



# Indian Institutes and Fermi lab Collaboration (IIFC) for project X

Development of 325 MHz Solid-State RF  
Power Amplifiers for Project X,  
under Addendum-V of IIFC

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- ❖ At BARC, we have been working on Radio Frequency (RF) systems for various scientific applications including accelerator. Simultaneously, as a technology development program, BARC had started design and development of 'Solid State RF Amplifiers' So, it was decided to continue our work under the collaboration for project X also.
  - ❖ The solid-state radio frequency (RF) power amplifier has several advantages over the tube amplifiers. These are mainly,
    - High reliability,
    - Simple start-up procedure
    - Graceful power degradation
    - Easy maintenance
    - Low voltage operation
    - Simpler cooling requirements
    - Use of low power circulators.

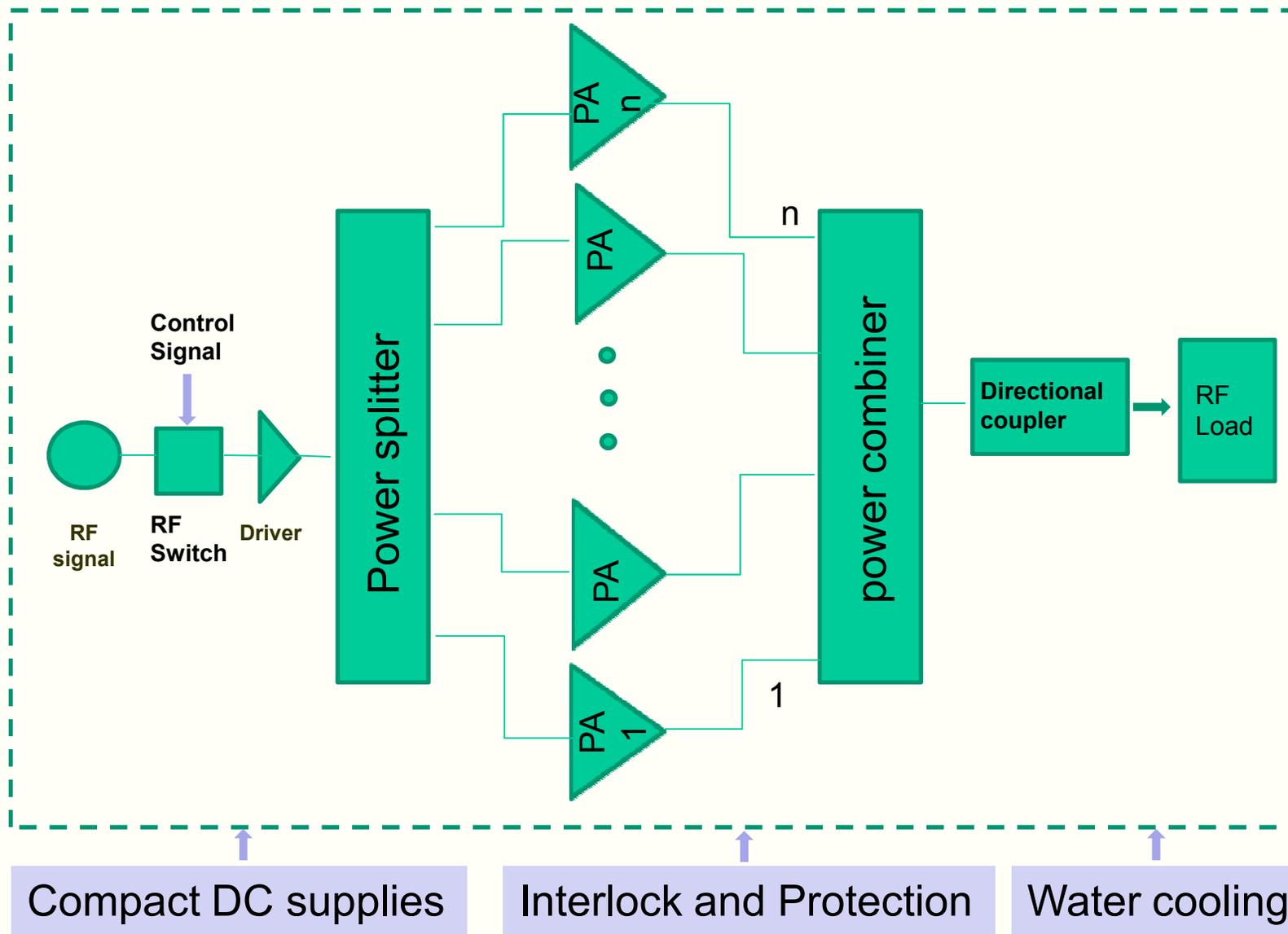
- Deliverables under the collaboration

- A. 1 kW, 325 MHz, solid state power amplifier (SSPA)
- B. 3 kW, 325 MHz, solid state power amplifier (SSPA)
- C. 7 kW, 325 MHz, solid state power amplifier (SSPA)

A solid state power amplifier (SSPA) comprises of:

1. SMPS DC power supplies
2. Driver amplifier
3. RF amplifier modules
4. Input splitter
5. Output combiner
6. Directional Coupler
7. Interlocking & protection circuit

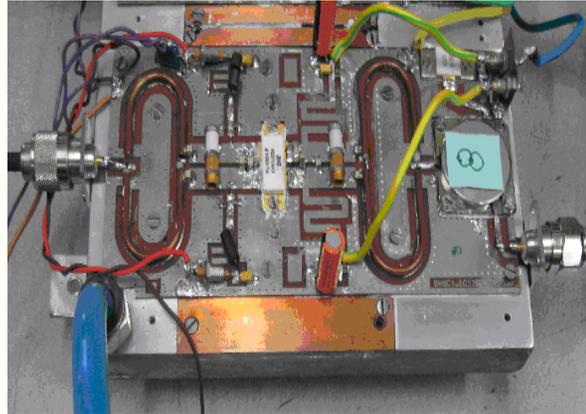
# Architecture of SSRFPA



Initially, we started with technology development of the most important basic building blocks of SSPA, i.e.

- 1) High efficiency RF amplifier power modules (1 kW) and
- 2) Power combiner /divider technology at various power levels.

## Initial development of SSPA



RF module 300 W at 350 MHz

Initially, as a part of technology development, a basic 300 Watt RF module at 350 MHz was developed.

Four such modules were developed and combined to develop 1.1 kW RF amplifier

Another eight such modules were developed and combined to develop 2.1 kW RF amplifier.

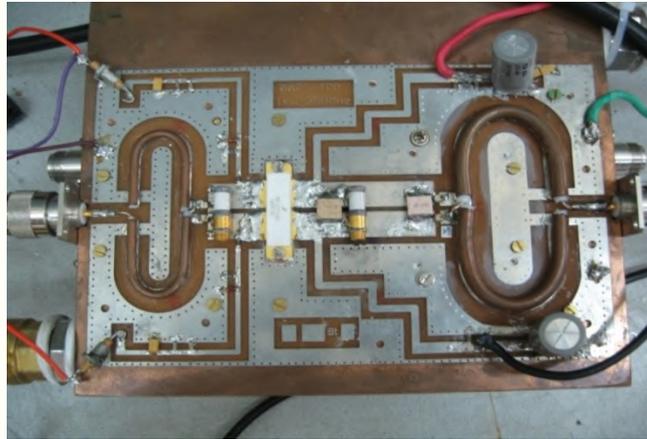
Then, 325 MHz, 1 kW Amplifier modules has been designed. Substantial investigation was done using different laminates based on their properties like dielectric strength, thermal conductivity etc.

RFPAs were developed in three types of printed circuit boards (pcb) material (laminates) as,

- a) FR4
- b) Ceramic filled PTFE and
- c) Glass microfiber reinforced PTFE

## A) 1 kW, 325 MHz SSPA: Test results

### a) 325 MHz Amplifier- FR4 –Single module: Results:



RF module 1000 W at 325 MHz

Short time test (1/2 hr) : 1 kW

Long term test (8 hrs) : 800 W

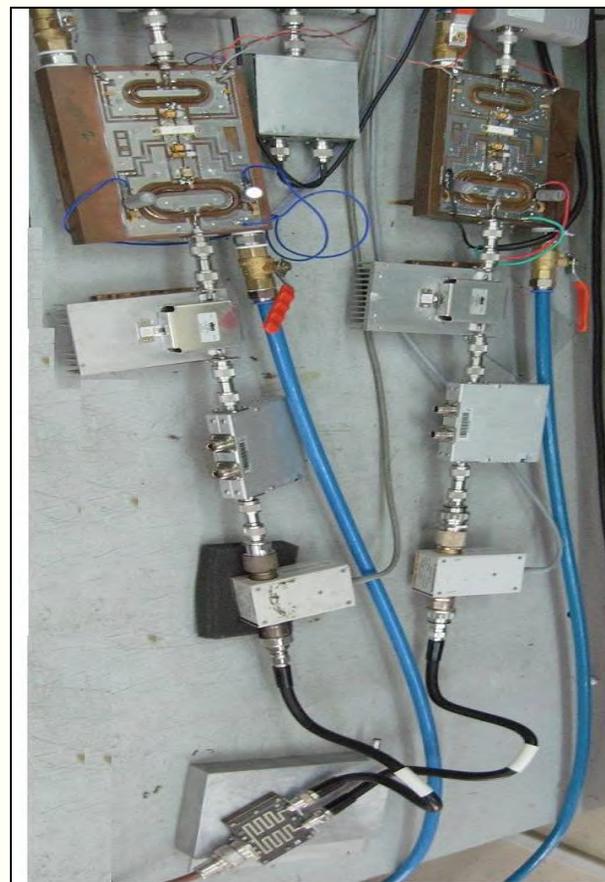
Power gain (1 dB) : 19.5 dB

Overall Efficiency : 68 %

- As a first prototype, two such FR4 boards, each board operating at 600 W were combined.

### Test Results

1. Power: 600 W /module
2. 2 modules of 600 W each and are combined
3. 2-way micro strip combiner
4. Overall power gain: 19.8 dB
5. P<sub>total</sub>:1.04 kW
6. Efficiency (DC/RF) : 62.7 %



Combined RF system under test

## A)1) 1 kW, 325 MHz SSPA

These two tested FR4 boards are now housed back to back on one single water cooled heat sink and in one single rack along with all other associated components like,

1. SMPS DC power supplies
2. Driver amplifier
3. RF modules
4. Input splitter
5. Output combiner
6. Directional Coupler
7. Interlocking & protection circuit

Size: 19" 6U rack

This total RF system has been tested with the following parameters :

1.  $P_o$ : 1005 watt
2. Efficiency (DC/RF): 65.26 %
3. Combined Gain (2 modules): 19.28 (dB)
4. Efficiency (AC/RF): 58.05 %

## A) b) 325 MHz Amplifier- ceramic filled PTFE laminate based board



1 kW RF module test set up

Another RF module based on ceramic filled PTFE laminate was designed, developed and tested.

### Test results of 1 kW RF module

1. Center frequency : 325 MHz
2. Power output (CW) (max.) : 915 W
3. Power output (CW) (typ.) : 893 W
4. Gain (typ.) : 22.8 dB
5. Cooling : Water Cooled
6. Efficiency (DC/RF)(PAE): 71.04 %
7. Efficiency (AC/RF) : 63.94 %

- Now, two such boards have been tested up to 900 Watt each.
- These are mounted back to back on one single water cooled heat sink.
- These will be operated at around 600 to 700 watt each and then combined via power combiner to get 1 kW+ power.



## A) c) 325 MHz Amplifier- glass microfiber reinforced PTFE laminate based board

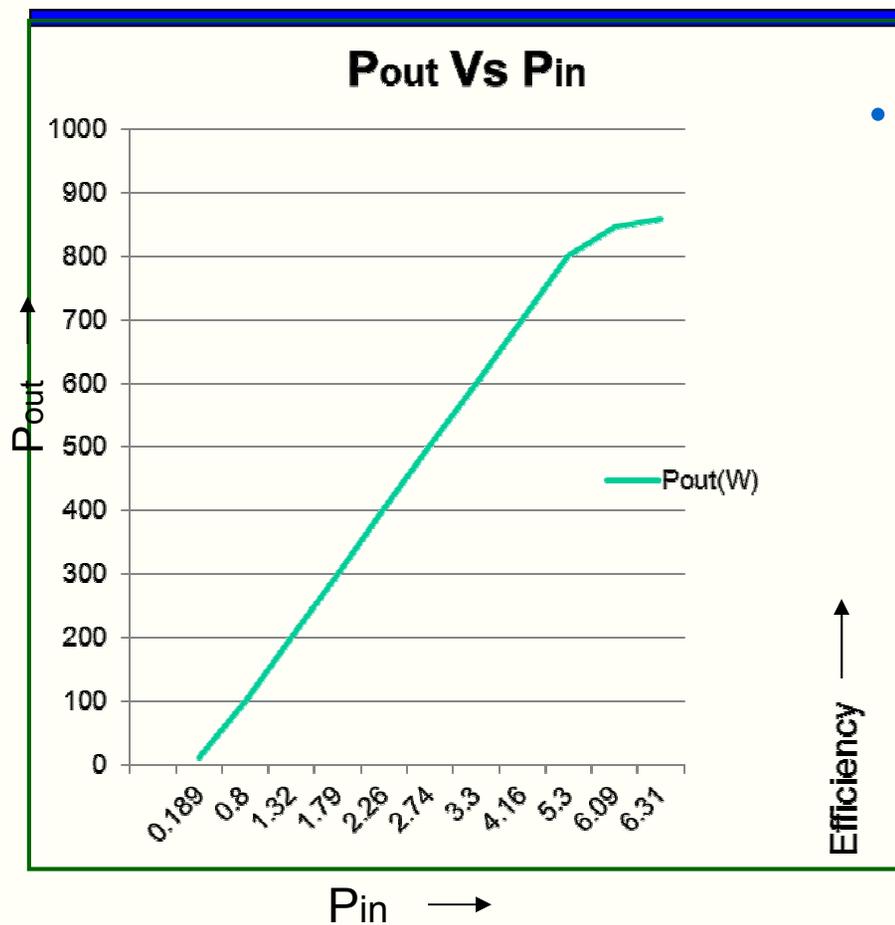


Initially one prototype board using PTFE based high frequency laminate was tested but experienced some problems. After taking remedial measures, then two more RF boards with improved design have been tested with following parameters:

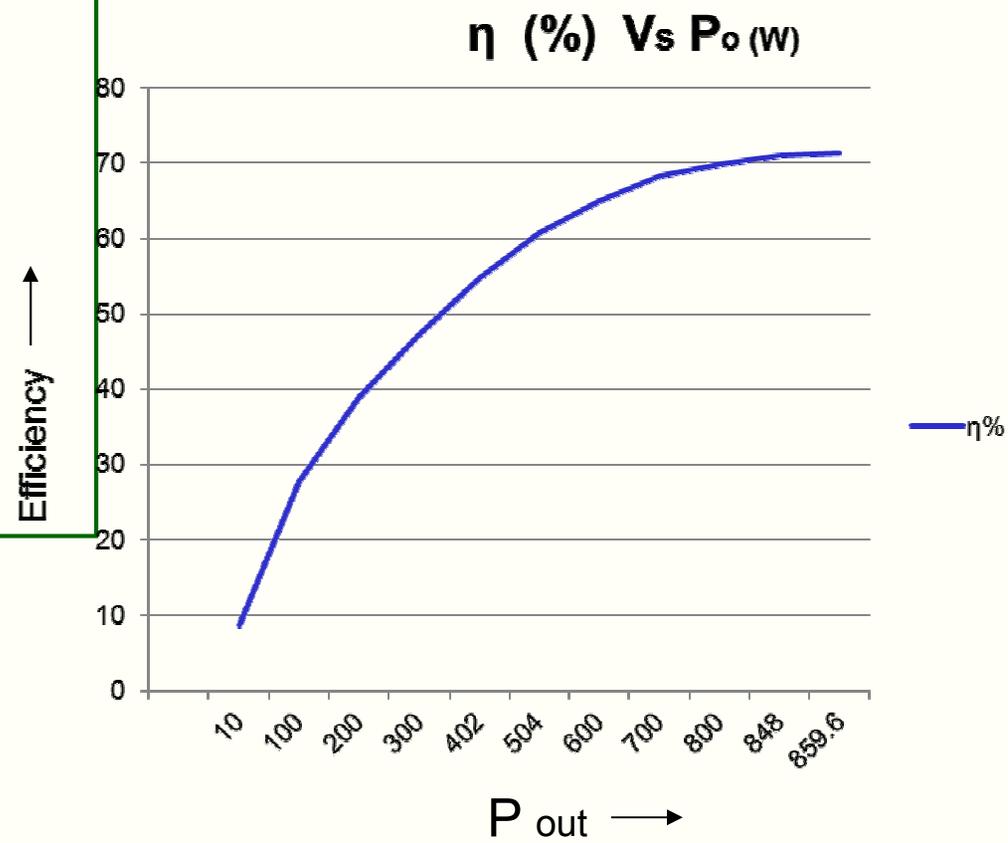
1. Center frequency : 325 MHz
2. Power output (CW): 800 W
3. Gain : 21.85 dB
4. Cooling : Water Cooled
5. Efficiency (PAE)(DC/RF) :69.41 %
6. Efficiency (AC/RF) :62.5 %
7. Gain variation: 0.165 dB @ 800 watt and for 5 Hrs.

These boards will be used in 3 kW RFPA.

## Graphs of one of the RF module tested



- Gain variation: 0.165 dB @ 800 Watt and for 5 Hrs.



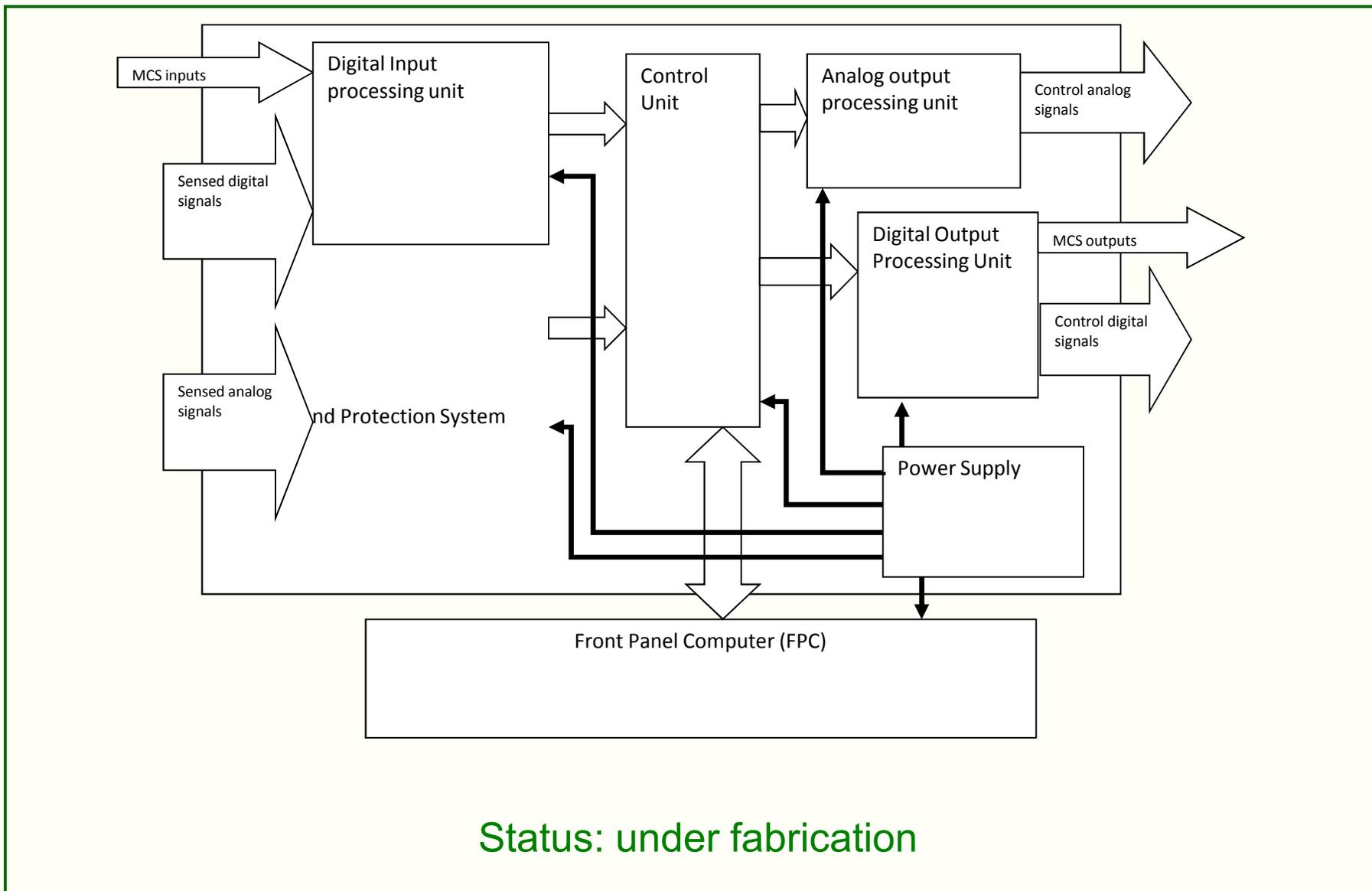
# Comparison of Specifications

Main Specifications	Fermi Lab specs	FR4 (BARC)	Glass microfiber reinforced PTFE (BARC)	Ceramic filled PTFE (BARC)
Center frequency (MHz)	325	325	325	325
Power output (W)	1000	1005 (2 modules combined)	800 (single module)	893 (single module)
Power Gain (dB) (Overall)	60	62 ( individual module19.28)	64 ( individual module: 21.85)	65 ( individual module: 22.82)
Efficiency(AC/RF) (%)	> 60	58.05	62.5	63.94
Thermal/Heat transfer efficiency	--	Poor	Good	V. Good
Other RF and non RF parameters	--	--	Not yet tested. These will be tested after integration of total RF system.	Not yet tested. These will be tested after integration of total RF system.

## Interlock and Protection for SSRFPA

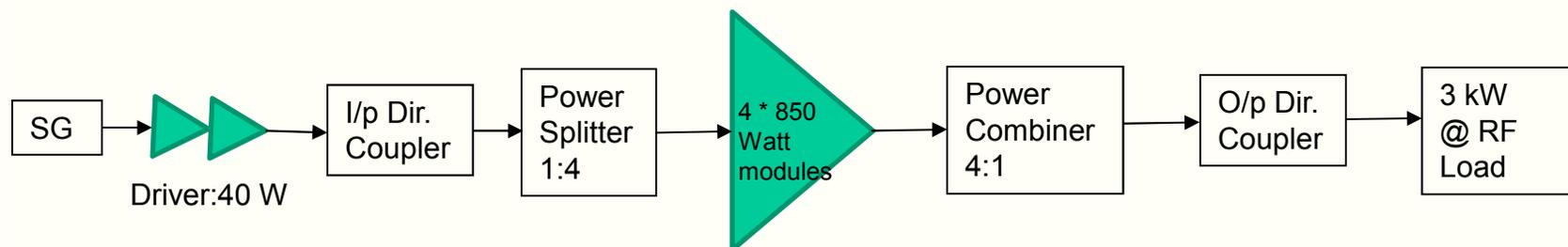
This system consists of circuitry required for processing number of process parameters obtained from the 1 kW RF system and generation of interlock and protection signals for it. It also includes communication interface signals for Main control system (MCS) and for the User Interface(FPC). As this system is used in high power RF environment, due consideration is given in enclosure design, circuit design and choice of components for mitigation of RFI related issues especially at the operating frequency of 325 MHz The system has 11 digital inputs, 27 analog inputs, 4 analog outputs and 5 digital outputs. A few signals (mutually decided) will be exchanged with the main control system of the accelerator

# Interlock and Protection for SSRFPA



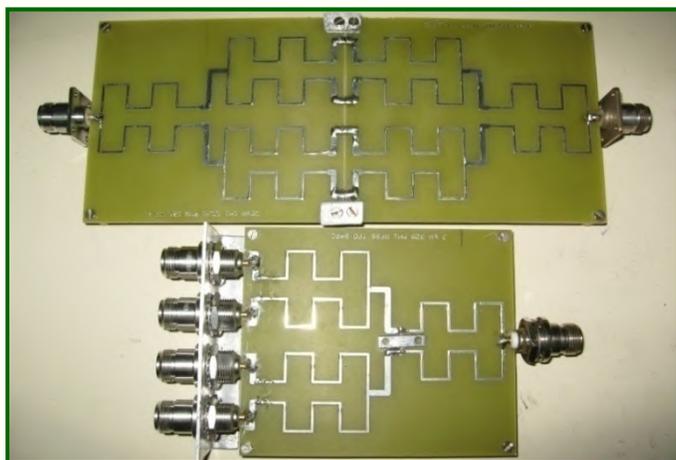
## B) 325 MHz, 3 kW SSRFPA

- Overall design of 3 kW, 325 MHz SSRFPA has been completed.
- Material procurement and fabrication of sub systems is mid way.
- Four RF amplifier modules (glass microfiber reinforced PTFE laminate based board, as in slide 8) have been tested up to 900 Watt (max) and 850 Watt (typ).



# Power Divider Combiner(PDC)

- Its input splitter (1:4) has been fabricated and preliminary testing is being done.
- Return Loss at i/p ports:  $> 20$  dB
- Return Loss at o/p ports:  $> 25$  dB
- Isolation among the ports:  $> 25$  dB
- Design of 4 way output combiner is complete and fabrication of first prototype is almost complete
- Directional coupler and interlock circuit is under design.



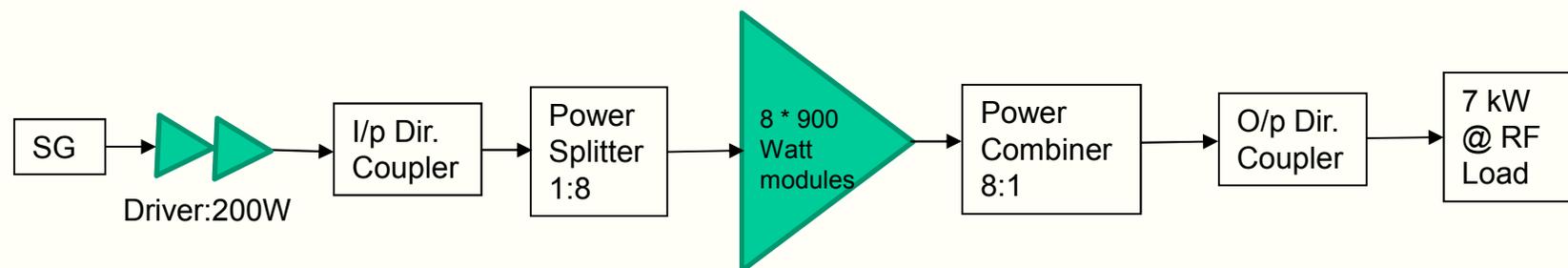
input splitter (1:4)



Output Power combiner of 3 kW rating is similar to this picture

## C) 7 kW, 325 MHz SSRFPA

- Design of 7 kW, 325 MHz SSRFPA has started
- Design of combiner/splitter, directional coupler is complete and is under fabrication. Interlock and protection circuit under design.
- Based on experience of earlier 1 and 3 kW RF systems, a decision on use of type of RF modules will be taken.



# Summary

- Research on main building block of system i.e. RF power module is almost over. Overall system integration for 1 kW system has started.
- For 3 kW system, partial development of subsystems is in the process.
- For 7 kW RF system, design is almost complete.

## RFSS Team

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2. Mr. B.V.R.Rao
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7. Mr. M. Thapad



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THANK YOU !