THE LAYOUT OF 352 MHz 400 kW RF POWER AMPLIFIER

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Abstract

In this paper, we present the current status of the RF power amplifier under development for European Spallation Source (ESS, Sweden) normal conducting and superconducting accelerating sections based on solid-state architecture. A single 400 kW pulsed machine is represented with four standard 19" cabinets. Brief description and technical solutions regarding 8 kW (Class-AB, Si transistor based) RF modules, different power combiners and control system are shown.

INTRODUCTION

High power RF sources are important elements for most of linear accelerators that have found growing number of applications in science and medicine. Current power amplifier is being designed and developed to fulfil the requirements for superconducting cavities in ESS accelerator facility [1].

Main benefits of the generator under development are its smaller footprint, perspective of lower cost, better reliability and higher efficiency, achieved with class-AB operation, compared to conventional RF power sources like klystrons or other vacuum tubes generators. The solid-state microwave power amplifier modules based on Freescale LDMOS transistors arranged in parallel scheme with use of Wilkinson dividers/combiners are designed on PCB boards.

One machine is planned to be assembled inside set of four 19" cabinets. Each will contain 12 RF power amplifier modules with individual power combiner. All modules are connected to a power combiner with 50 Ohm coaxial cables. The set is terminated with a single common power combiner.

RF POWER MODULES

We have designed and manufactured compact RF power amplifier (RFPA) module prototype. The principal RFPA scheme is shown in Fig. 1. The driver stage is built using Freescale MRFE6VP100H transistor pair. The device is operated in Class-AB. Downstream the driver stage; there is a lumped element 1-to-8 Wilkinson-type splitter with final stage amplifiers at its outputs. All splitter ports have impedances of 50 Ohm.

Freescale MRFE6VP61K25H transistor pairs are being used for the final stage amplifying.

The second Wilkinson 8-to-1 power combiner is located downstream to the final stage amplifiers. The intermediate impedance of this combiner equals to 12.5 Ohms, which results in lower insertion loss. Additionally a lumped element mathing network is used to match the 12.5 Ohm intermediate impedance to output 50 Ohms. In Fig. 2, one of the fabricated RFPA modules is presented.

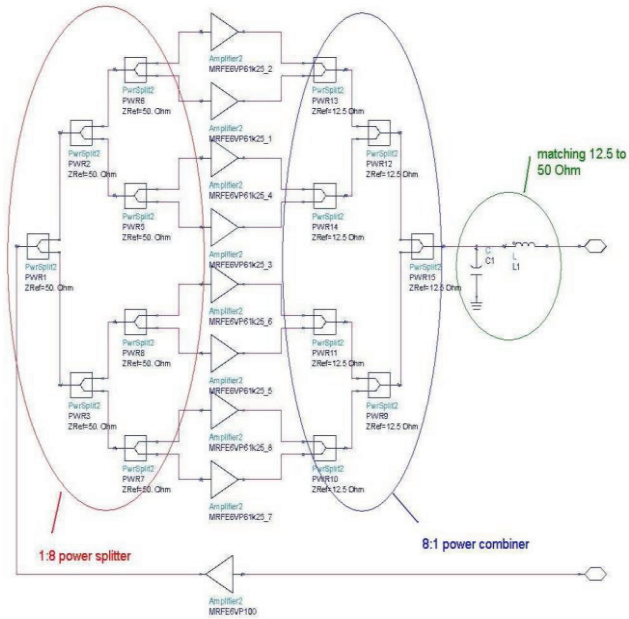

Figure 1: Single RFPA module principal scheme.

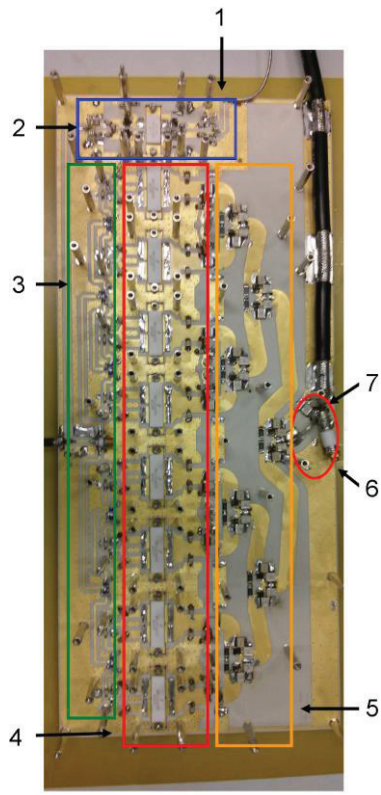

Figure 2: RFPA module: 1 – RF input; 2 – driver stage; 3 – input Wilkinson splitter; 4 – front-end amplifiers; 5 – output Wilkinson combiner; 6 – 12.5 to 50 Ohm matching circuit; 7 – RF output.

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Total efficiency dependence on the output RF power is shown in Fig. 3.

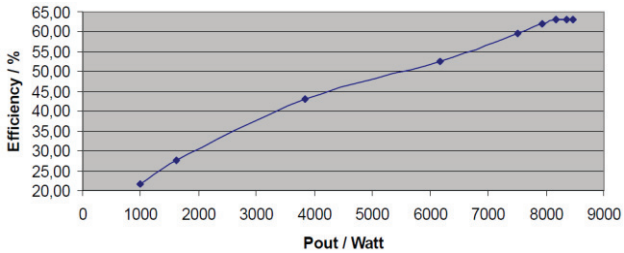

Figure 3: Efficiency vs. output RF power.

This prototype module is lying on a 5 mm thick copper plate that is air cooled, but in future it is planned to replace it with water based heat sink to guarantee heat sink temperature of less than 40°C.

RF performance features of a single RFPA are listed in Table 1.

Table 1: RFPA Specifications

Parameter	Value
Operation Frequency	352.21 MHz
Operation mode	max. 4 ms pulse, 5% duty cycle
Output RF power	8000 W
RF efficiency	~63%
Gain	50 dB
Input RF power	max. 10 W
Supply voltage	50 V
Input/Output impedance	50 Ohm
Dimensions	190×440×80 mm^3

POWER COMBINER

The current amplifier design implies an arrangement of 48 modules (giving required total RF power of 400 kW) in four 19" cabinets with 12 RFPAs and individual 12-to-1 power combiners in each of them. We have designed and fabricated compact power combiner based on rectangular-coaxial line with 12 7/16 input RF connectors and 3-1/8" EIA output flange like shown in Fig. 4. The 12 inputs are arranged in two rows with 6 in each.

The shapes of the copper inner conductor and coupling loops have been optimized to achieve best matching between inputs and 50 Ohm output, low surface fields and equal amplitude and phases of transmission coefficients between every input and output. The inner conductor plate is connected to the same outer case wall on which the inputs are located. This gives an opportunity to easily insert water cooling channels inside this plate as it is the hottest part of the combiner.

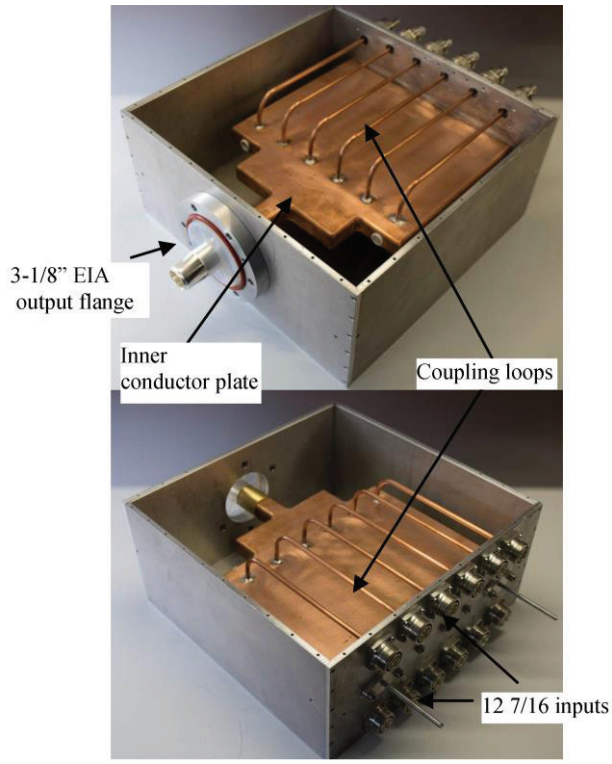

Figure 4: 12-to-1 power combiner prototype.

S11 measurement result referring to the common output port 1 is plotted in Fig. 5; other RF characteristics are listed in Table 2.

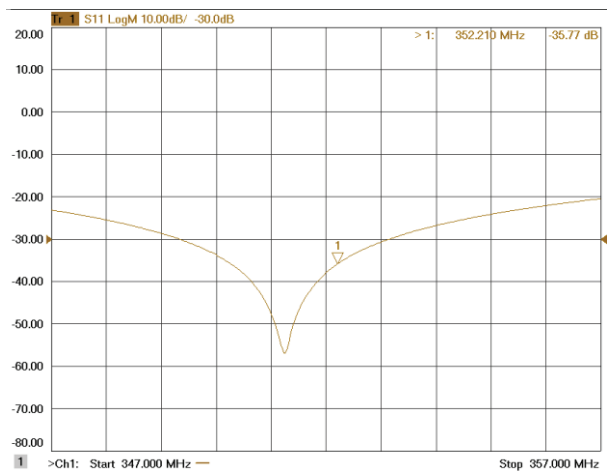

Figure 5: Measured return loss plot.

Table 2: Power Combiner Features

Parameter	Value
Operation frequency	352.21 MHz
Return loss	36 dB
Dissipated RF power ratio	0.5 %
Power splitting equality	~3 %
Dimensions	45×43×16 cm^3

The device showed good performance and can be used in the amplifier. Currently the test bench for high power tests is under development. The next step will be to redesign this combiner so that inputs and output will be on the same side.

GENERATOR FORMFACTOR

All blocks including RFPA modules, power distribution, control, measurement and water-cooling systems will be assembled in four 19" cabinets ending up with a common 4-to-1 power combiner as shown in Fig. 6.

We assume that total height of the final generator assembly would not exceed 42 units (~190 cm) which is less than typical door height.

Figure 6: A row of 4 19" cabinets with common output power combiner.

An arrangement in each cabinet is in the following order from bottom to top: water-flow system, 12 19" racks with RFPAs, control system and 12-to-1 power combiner.

In each rack (see Fig. 7), there is a capacitor bank, supply power distribution system, 2 RFPA modules and water-cooling system with heat exchanger.

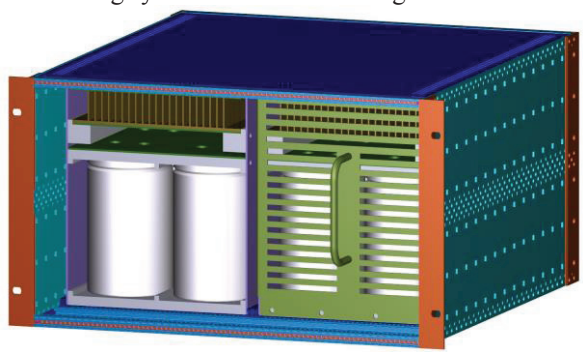

Figure 7: A single 19" rack with 2 RFPA modules arrangement scheme.

As for now the height of the racks is approx. 6 units (~27 cm) and is subject for further ompitimization.

The final 4-to-1 power combiner is assumed to have 4 3-1/8" EIA input flanges and a single 6-1/8" EIA output.

SUMMARY

The 352 MHz 400 kW pulsed machine is now in the design stage. In this paper, class-AB power amplifier modules based on Freescale 50V LDMOS transistors, box-shaped power combiner and the current system topology are described.

We are now working on the flexibility and scalability of the system so that it can be easily adapted to wide variety range of customers requirements on total output RF power, pulse length, duty cycles etc.

REFERENCES

[1] R.A. Yogi, A. Rydberg, et. al., Uppsala High-Power Test Stand For ESS Spoke Cavities, Proceedings of LINAC-12, Tel-Aviv, Israel, 2012.

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