176 MHZ SOLID STATE MICROWAVE GENERATOR DESIGN

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Abstract

This paper concerns the R&D work upon design of a compact RF amplifier to be used for linear accelerators. The machine under development will operate at 176 MHz with output power of 25 kW in continuous wave regime. It consists of 50 push-pull PCB modules (approx. 500W output power each), connected in parallel to several radial filter rings, which both allow class-F operation and combine the power from the modules, delivering it to a single 50 Ohm coax cable. The CST simulations and the design of 324 MHz test prototype are presented.

INTRODUCTION

High power RF sources are important elements for most of linear accelerators that have found growing number of applications in physics and medicine.

The main benefits of the generator under development will be its smaller size, perspective of lower cost, better reliability and higher efficiency, achieved with class-F operation, compared to conventional RF power sources like klystrons. The solid-state microwave power modules based on SiC vJFET transistors arranged in parallel push-pull circuits, will be designed on PCB boards.

All modules will be connected to a power combiner with common output 50 Ohm coaxial cable.

This generator is planned to be a predecessor to the 'big' 324 MHz machine with pulsed RF output power of 3 MW.

RF POWER MODULES

We have designed and manufactured compact RF power modules with one pair of SiC transistors arranged in circlotron topology [1] as shown on Fig.1.

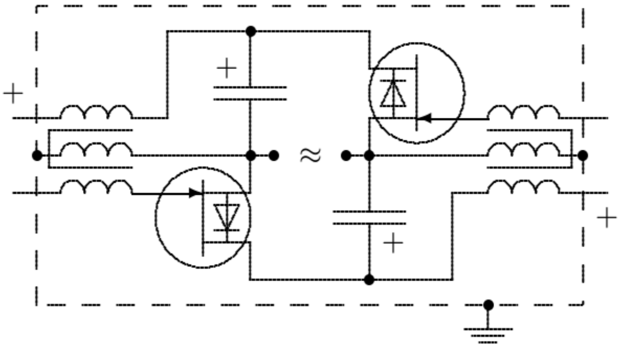

Figure 1: Parallel push-pull circuit

The manufactured module layout is presented on Fig.2. We used Rogers 4003C with ε=3.55 as a substrate material. The transistors are fed with 180^0 phaseshift, provided with external balun. The module provides maximum available gain of 18.9 dB at output power of 2.0 kW and with supply voltage of 150 V.

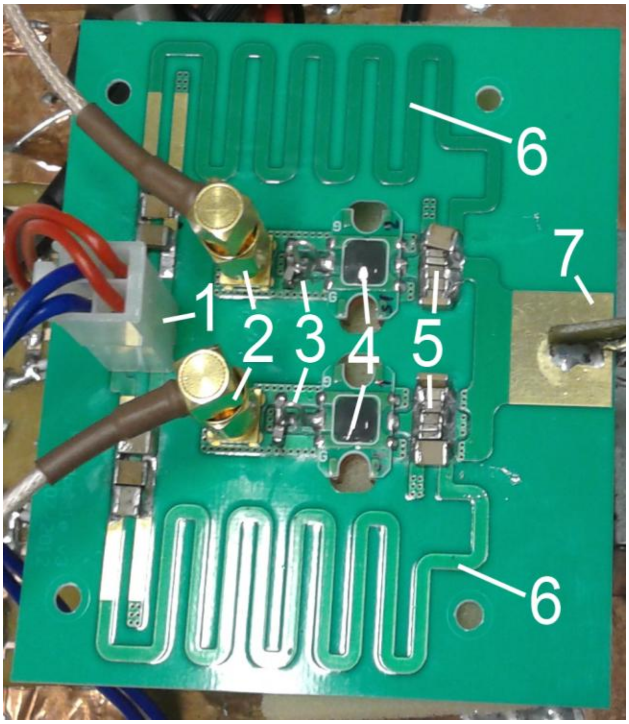

Figure 2: RF power module (heat sink is not shown): 1 – DC supply voltage; 2 – RF inputs; 3 – input matching circuit; 4 – SiC transistors; 5 – DC-blocking capacitors; 6 – quarter-wavelength lines; 7 – symmetric output stripline

Each transistor will be mounted on a water-cooled heat-sink with a sinter paste, as shown on Fig. 3, which can dissipate up to 300 W average thermal power.

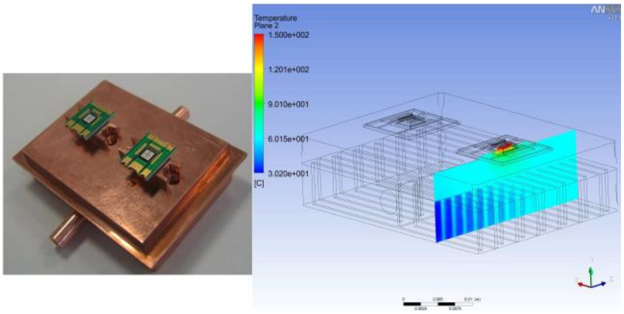

Figure 3: Transistor package mounted on a water-cooling module with temperature distribution

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POWER COMBINER

In [2], a possibility of parallel power combining with use of a resonant cavity was shown. In this work, we present a non-resonant power combiner concept based on a stepped coaxial line, shown on Fig 4. It benefits in avoidance of energy storage and thus in lower power dissipation.

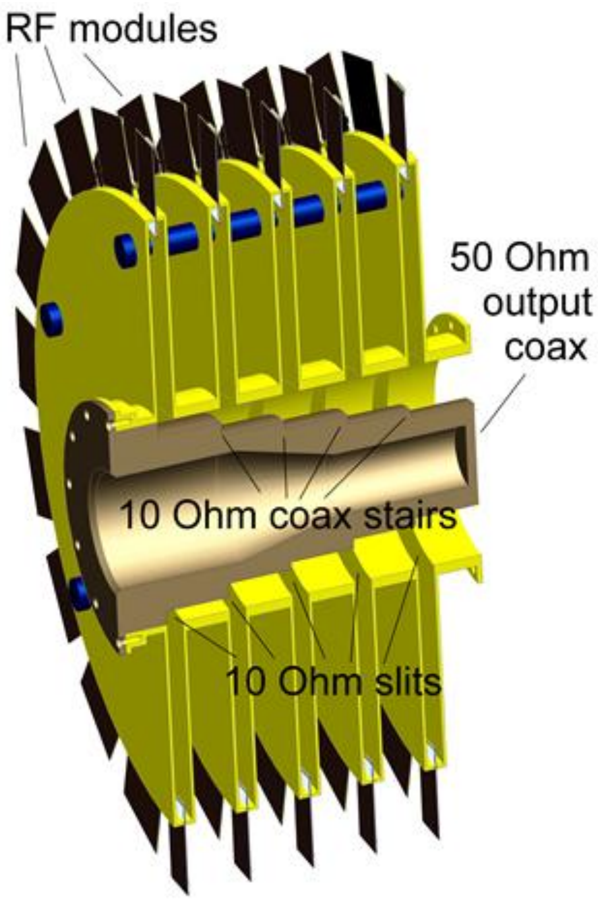

Figure 4: Stepped-line power combiner

The inner conductor represents sequence of coaxial segments with impedances from 10 to 50 Ohm with 10 Ohm steps. The whole number of modules can be distributed among 5 rings that are mounted on the outer conductor of the coaxial cable and feed it through 5 circumferential slits, each ring having output impedance of 10 Ohm.

Due to the offsets between the rings the drive amplifier must provide the phase shift between the groups of RF modules hooked up to each ring. Meanwhile, the distance between the first and the last slits must not exceed quarter-wavelength to avoid the resonance in the coaxial cable.

Each ring has to be surrounded with metal housing that introduces high shunt inductance which will serve to reduce the power leakage.

RADIAL FILTER

In combination with a suitable resonant load, the RF module can operate in class-F mode at very high efficiencies (over 85%). In an ideal class-F operation, current and voltage are shifted in phase by 180^0, the output voltage waveform having square shape and the drain current being sine-like. A filter at the drain of the transistor with the proper values of input impedances at fundamental frequency and at odd harmonics is required to shape the waveforms [3]. The shaping minimizes the overlap of the voltage and current waveform which reduces power dissipation in the transistor and increases the efficiency.

Henceforth, we consider the third harmonic filter only. Even harmonics are shorted inside each RF module.

The input impedance constraints for the filter are as follows:

let

$$Z_{module}^{1}=R^{1}+jX^{1}$$
$$\text{and } Z_{module}^{3}=R^{3}+jX^{3}$$

be the output series impedances of a single RF power module at fundamental frequency and at the third harmonic respectively. Since we need to extract the power at fundamental with high efficiency and to reflect the third harmonic back in-phase, the input impedance Z_{filter} has to

- compensate the imaginary part at both frequencies;
- provide power dissipation in the load higher than in the transistors by a factor of 10 (~90% efficiency);
- behave as an open-circuit at odd harmonic

or

$$Z_{filter}^{1}=10R^{1}-jX^{1}$$
$$\text{and } Z_{filter}^{3}=500R^{3}-jX^{3}$$

at the fundamental frequency and the third harmonic respectively.

We design the filter which fulfills these two complex constraints using four λ/16 transmission lines (four segments) with different line impedances. We calculate the line impedance of each filter segment using scattering matrix approach, taking into account that the filter eventually acts like an impedance transformer of the load R_{load}; see Fig. 5.

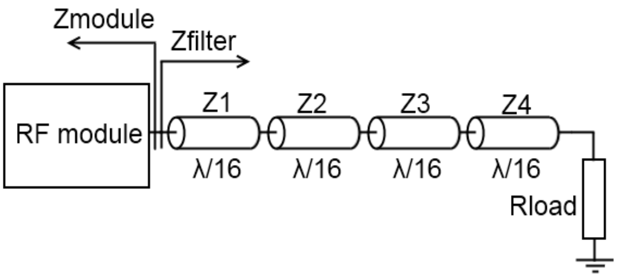

Figure 5: Filter schematics

The preferable concept of the filter design is to use segments formed from radial transmission lines, driven with non-dispersive TEM-like wave. This leads to a filter

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that serves to a plurality of the RF modules connected in parallel through horn antennae as shown on Fig.6.

We use CST Microwave Studio to optimize the filter interior shape in order to get desired input impedance values at the antennae tips, to which the modules are connected.

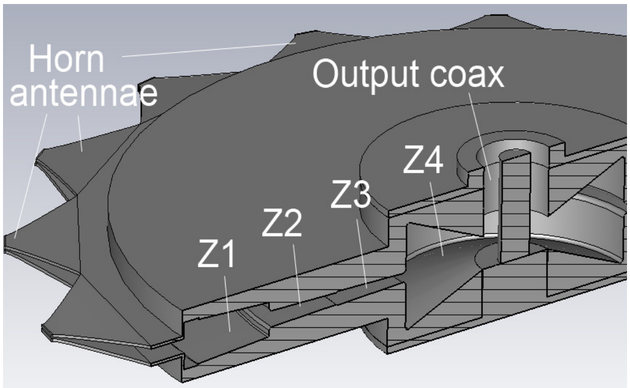

Figure 6: Radial filter CST model

The numerical simulations showed that the radial filter made of copper will dissipate 4.5 times less power than in case of using stripline-based filters connected to the output of each RF module individually. This filter geometry can be easily embedded inside every ring of the power combiner.

Test prototype

In order to verify the CST predictions we have designed one filter ring with 16 horn antennae (see Fig. 7), which is currently under manufacture.

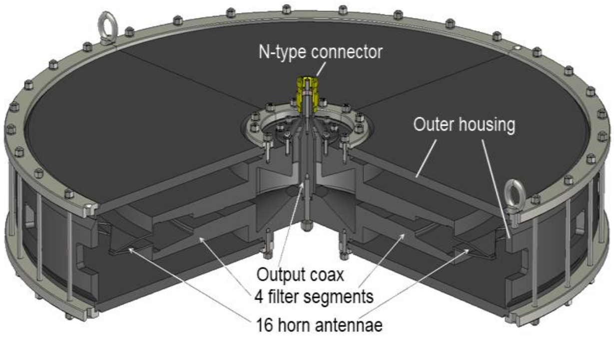

Figure 7: Test prototype CST model

SUMMARY

We have described our preliminary design of the basic RF generator components. The next steps will improve the RF modules' performance in terms of output power and gain; reduce the size of the power combiner by shortening each filter segment and by tuning each horn antenna shape to make it work as the first filter segment itself.

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