

# HIGH POWER AMPLIFIER SYSTEMS FOR SARAF PHASE II

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### Abstract

Soreq NRC initiated the establishment of SARAF- Soreq Applied Research Accelerator Facility. SARAF is based on continuous wave (CW), proton/deuteron RF superconducting linear accelerator with variable energy (5-40 MeV) and current (0.04-5 mA). RF power to each cavity is driven by a High Power Solid State Amplifier. The paper outlines the design concept of 10 and 15 kW at 176 MHz power amplifiers. 10 kW amplifier was successfully tested at the beginning of 2012. 15 kW system is now under final design stage. The amplifiers are combined from basic 5.5 kW compact 19" 7U water cooled drawers.

### INTRODUCTION

The paper describes the basic 5.5 kW amplifier drawer and method of building and construction of High Power amplifier systems. The need of High Power Amplifiers appears when the 6 exiting 2 kW 176 MHz amplifier built by "Accel" for Prototype Cryogenic cavities limits to rise the current of the accelerator. The 4 kW amplifiers were designed and built to exchange the 2 kW.

The 5.5 kW is designed and built for future design of high energy cavities for the Phase II project.

### BASIC 5.5 kW RF POWER AMPLIFIER

The 5.5 kW High Power Amplifier (HPA) consists of following sub modules and components:

- 4 double 800 W water cooled RF modules.
- 8 ways 100 W RF Power Splitter.
- 8 ways 5.5 kW RF Power Combiner.

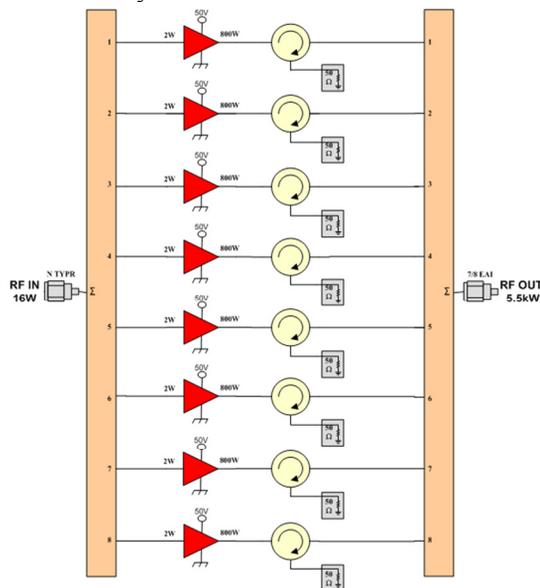


Figure 1: 5.5 kW block diagram.

### 800 W RF Power Module

The power amplifiers are attached to opposite sides of a joint heat sink to reduce separate water cooling and optimize the design. This permits to enter in very small volume 100x200x350 mm. Each amplifier delivers 800 Watt P1dB CW RF power. The amplifiers are protected by two circulators and two 800 Watt RF resistors. This permits safe operation with full reflected RF power.

The following control signals are available from each amplifier:

- C max, normally high, low in case overheat.
- Temperature measurements, 10 mV / deg C.
- REF Power Detector Pout@800W 40°C-1.5v.
- FWR Power Detector Pout@800W40°C-1.5v.

This signals permits to monitor the status of each amplifier in the drawer.



Figure 2: The double 800 W amplifier module view.

### 8 way 100 W RF Power Splitter

The splitter divides the driver's RF power into 8 equal signals to drive each of eight Power Amplifier modules up to 800 Watt. The splitter is designed by micro strip line technology and is mounted in aluminium milled case. The splitter was computer simulated and has very low loss and good matching. The RFin connector is N-type and 8 output connectors are SMA type.



Figure 3: 8 way 100 W splitter (divider) view.

### 8 way 5.5 kW RF Power Combiner

The RF Power Combiner is summing the RF power of 800 Watt from 8 modules and applies the 5.5 kW into the output connector of the Combiner. The Combiner is built as a quarter wave air dielectric coaxial line technology. The combiner model was simulated using RFSim99 and has extremely low insertion loss (0.15 dB) and very good matching on the operating frequency 176 MHz. The 8 input connectors are special N-type – low loss and high power. The 7/8" EIA output connector is the part of the air dielectric coaxial line. Input to output port ratio is measured 9.03 dB; and returned loss is 66 dB at 176 MHz.



Figure 4: 5.5 kW 8 way Combiner view.

### 5.5 kW HPA RF conceptual diagram

The RF conceptual electrical diagram is shown on Fig. 1. RF input from driver is connected to the RFin on the rear panel. The RF cable delivers the 16 W driving signal to the N-type input of the 8 way RF Power Splitter. The Splitter divides 16 W into 8 equal 2 W signals. The equal length (phased) RG223/U cables connect the output SMA connectors of the RF Power Splitter to the RF input SMA connector of the eight RF Power Modules. The equal length (phased) H2000 cables connects the output N-type connectors of the RF Power Modules to the N-type input connectors of the RF Power Combiner. The 5.5 kW RF output connector 7/8" EIA is built in into RF Power Combiner. The Combiner is mounted on rear panel of the drawer, so that the connector is the Output Connector of the Drawer.

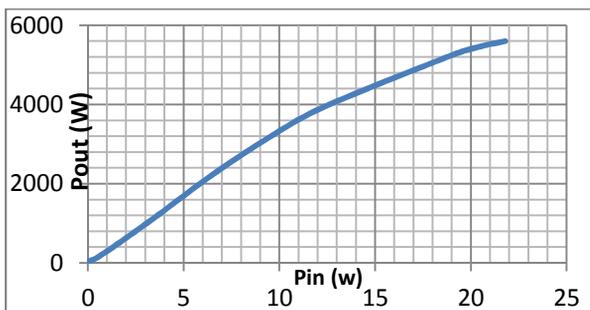
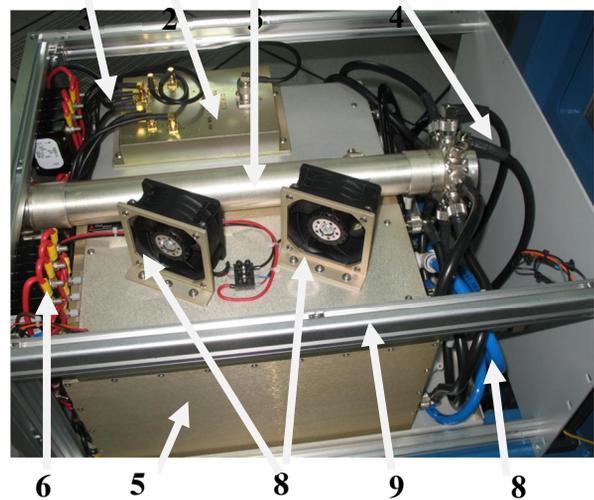


Figure 5: 5.5 kW drawer power test data graph.

### 5.5 kW HPA Drawer Assemblies

The 4 double RF power modules, RF Splitter, RF Power Combiner and some other components are assembled in 19" 7 U 550 mm long drawer. The drawer is purchased as a Kit. The front panel, rear panel and the mounting chassis were reconstructed. The Front panel includes: DC ON green Led, Fault red Led, water coolant quick pipe connectors and drawer handles. The Rear panel includes: 8 x 30 Ampere Breakers for current protection of 8 amplifier modules, N-type "RF in" connector, 7/8" EIA RF connector "RF output", DC Input bolts +/-50VDC, 200 Ampere with protection cover and control D-type connector. Four RF Double Power modules are mounted on chassis one aside one. Two six mm aluminium plates are placed on each two modules. One plate is the base of the splitter. Another is a base for two fans for air cooling of the combiner. The combiner is mounted on the rear panel and has two supports on each plate. The 12 mm plastic tubes connect the RF modules inlet and outlet with the water dividers 1:4, mounted on the front panel. Equal (phased) input RF cables RG223/U connects the input SMA connectors of the modules to the outputs of the splitter. The RF outputs of the modules are connected with equal (phased) H2000 cable to the combiner's N-type inputs.



1. RF power splitter
2. RF power combiner
3. RF input RG232/U phased cables (equal length)
4. RF output H2000 phased cables (equal length)
5. Double 800 Watts module
6. 30 A DC breakers
7. Fans
8. Water coolant distributing pipes
9. Drawer aluminium frame

Figure 6: Inside view of the 5.5 kW drawer.

### 10 kW RF AMPLIFIER SYSTEM

The 10 kW system is built by combining the RF power from two 5.5 kW drawers using 3 dB 90° High Power Quad Hybrid Coupler (HPQHC). The HPQHC requires 90° shifted signals so the kind coupler, but 100 W, is used as a splitter between the driver and the inputs of

the 5.5 kW amplifiers. The conceptual electrical diagram is presented in Fig. 7.

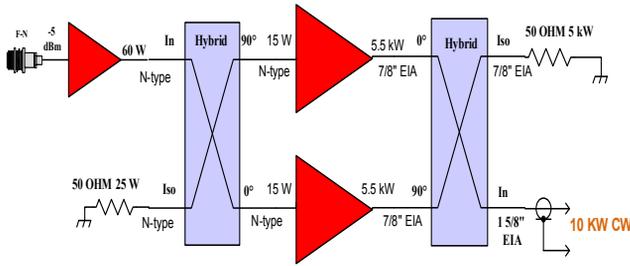


Figure 7: 10 kW HPA conceptual diagram.

The two amplifier system required a single 60 Watt driver. The driver is built from 100 Watt pallet with 2.5 Watt hybrid amplifier as the first stage. The total gain is 48 dB, so 0 dBm is enough to get the required 10 kW. The driver has a circulator in the output for better matching.



Figure 8: 60 W Driver inside view.

The driver case is mounted on cooper water cooled plate and has a thermal switch disconnecting voltage of the pallet and the hybrid if the temperature riches 50° C. The system is mounted in 25" 48 U Rack. Two 5.5 kW drawers, two 12 kW power supplies and Driver occupied 1/2 of 19" inner cage. The combiner and splitter are mounted on the sides of the 19" cage, as well as the cooling PVC pipes and valves. Two 10 kW systems will be installed in total 48" rack. The mains distributing board is mutual for two systems. First 10 kW system is recently tested and shows good linear results. See test data graph Fig.9.

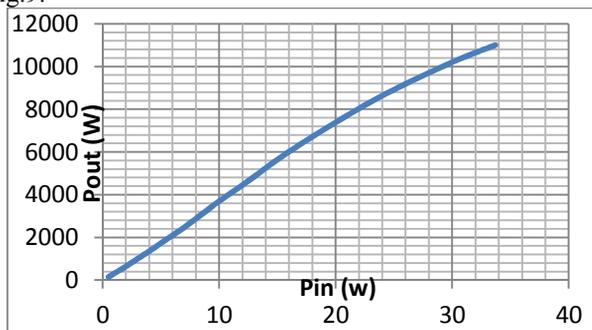
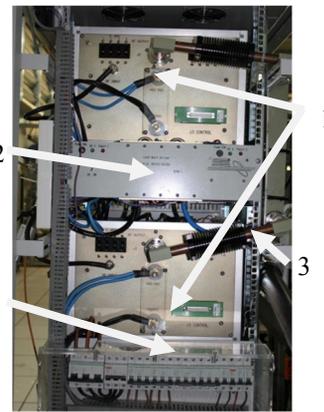


Figure 9: The 10 kW system test data graph.



- 1 – 5.5 kW amplifier drawers
- 2 – 60 W driver
- 3 – 3 dB 90° hybrid combiner
- 4 – Mains electric board

Figure 10: 10 kW Amplifier system view.

### 15 kW RF AMPLIFIER SYSTEM

The 15 kW system is built by combining the RF power from three 5.5 kW drawers using 3:1 RF Power combiner.

The combiner is in phase type and has very low loss 0.3 dB and good isolation 22 dB. The electrical diagram is presented in Fig 11.

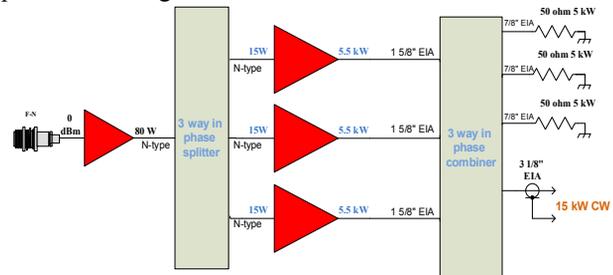


Figure 11: 15 kW HPA conceptual diagram.

The three amplifier system requires a single 80 Watt driver. The same driver as in 10 kW systems is used. The in phase type 1:3 splitter is installed in the driver 19" 2 U drawer.

The 15 kW system is installed in 25" 48 U Rack. Three 5.5 kW drawers, three 12 kW power supplies, Combiner and Driver occupied the total height of the 19" inner cage of the Rack. The inlet and outlet cooling pipes are on the sides of the cage. Equal length 1 5/8" rigid coaxial lines are connecting the Combiner with the RF output connector of the 5.5 kW drawers. Three 5 kW water cooled resistors mounted direct on the 7/8" EIA connectors in the rear of the combiner. The 3 1/8" EIA output connector is in the front of the Combiner and serves as the output connector of the 15 kW system.

### SUMMARY

The 10 kW system is tested and shows good results. The 15 kW system is now under advanced design. The project is very low risk design and production.