

Overview and Progress of RFT-30 High Power RF Amplifier



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01 Introduction

» RFT-30 cyclotron (Prototype)



RFT-30 (30 MeV cyclotron)

Design specifications	
Type of accelerated ions	Negative hydrogen
Extraction method	Stripper carbon foil
Beam energy (proton)	15 ~ 30 MeV
Beam current (proton)	Max. 300 uA
Number of beam lines	4
Dee voltage	58 kV
Resonant frequency	63.96 MHz

Applications

- RI production: F-18, Sc-44, Zr-89, Ge-68 (test)
- Proton beam irradiations
- Research on compact neutron source

01 Introduction

» Objectives for performance upgrade

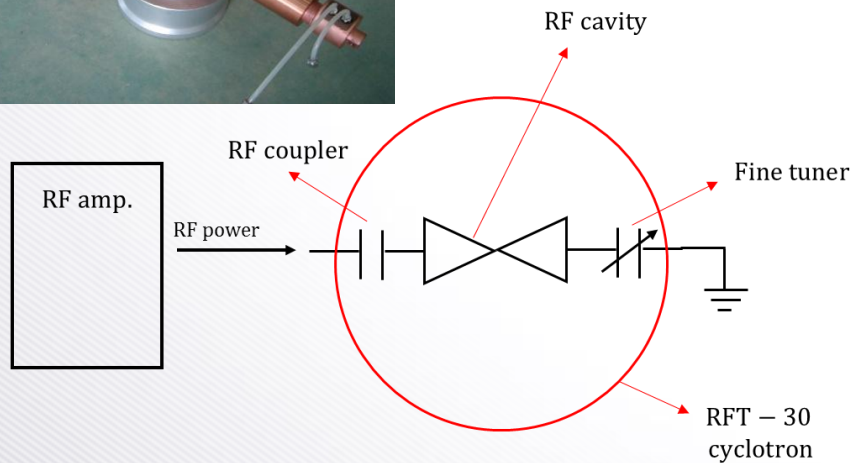
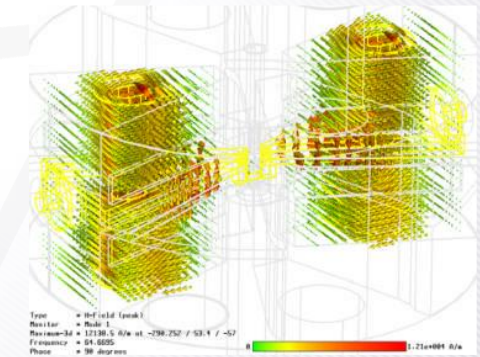
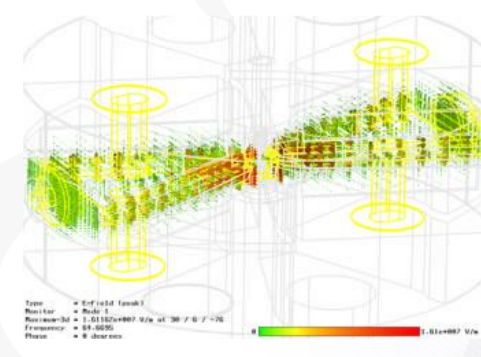
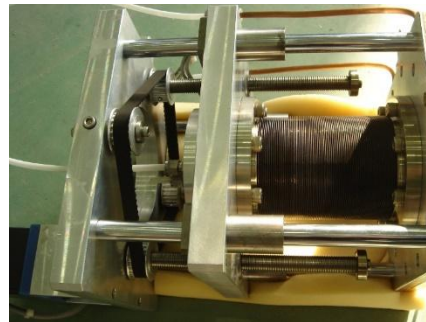
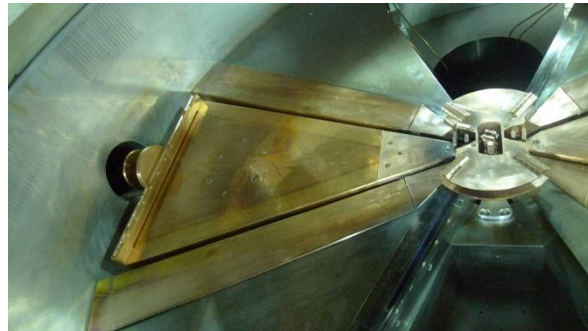
- Increase RF efficiency, beam transmission efficiency
- Increase intensity of proton beams
 - Stable proton beam extractions at any currents
- Requirements for RF system
 - Stable 50 KW amplifier
 - Stable control system (LLRF)

- In this study, the talk will be focused on the view of RF system especially RF amplifier

02 RF system

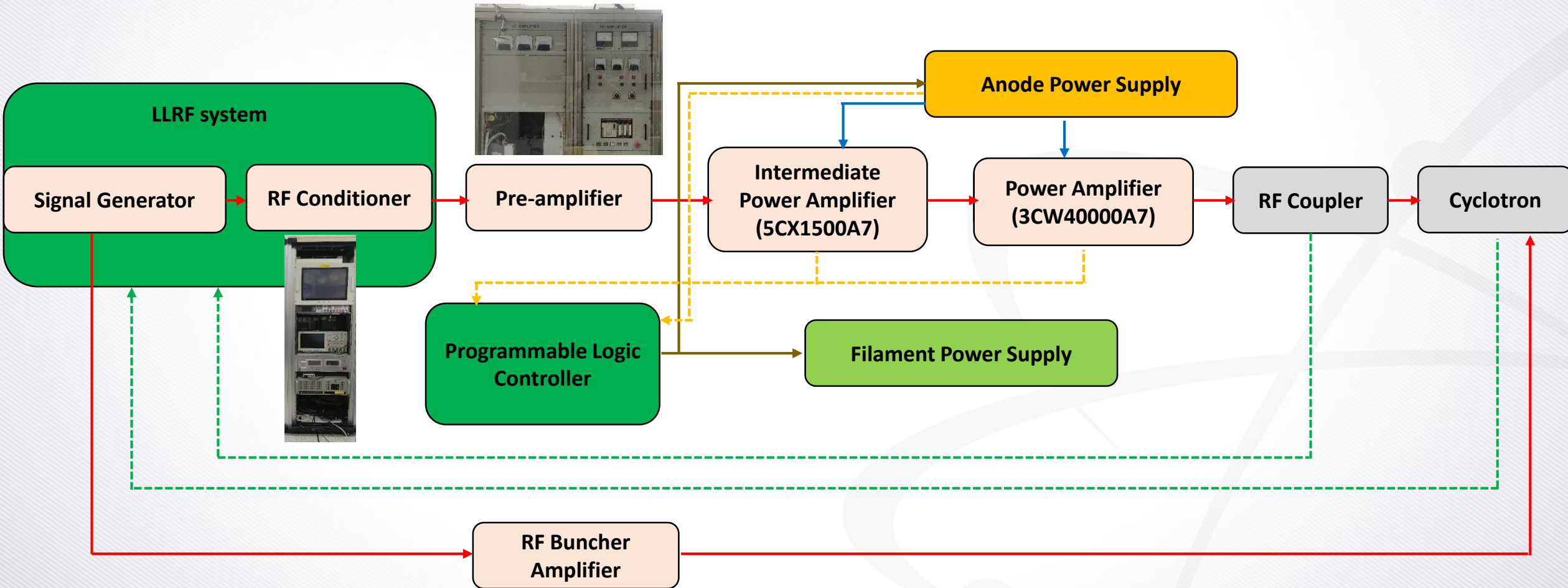
RF system description

Parameter	Value
Resonant frequency	63.96 MHz
Harmonic number	4 th
Dee voltage	(Nominal) 55 kV
Resonant mode	$\lambda/2$ mode
Impedance	50 Ω
Number of Dee	2



03 RF amplifier

» RF amplifier architecture

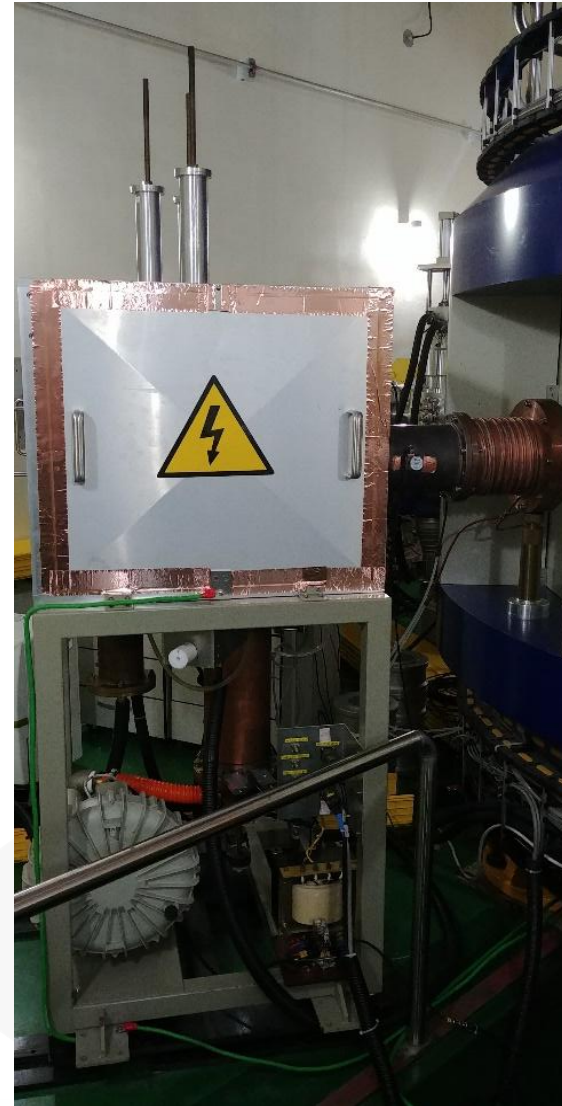


- 50 kW RF amp. made by Converttech

03 RF amplifier

» RF amplifier

Parameter	Value
Operating frequency	63.96 MHz
Operating mode/class of operation	CW PWM/C class
Solid-state pre-amplifier	OPHIR RF 5303006A/50 W
Power amplifier tube	3CW40000A7
Intermediate power amplifier tube	5CX1500B
Dee voltage	58 kV
PA anode voltage (low/high)	6200 V/10800 V
IPA anode voltage (low/high)	2400 V/4200 V
Filament power (IPA/PA)	38.5 A @ 5 V/110 A @ 12 V
Characteristic impedance	50 Ω



03 RF amplifier

» RF amplifier

Issues:

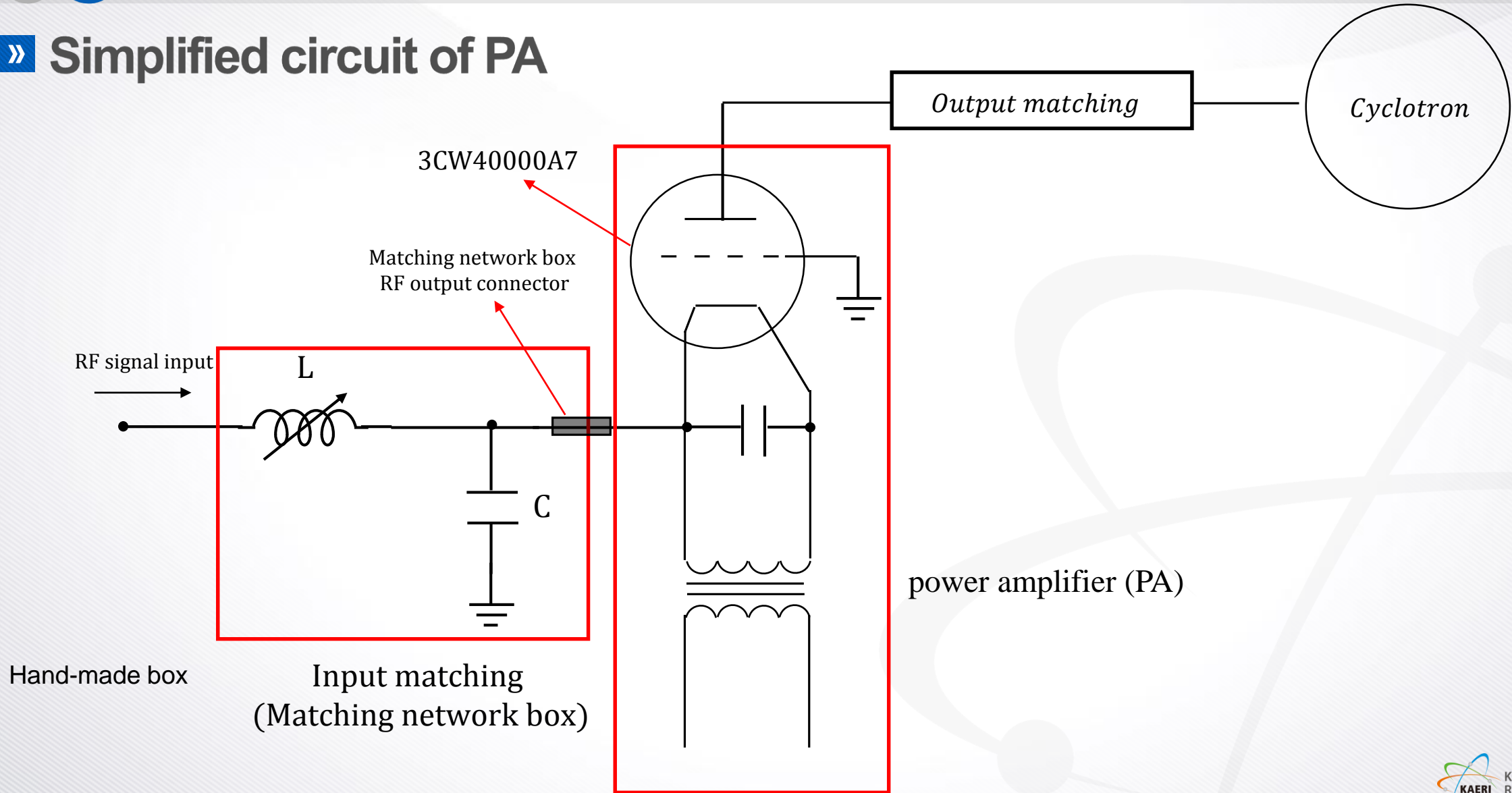
- Normal operation at PWM mode (duty: 20 – 50%)
- Short operation at CW mode
- Unstable at high duty mode (> 50 %)
- LLRF is not optimized for high duty mode

Limitations:

- Limited time for maintenance and test
- Maintenance is limited on specific period
- Try to reduce risks on normal beam irradiation period

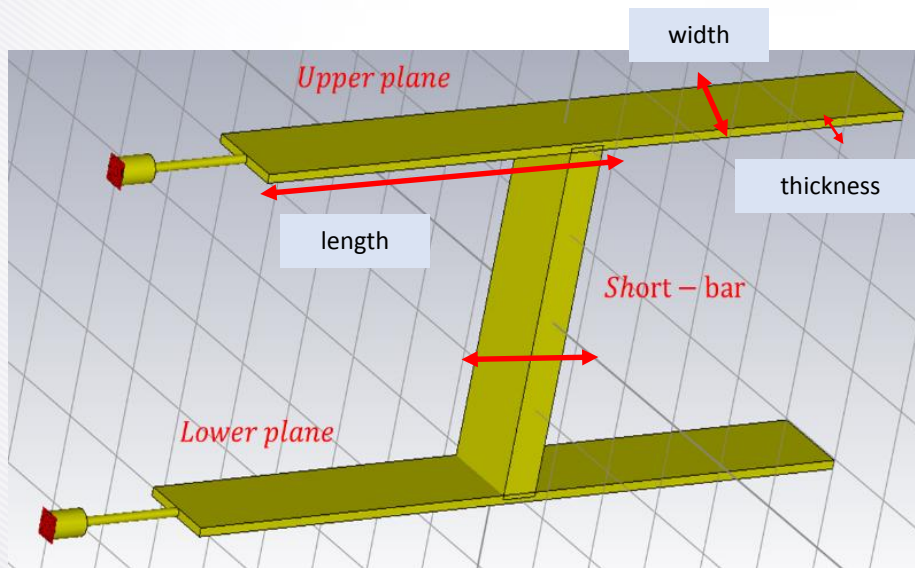
03 RF amplifier

» Simplified circuit of PA

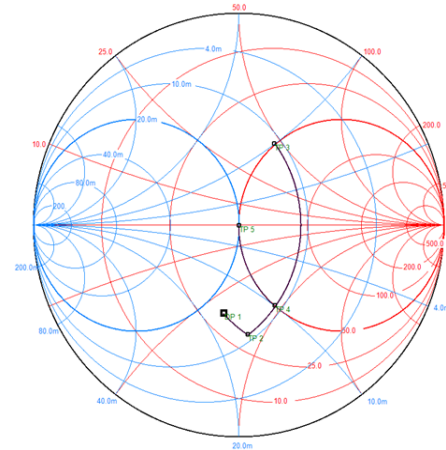


04 Changes and Improvements

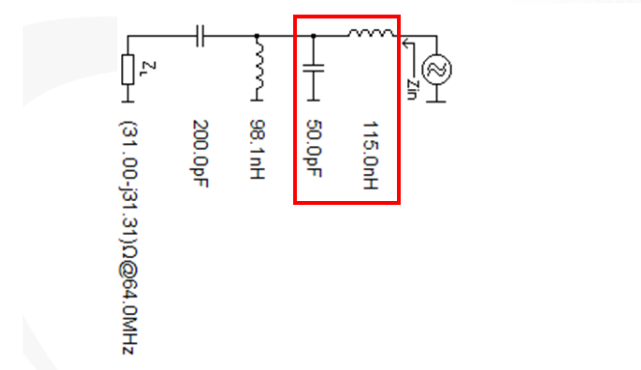
» Impedance matching box



Stub-line inductor

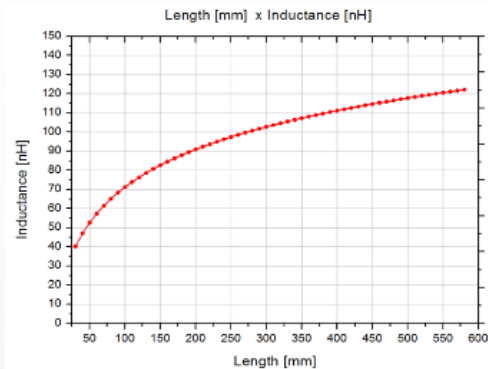
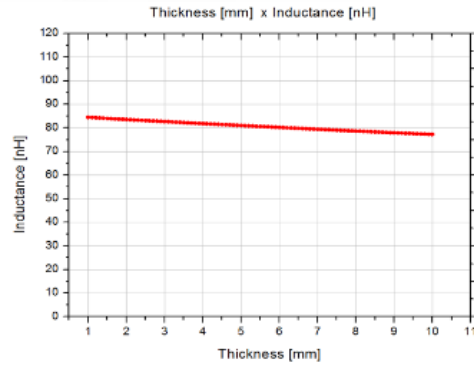
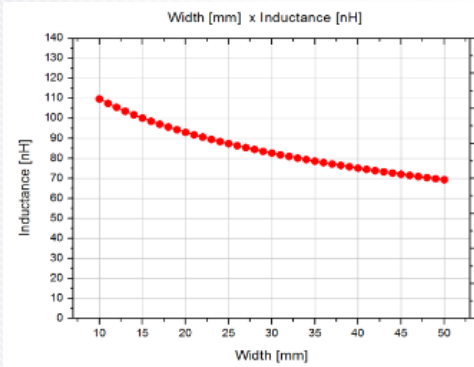


Smith Chart: Impedance matching box

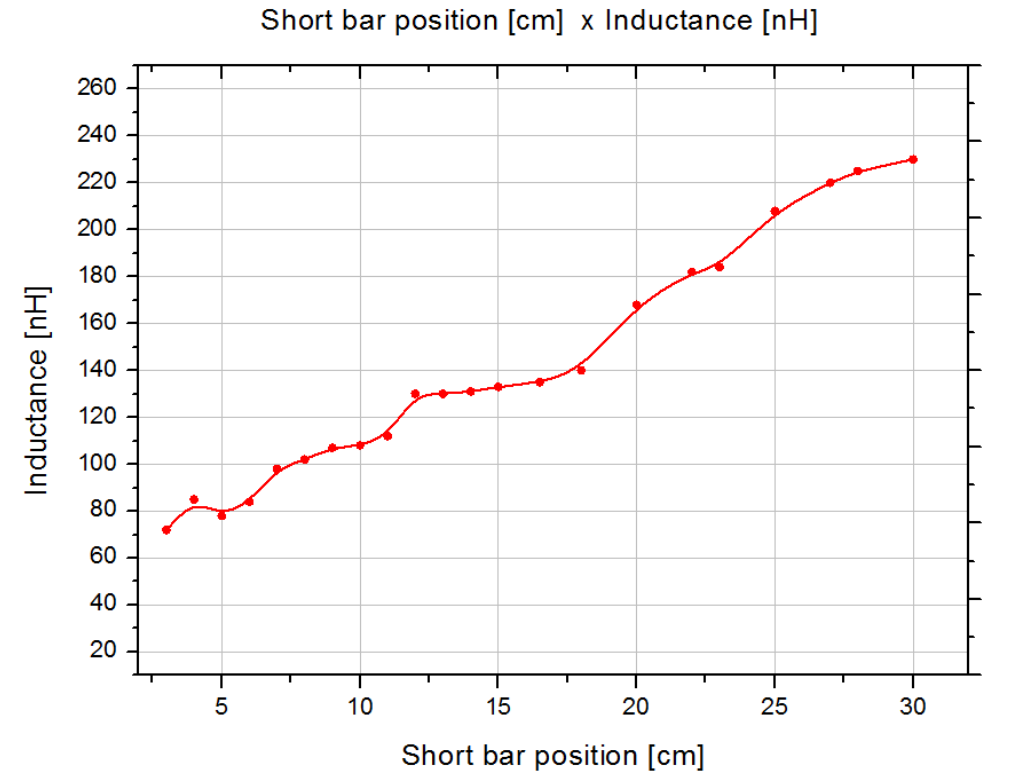


04 Changes and Improvements

» Impedance matching box



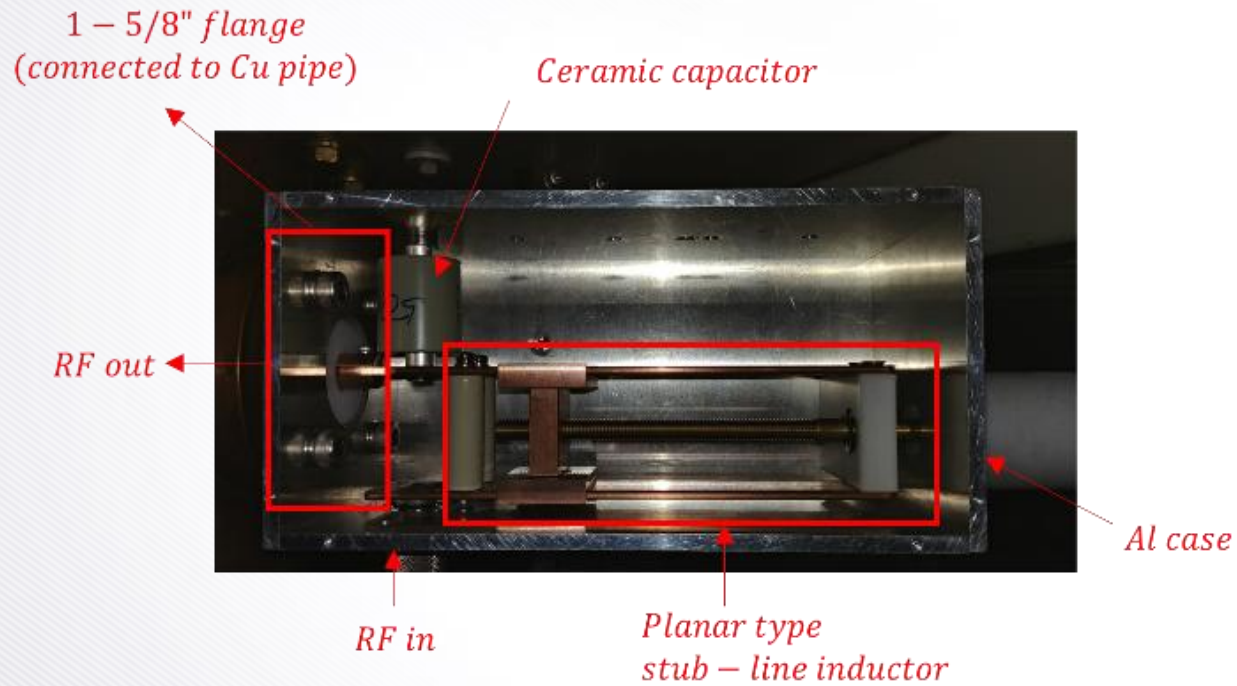
Stub-line inductor simulation (width, thickness, and length)



Measurement of inductance of stub-line inductor

04 Changes and Improvements

» Impedance matching box



Impedance matching box structure



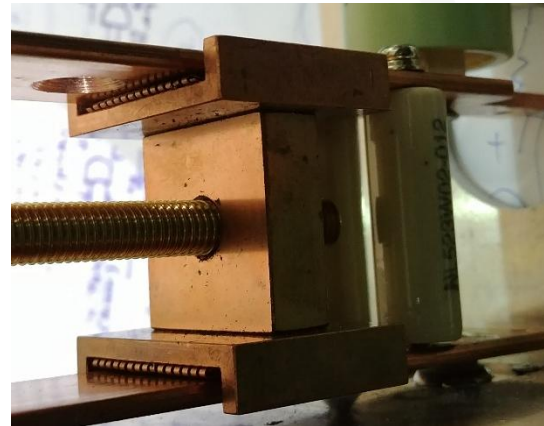
Output connector (Brass)

04 Changes and Improvements

» Impedance matching box

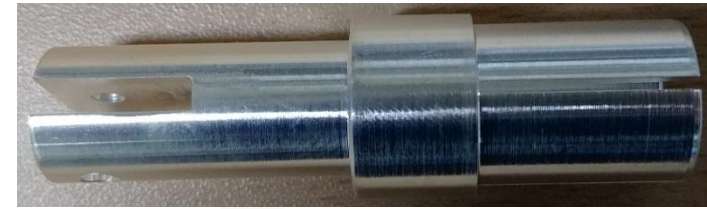
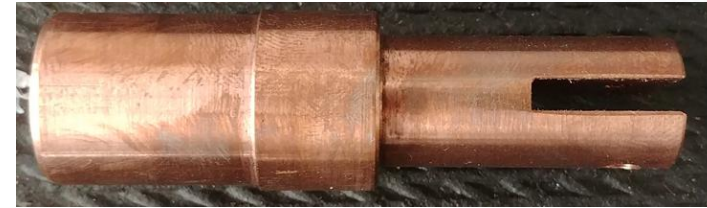
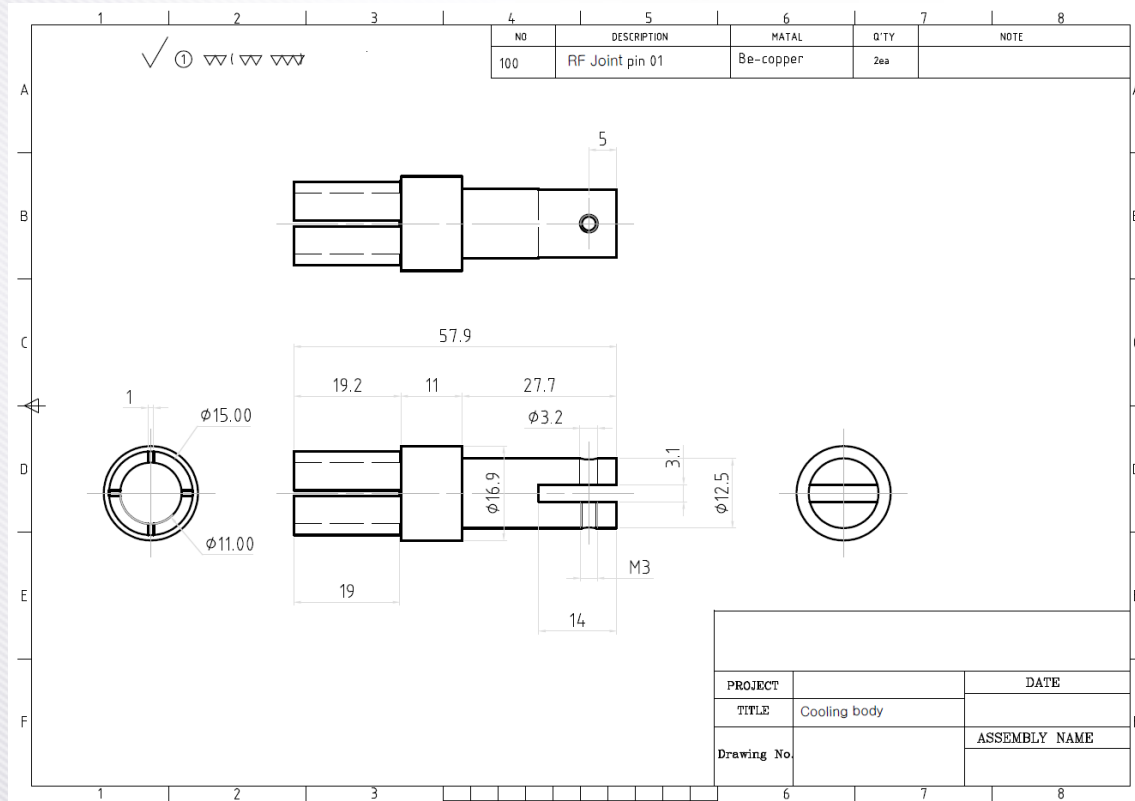
Problems:

- Stub-line inductor is not tightly fixed
→ the structure is tilted to one side
- Output connector material: brass
→ low conductivity, possibility of oxidation
- Input connector part is not well manufactured
- Others



04 Changes and Improvements

» Impedance matching box



- Connector material: BeCu, BeCu+Ag plated

SG Condition: 950 mVpp, duty: 20 %

-> forward power increased by 10 % (1.6 kW -> 1.8 kW)

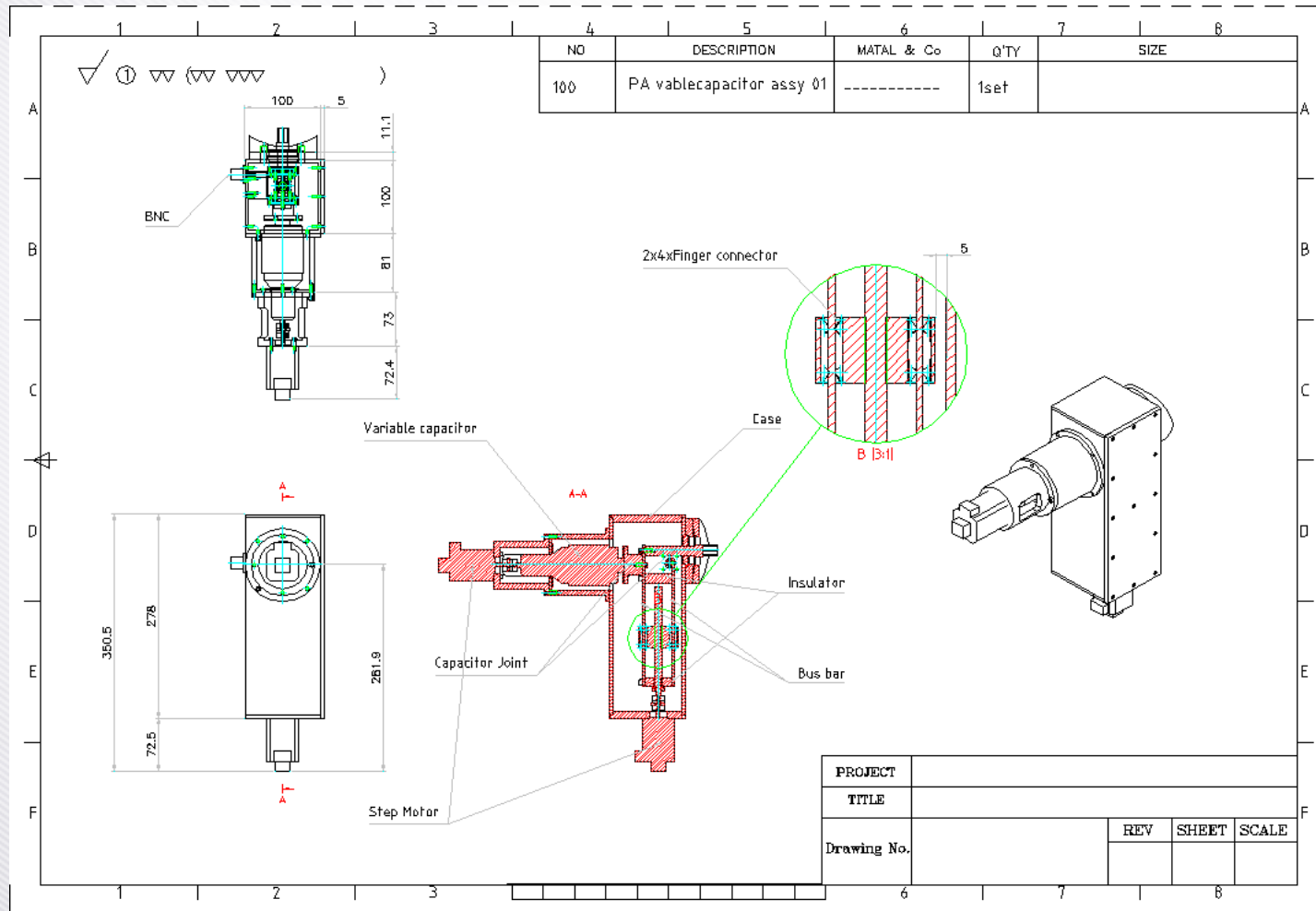
-> Clear RF pick-up signal

More performance expected using BeCu+Ag plated connector

Only variable inductance, variable capacitance needed!

04 Changes and Improvements

» Impedance matching box



✂ Manufacturing on progress

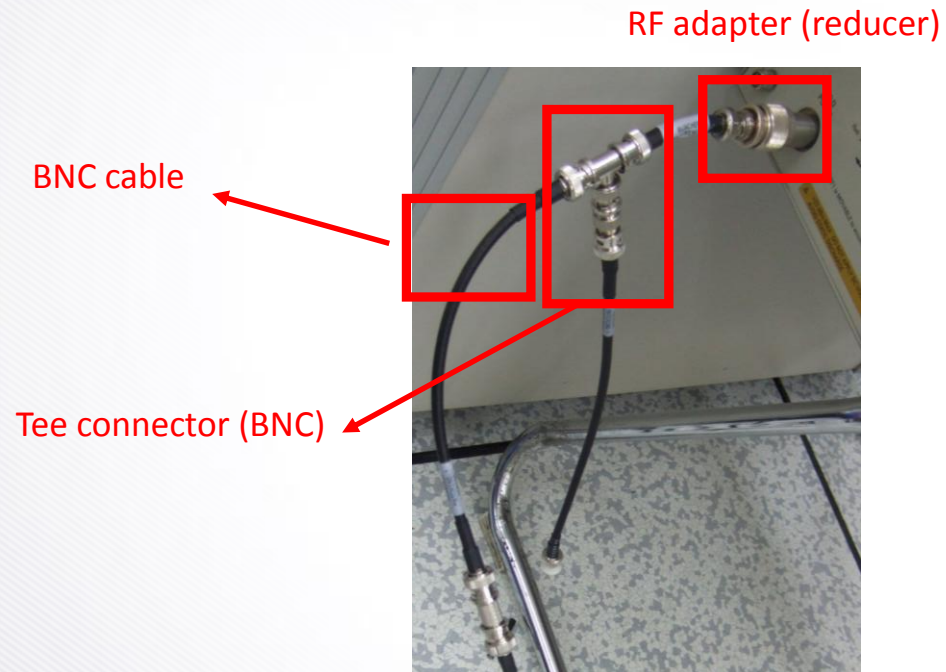
Try to improve RF characteristics as well as mechanical and electrical properties

Features:

- VVC (Vacuum Variable Capacitor)
- Real-time motor control (position, direction)
- Control program

04 Changes and Improvements

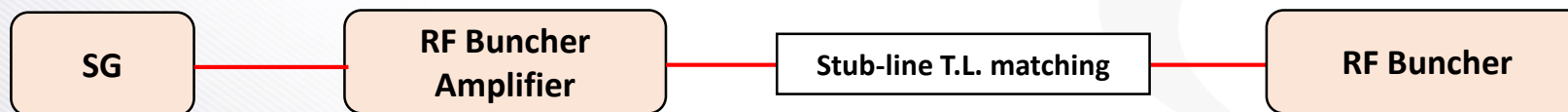
» Transmission line matching



Problems:

- Not enough cable length margin (from buncher amplifier to RF buncher)
- Mechanical tension gives higher resistivity, higher cable loss
- Unnecessary RF adapters (reducer, cables)
- Thermal loss at tee connector and BNC cable (50°C), when operating 2-3 hours

* Optimization of impedance matching appropriate use of cable is required

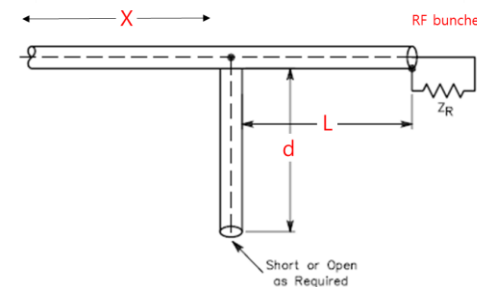
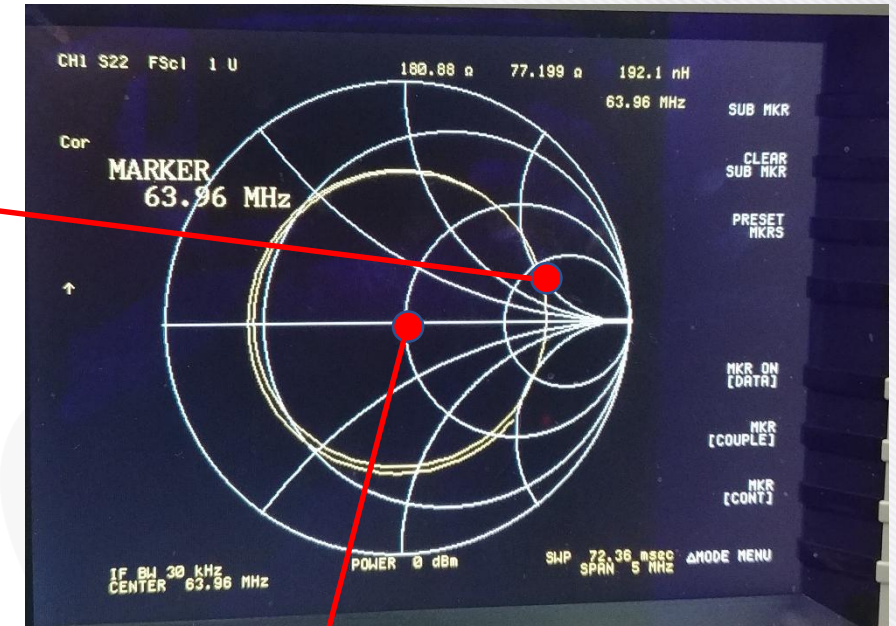


04 Changes and Improvements

» Transmission line matching

- Redesign and manufacture the transmission line
- Lengthen 4.6m RF cable: same impedance
- Two possible solutions (calculation)
 1. $L = 57.1 \text{ cm}$ (0.1975λ), $d = 99.3 \text{ cm}$ (0.34λ)
 2. $L = 99 \text{ cm}$ (0.1975λ), $d = 45.6 \text{ cm}$ (0.1575λ)

Reference point (load impedance, 4.6m)



Ref VF (RG-213) = 66 %
 Measured VF (RG-213) \approx 61.89 %
 $\lambda = 2.896 \text{ m}$
 $S_{21} \approx -0.5 \text{ dB}$ (10 % loss)

04 Changes and Improvements

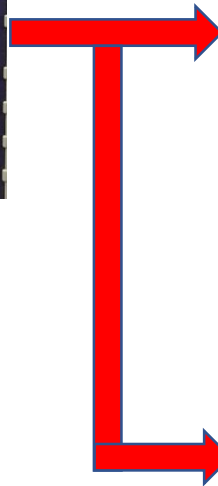
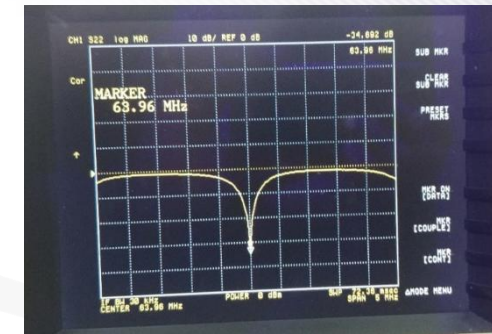
» Transmission line matching

Reference point: existing cable + 4.6 m RF cable

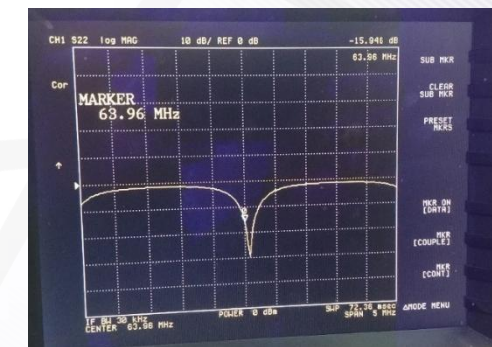


Load impedance

Solution 1)



Solution 2)



Sol 1): $L = 61$ cm, $d = 108$ cm

Sol 2): $L = 102.5$ cm, $d = 54.5$ cm

Calculated value

Sol 1) $L = 57.1$ cm, $d = 99.3$ cm

Sol 2) $L = 99$ cm, $d = 45.6$ cm

Length variation (1st),

distance variation (2nd),

04 Changes and Improvements

» Transmission line matching

- Cable: RG-58 -> RG-213
- Connector: BNC type Tee connector -> N type Tee connector
- Choose 2nd solution with open-stub

Network analyzer measurement

S11: -25 dB @ 63.96 MHz

L: approx. 101 cm, d: 49.6 cm

RF test (Over 3 hour beam irradiation)

Less heat generated (around 30 degree on surface)



05 Summary

» Summary and Future work

- Numerous Amplifier Failure Modes have been observed and studied
- Improvement has been made over the time and much better reliability has been achieved
- Impedance matching box connector was revised and 10% increment of low power has been seen. A new matching box manufacturing is on progress
- Transmission line matching between buncher amplifier and RF buncher was conducted and showed S11: -25 dB. Less heat generated during 3 hour beam irradiation
- Analyze and redesign IPA, PA Cathode and anode Impedance matching
- Long-term RF test needs to be conducted
- Solid-state RF amplifier
- Others

Some Failures



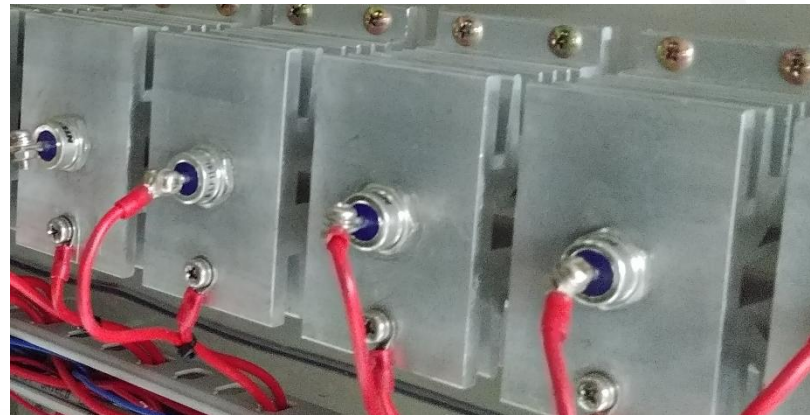
MCCB malfunction



Kapton film



Cooling hose



Zener diode



HV connector

THANK YOU

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