combination
For 8.5kW

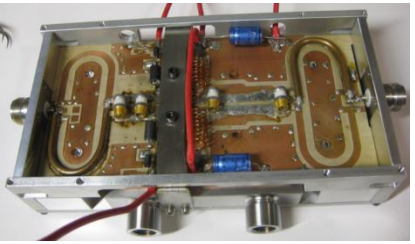


100-module combination
for 80 kW

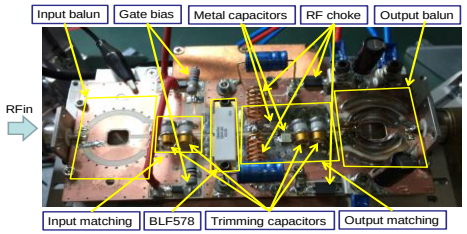


Hybrid RF source combine for 140 kW

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021



900W SSPA circuit



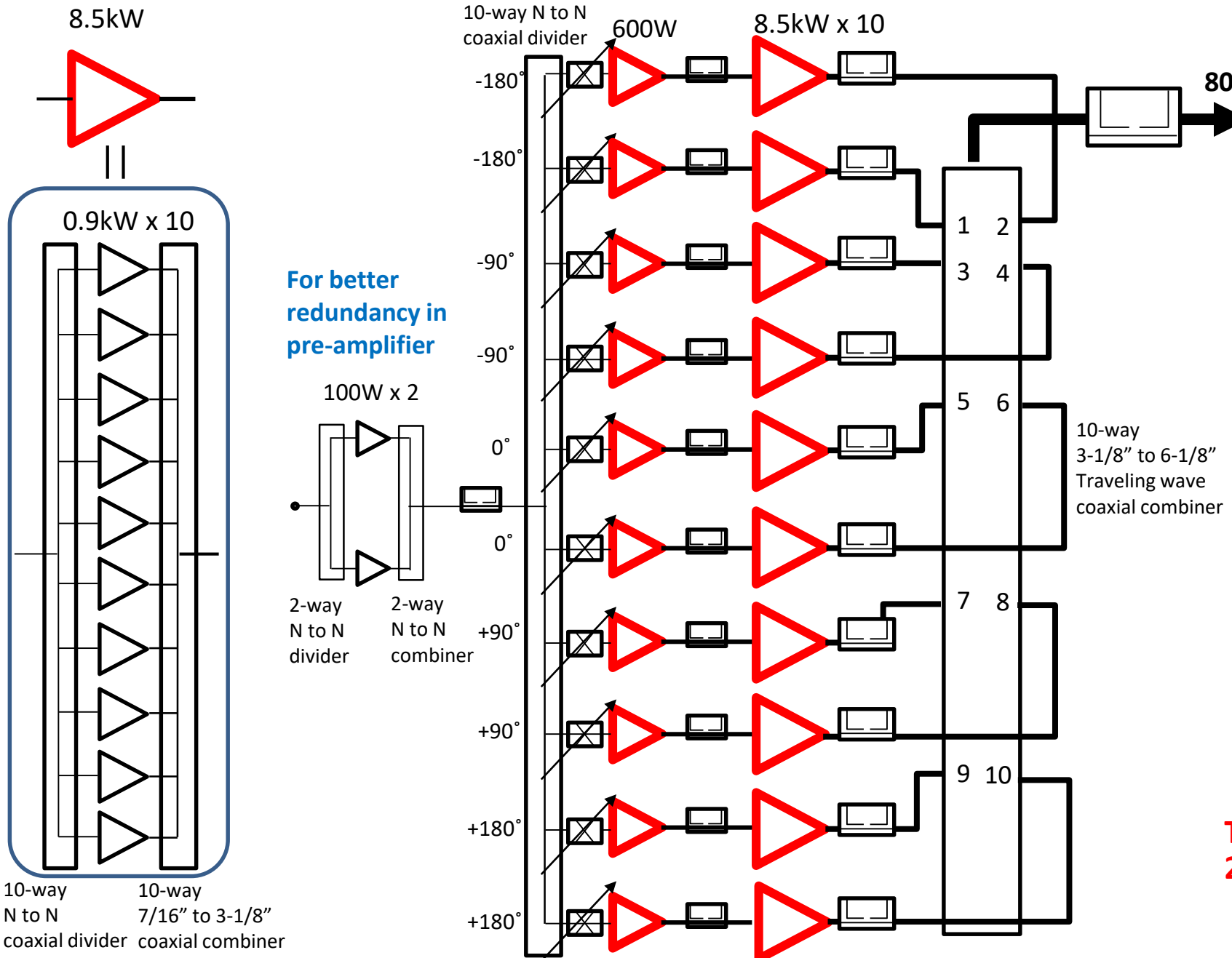
950W SSPA circuit

2-way combine 1.8kW

20-way combine 18kW

320 kW by combine 4 x 80 kW towers

NSRRC home made 80kW SSPA at laboratory (2018~2019)

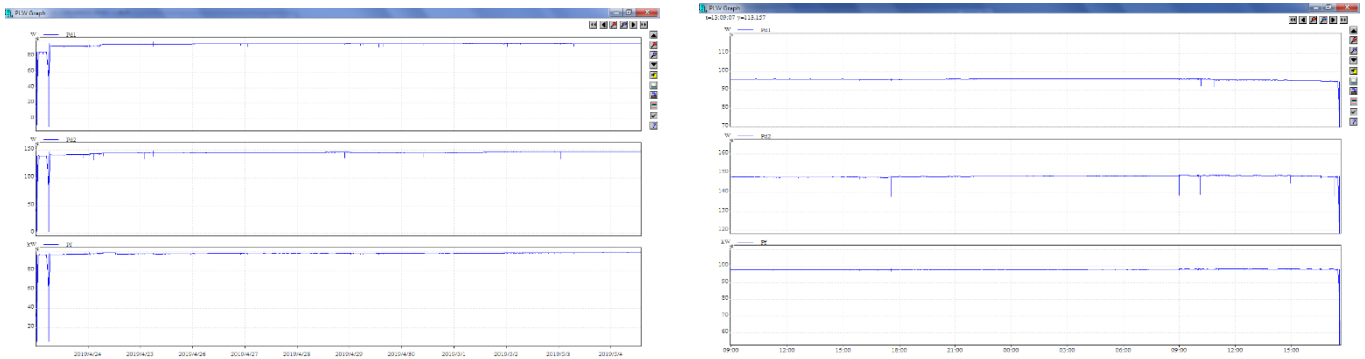


completed assembly before high power test.

Total modules: 100+10+2
20 modules with analog module included.

Long-term Test at Full Power on 80kW Set

- Target: continuous operation at full power for weeks with no trip event.
- Full RF Power test (3 times)
  - 1st test 2019.04.23-05.08: 15 days (1 module fault)
  - 2nd test 2019.05.29-06.12: 15 days(2 module faults)
  - 3rd test 2019.06.13-06.17: 5 days (no module fault)
- There was no trip event due to any module abnormality, as the expected advantage of SSPA.

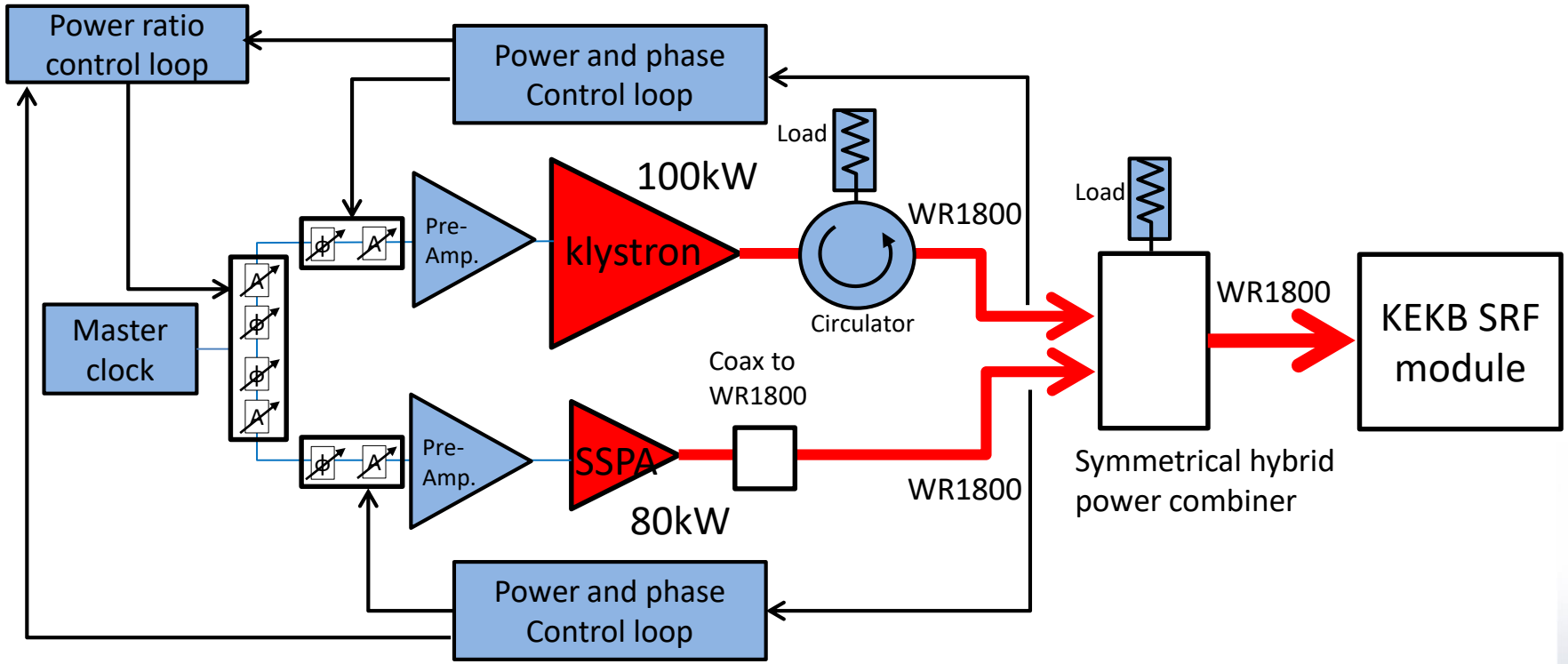


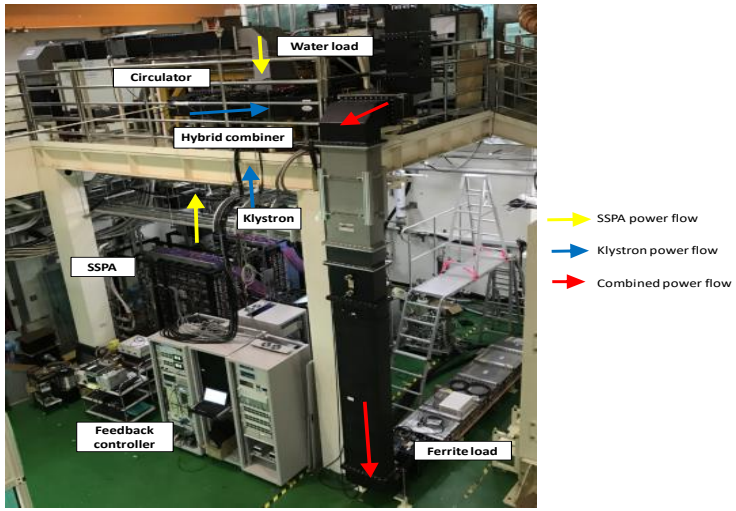
5

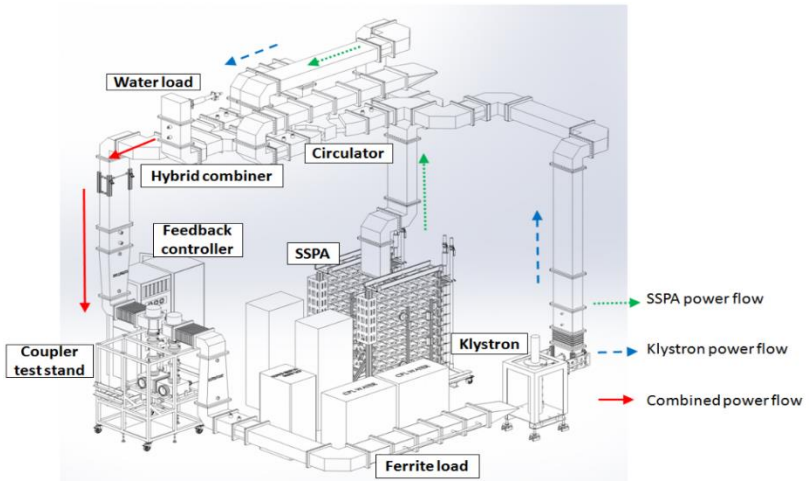
2019.4.23 17:15 15 days continuous run without trip 2019.5.8 17:30

Hybrid Combination with SSPA and klystron

- The 80kW SSPA was combined to a 100-kW klystron
- High-power test on the SRF module of the 3rd RF plant.







- Observe Pr of each power source & Pf_total to see if the power is balance

Serious Damage

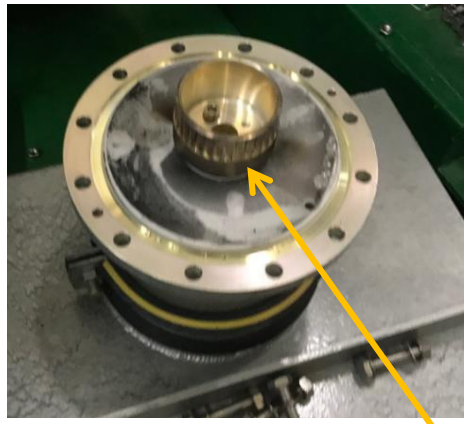
- (1) RF power up to 120kW → no trobule
- (2) RF power up to 140kW → water load crash

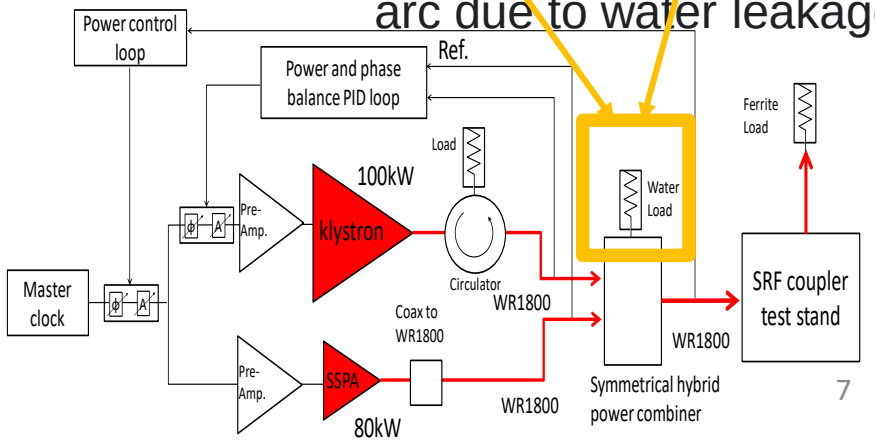
Damaged modules:

- After water load crash event: (water leakage)
  - 13 modules were repaired
- After CPL aging:
  - 22(No DC current)+2(current low)=24 modules.

✓Most arc happen due to non-proper IC model

(BLF578XR(low efficiency) → BLF578)





Cause of issue

- Damage Devices

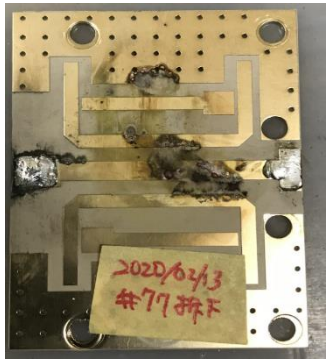
Reason	SSPA module				
	IC-BLF578	1000W-Circulater	1200W-RF Load	RF Circuit Board	analog Circuit
ARC (Reflection Power)	★	★		★	★
CPL aging	★	★	★		
Operation RF Power	★	★		★	★

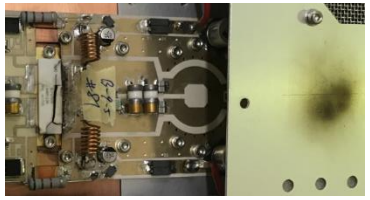
BLF 578XR

circulator

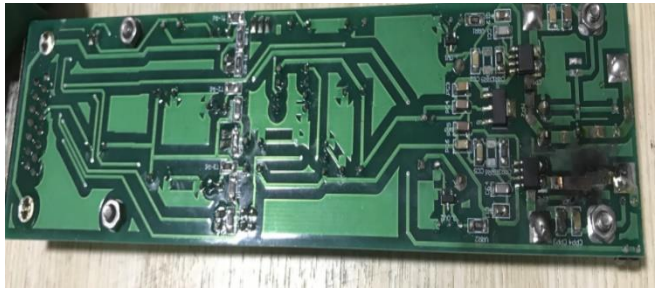
RF Load

RF Circuit Board





Analog Circuit



Project (5y) 2018~2022

- To build the 3rd Superconducting RF plant at TPS.

We Need ~

(1).LLRF system

(2).SRF Module (KEKB-type) + electronic system (home made)

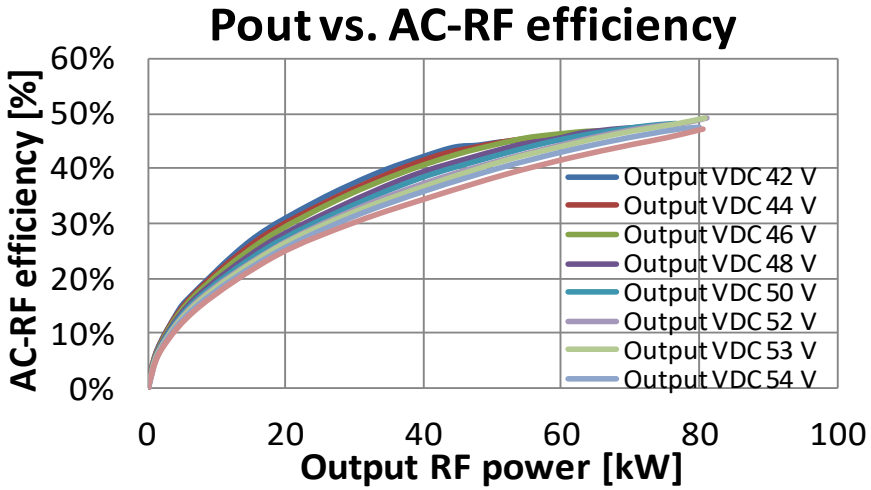
(2).Cryogenic transfer system + Valve box + cryogenic electronics

(4).RF Power + RF loads + circulator +waveguide

(5).Utility support. (Air, Cooling Water, AC-Power…..)

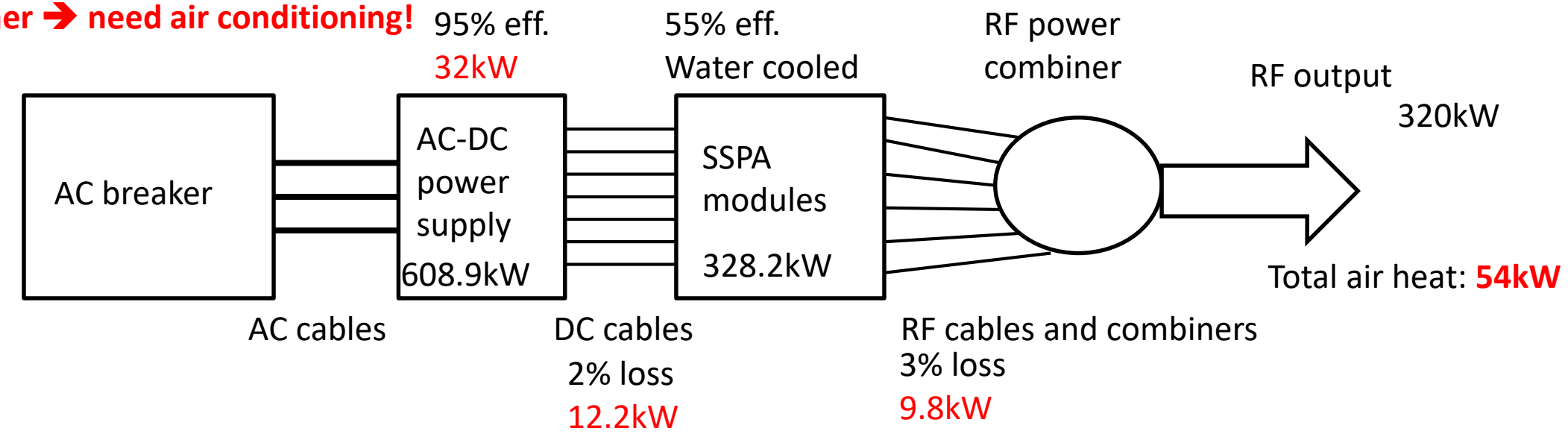
Estimation: 320kW efficiency

- The possible loss in SSPA system
  - AC-DC efficiency: 90%
  - DC power loss at wires: 3.5%
  - DC-RF efficiency: 55-60% (BLF578XR has lower efficiency)
  - RF cable efficiency: 98.2% (-0.05dB/m)
  - RF combiner efficiency: 98.7%
  - Theoretical efficiency: 45.7%-50%
  - The best AC-RF efficiency to obtain: **49.5%**



Estimation of the heat of 320kW SSPA to air:

A Big warmer ➔ need air conditioning!



Improve and upgrade SSPA System

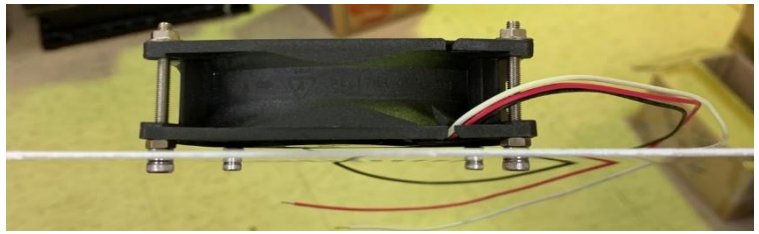
- (1). Product standard operating procedure (S.O.P) -> similar RF Power for each module
- (2). Choose the **high-Efficiency** IC: BLF578XR -> BLF578
- (3). **Simplify** the assembly of analog modules into SSPA
- (4). Mount the DC-Power Supply on support top (to reduce the wire-loss)
- (5). Using **communication interface** for data capture and operation
  Operation interface <-> Raspberry <-> CAN BUS <- Power Supply(Vdc)
  Raspberry <-> local PLC <->Data(analog-SSPA) and interlock
- (6). Redundant **pre-amplifier , SSPA module**
- (7). More powerful **air conditioning**
- (8). **Noise** reduction
- (9). Add **power balance** device

Simplify the assembly of analog modules into SSPA

(1).Vdc current/voltage
(2).Temp(balun-IC-Load)
(3).Fan frequency

15pin-D_Sub

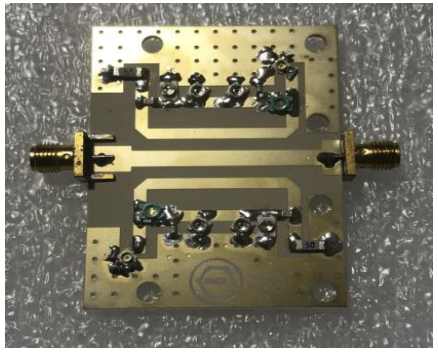
Need Shielding (EMI)

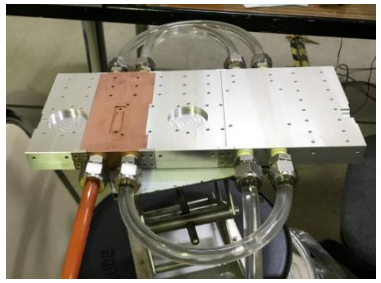


15pin-D_Sub

SSPA circuit assembly

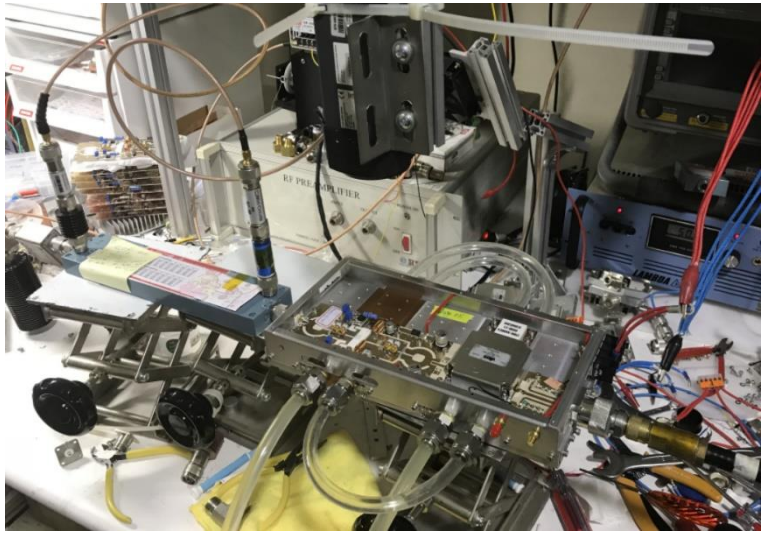
BLF578-Circuit Board





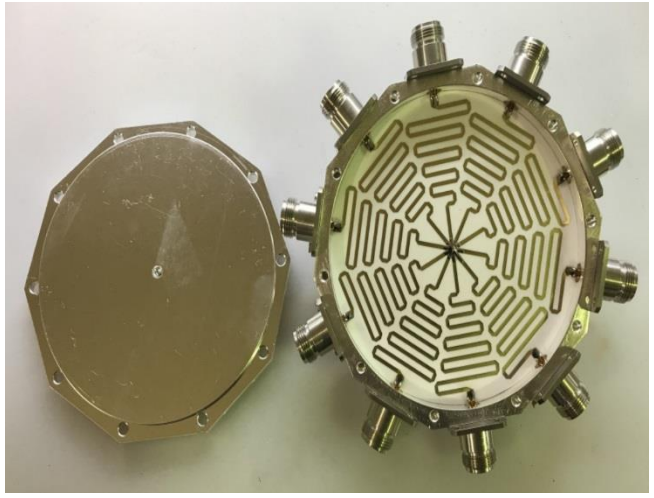
Water Cooling

Lab Test Area



10kW 7/16”to 3-1/8”
10-way power combiner

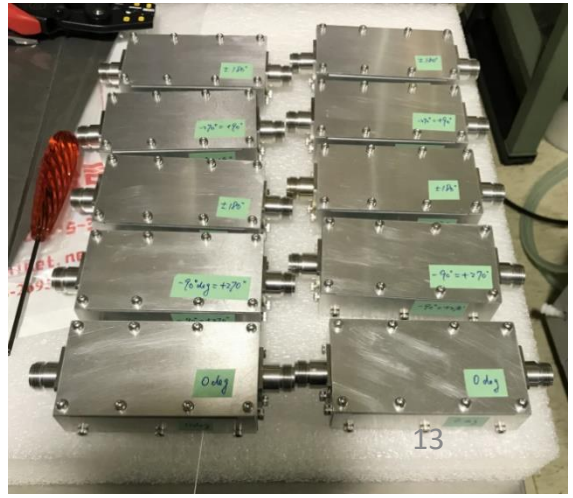
11 way-Power Divider



Analog module

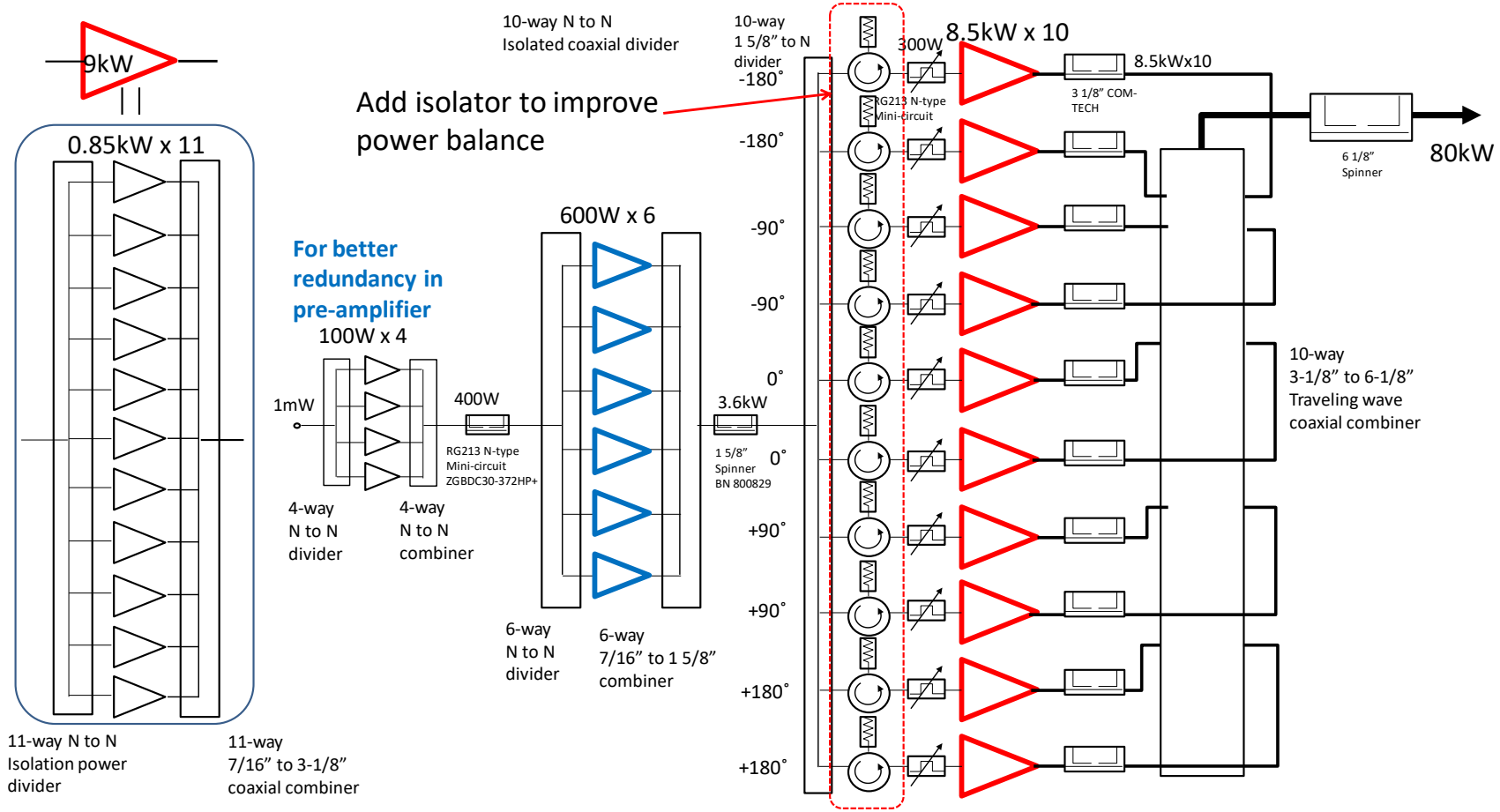
(1).DC current/voltage
(2).Temp(balun-IC-Load)
(3).Fan frequency

Phase shifter



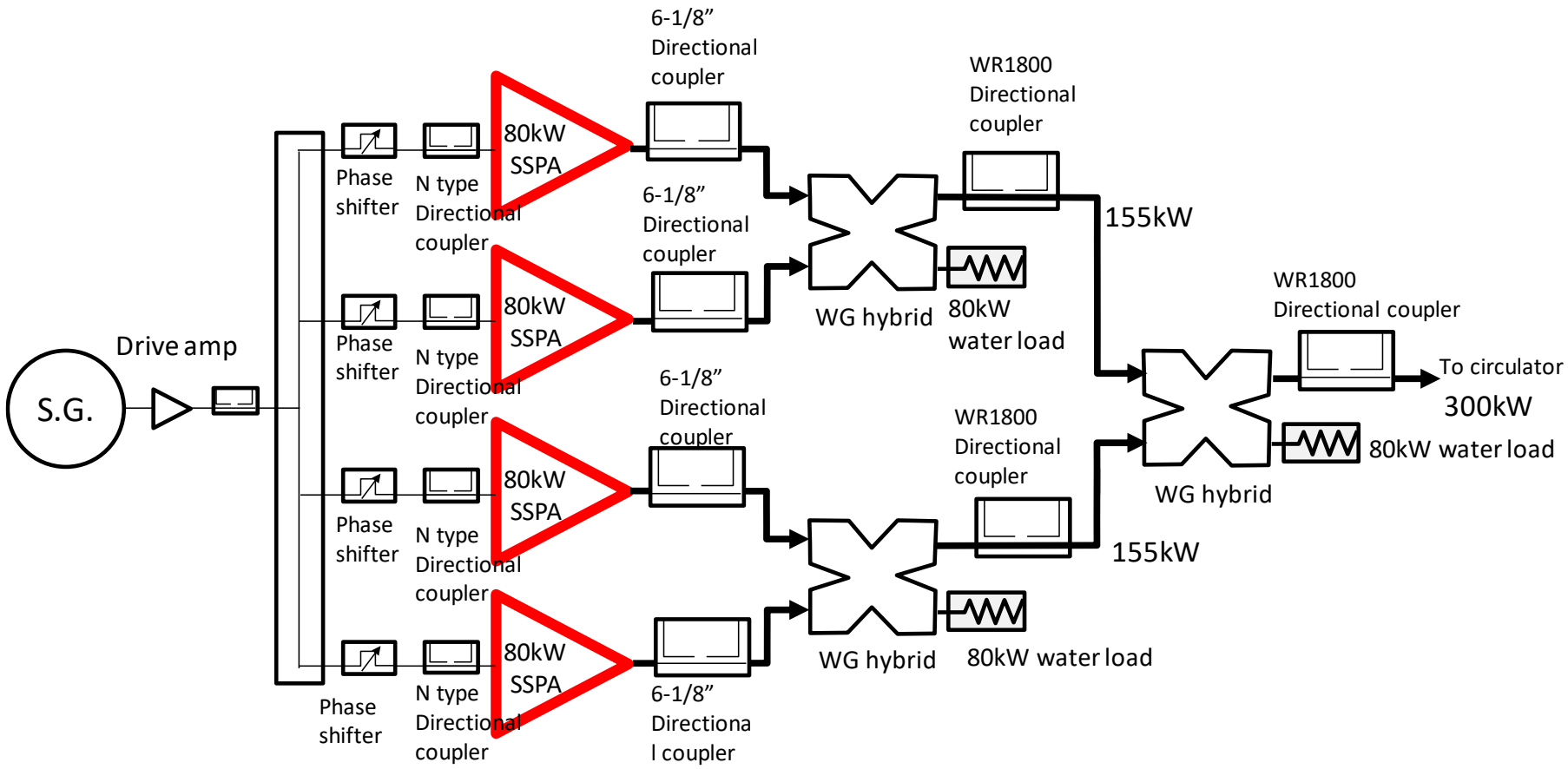
Single 80kW SSPA Tower design

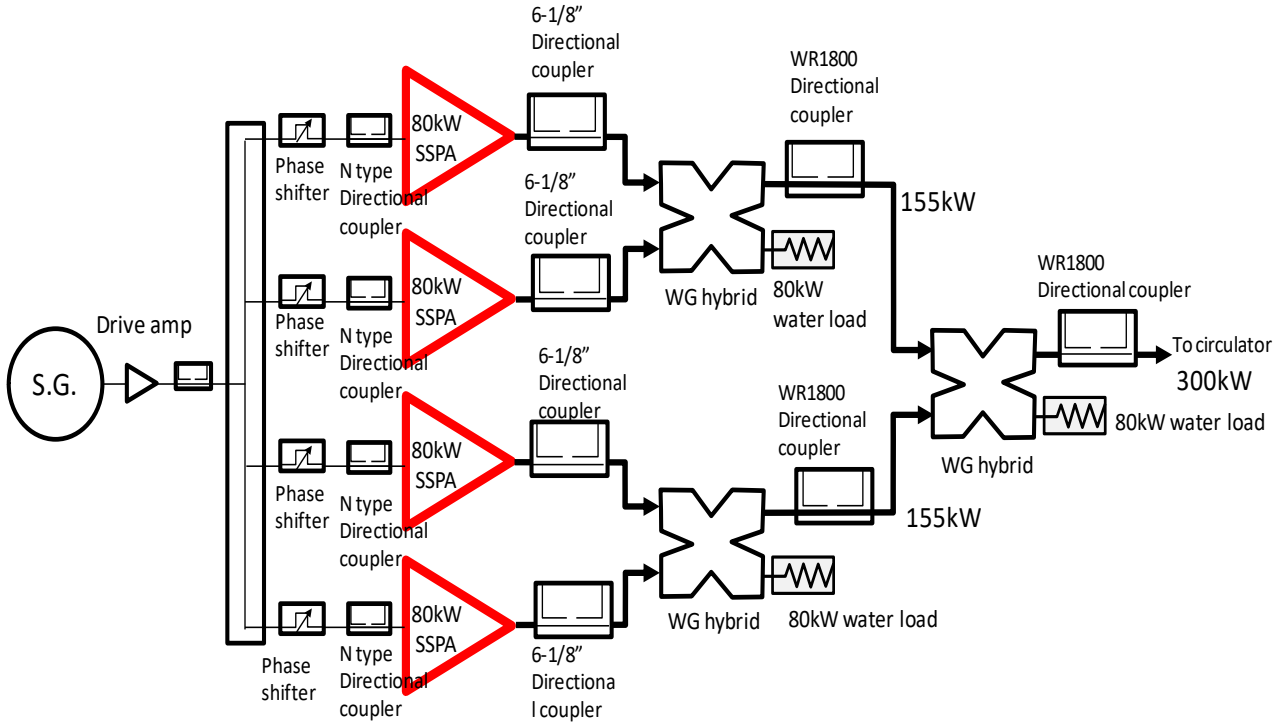
- Frequency: 499.65 MHz
- Power rating: ≥ 80 kW
- Bandwidth: ≥ +/-1 MHz
- Power gain: ≥ 80 dB
- Side band noise: ≤ 65 dBc
- Harmonic: ≤ 40 dBc
- Elements:
  - 100 W pre-amplifier x4
  - 600 W drive amplifiers x6
  - 880 W amplifiers x110
  - 4-way divider/combiner (400 W) x2
  - 6-way combiner (3.6 kW) x1
  - 10-way divider (3.6 kW) x1
  - 11-way divider (300 W) x10
  - 11-way combiner (8.5 kW) x10
  - 10-way combiner (80 kW) x1

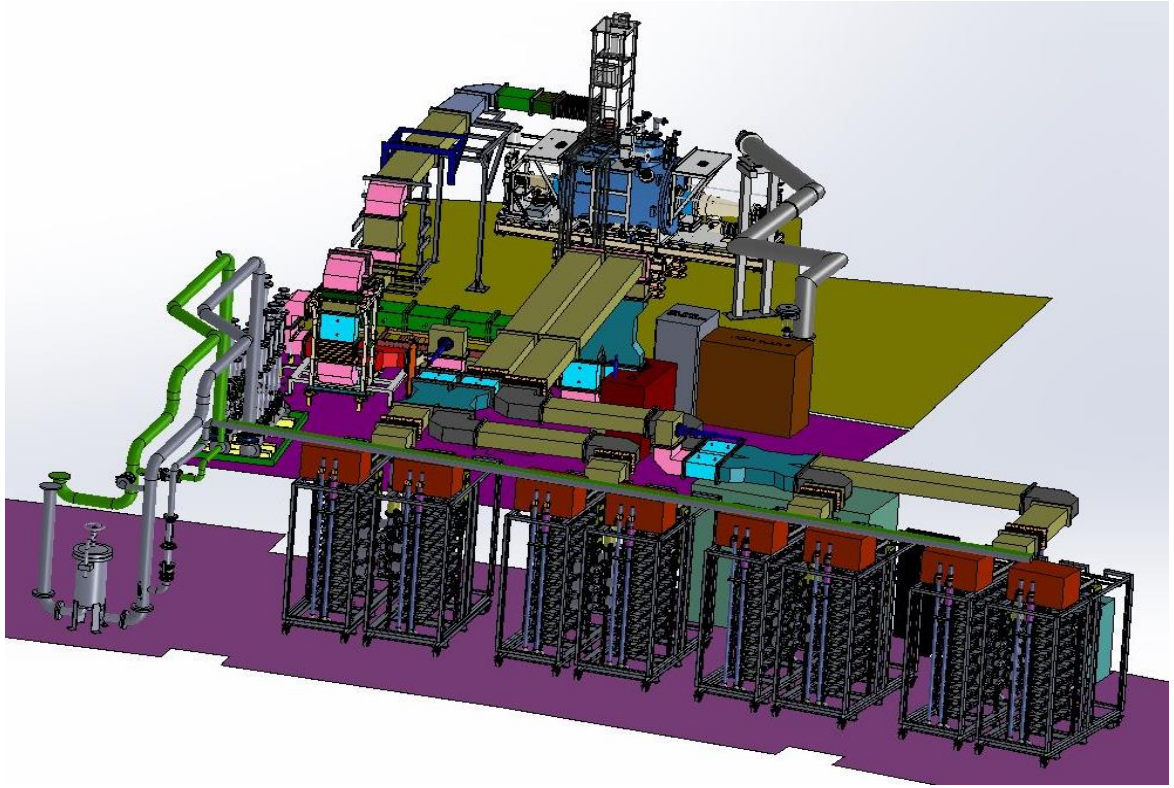


500MHz RF power 300 kW SSPA System Design

- Frequency: 499.65 MHz
- Power rating: ≥ 300 kW
- Bandwidth: ≥ +/-1 MHz
- Power gain: ≥ 75 dB
- Side band noise: ≤ 65 dBc
- Harmonic: ≤ 40dBc




S.G.
Drive amp
Phase shifter
N type Directional coupler
80kW SSPA
6-1/8" Directional coupler
WG hybrid
80kW water load
WR1800 Directional coupler
155kW
WR1800 Directional coupler
To circulator
300kW
80kW water load
WG hybrid
6-1/8" Directiona l coupler



Long-term Reliability Test

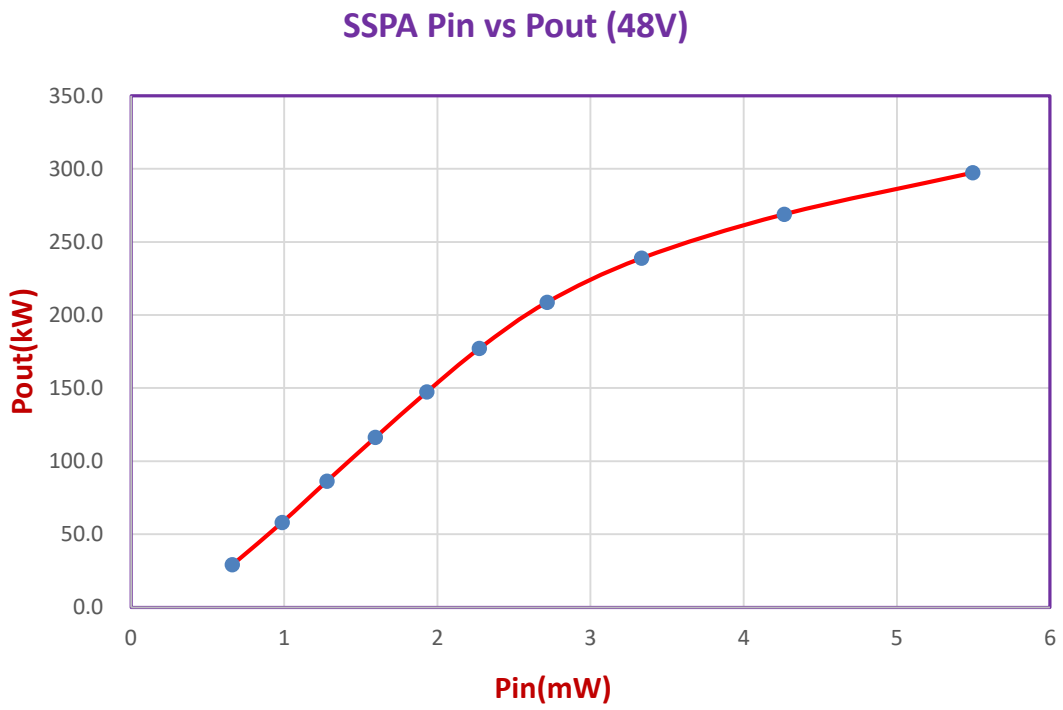
Cryogenic System:

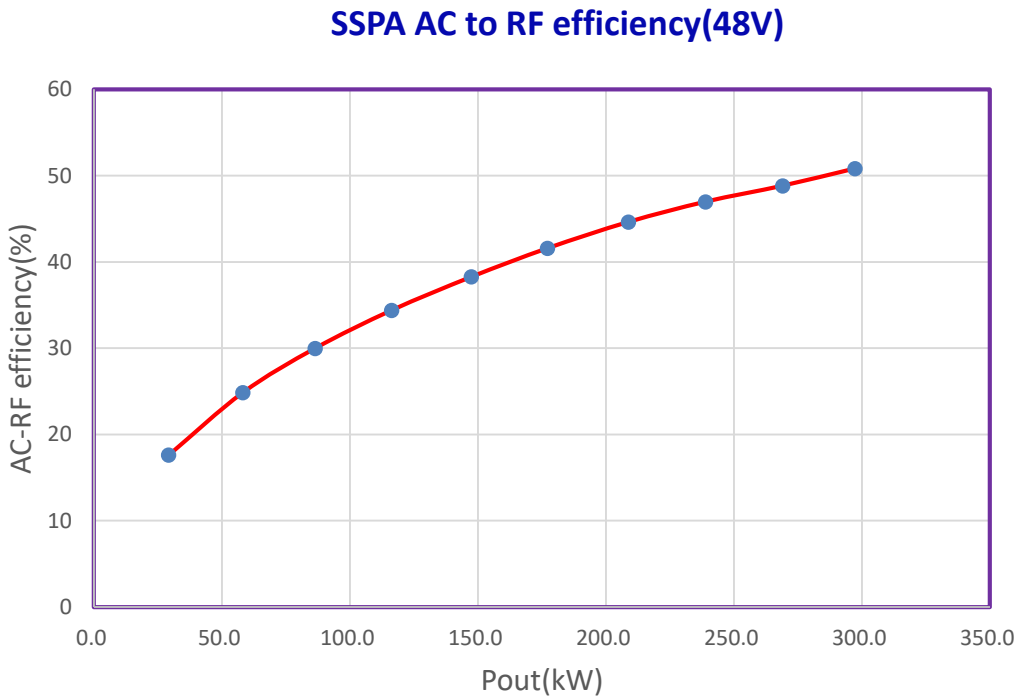
Refrigeration Capacity decreased

(1).3rdSRF Off-line

(2).SSPA Only, for long time test

(3). 3 SSPA modules were repaired (to August 2022)





Conclusion

What must do:

(1).Reduction on module damage rate during CPL aging

(2).Reduce acoustic noise.

(3).Higher operation stability and reliability

(4).Greater energy efficiency

(5).**Keep working hard**

Thanks for your attention