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DEVELOPMENT OF 4-WAY 81.25 MHz 20 kW HIGH POWER COMBINER USING PARALLEL PLATE STRUCTURE *

Kitaek Son†, Hyojae Jang, Ohryong Choi, Doyoon Lee and Hoechun Jung
Rare Isotope Science Project, Institute for Basic Science, Daejeon, Korea

Abstract

The recent development of semiconductor technology has proved that solid-state RF amplifier is a quite effective alternative high power RF source for numerous accelerator applications. To develop a high power SSPA system, high power combiner is required to combine the RF power from a lot of solid-state RF module [1]. The parallel plate RF power combiner, which is designed to combine various high power modules, is developed for RAON (Rare the rare isotope accelerator complex for online experiment). In this presentation, the status of developed 81.25 MHz 20 kW power combiner will be described.

INTRODUCTION

The RAON adopts solid state power amplifier as a power source for providing RF fields in RF cavity. Until now, the source of the HPRF (high power RF) system is mainly using klystrons to supply E-field in the cavity at the accelerator. However, in recent years, performance of SSPA (solid state power amplifiers) has been improved, and it is good enough to replace klystrons as the main system. Semiconductor Transistor using LDMOS (laterally diffused metal oxide semiconductor) technology currently has more than power of 1 kW [2]. In addition, it is developed to prevent the reflecting power effectively generated from impedance mismatching. SSPA devices used for RFQ cavity in RAON are equipped with four units in the 19-inch rack. In order to provide RF power of 10 kW or more in 19-inch rack, combiner that can integrates multiple SSPA devices is required to synthesize high power. Power combiners of less than 5 kW can be fabricated on a conventional PCB. But the high power combiner more than 5 kW has limitations in fabrication based on conventional a PCB. Therefore, RF group working for RAON project designed the combiner that can synthesize more than 20 kW RF power by using two thick silver-plated plates separated by 1~2mm.

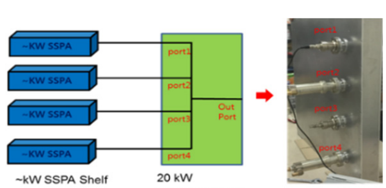

Figure 1 : Structure of 4way combiner to integrate SSPA(solid state power amplifier) unit.

We performed drawing work by using 3D inventor tool. The combiner was fabricated based on the 3D drawings and the result is obtained by using VNA (vector network analyzer). Figure 1 shows a combiner structure to integrate four SSPA devices. In order to combine SSPA devices for RFQ cavity, the high power combiner that can withstand more than RF power of 20 kW is required [3]. Generally, n-way RF combiners are designed with two types; Wilkinson-type or Gysel-type. The structure of combiner was designed with the Gysel method to synthesize high power over 20 kW. The Gysel structure has the advantage that a ballast resistance over 1kW can be connected to an external ground. In addition, the two silver-plated plates inside the combiner are designed to be in a stable quasi-TEM mode by keeping the spacing in parallel. Figure 2 shows the Wilkinson and Gysel structure.

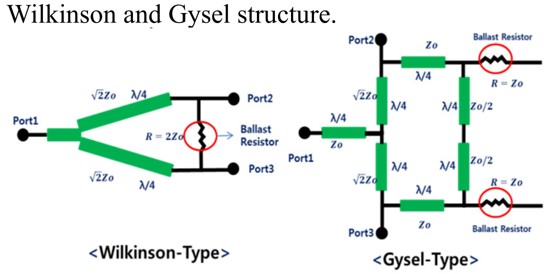

Figure 2 : Two structures to fabricate high power RF combiners.

SIMULATION OF THE GYSEL COMBINER

The HPRF SSPA used in the RFQ cavity consists of the 20 kW power systems in a 19-inch rack. There are four SSPA (solid state power amplifier) units in the rack and the 4-way high power combiner to synthesize the power of the four SSPA units. The thickness of the silver-plated plate inside the combiner is designed to withstand a high power more than 20 kW.

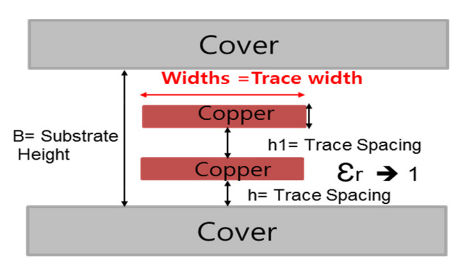

Figure 3: Structure of parallel plate.

†skt1385@ibs.re.kr

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Figure 3 shows the theory for a silver-plated plate inside the 4way Gysel combiner. The characteristic impedance of the silver plate in the combiner is determined by the width of the plate. In order to withstand a high power more than 20 kW, the trace thickness range must be designed at in such a way that insulation breakdown does not occur.The characteristic impedance is given by (1) below.

$$Z_0 = \frac{80}{\sqrt{\varepsilon_r}} \ln\left(\frac{1.9(2H+T)}{(0.8W+T)}\right)\left(1-\frac{H}{4(H+H_1+T)}\right) \qquad (1)$$

Where T is trace thickness, W is trace width, H is trace spacing and B is substrate height. At 81.25 MHz, the wavelength is about 90 cm. So when designing Gysel-structure is made in straight line, the inner space of combiner becomes large.therefore, when designing the 4way combiner, the length and width of the silver-plated plate should be optimized to minimize the inner space of the 4 way combiner.To minimize the widths of the silver-plated plate, characteristic impedance has to be fine-tuned. The characteristic impedance is determined by the combination of dielectric value, trace spacing, and substrate height. The trace spacing affects the loss of S21 (transmission coefficient) and S11 (reflection coefficient). Figure 4 shows the shape of the silver-plated plate at 81.25 MHz by using the HFSS tool.

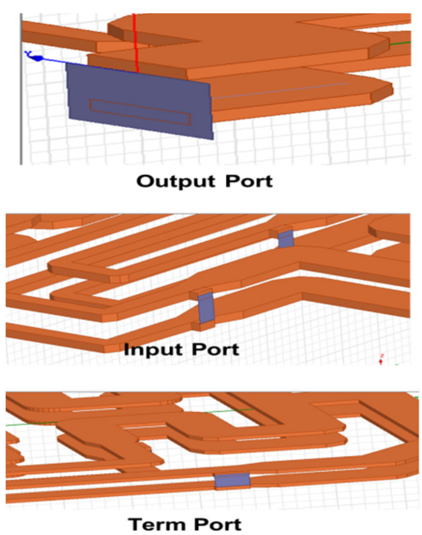

Figure 4: Shape of plate at 81.25 MHz

As shown in Fig. 4 the combiner has four input ports to receive output power from four SSPAs in rack. And there are four terminal ports to dump the reflected power generated from the mismatching of the final output. Isolation terminals of the combiner are connected to external terminals to use the ballast resistance above 1 kW. When there is a gap between two plates, the E-field and the H-field propagate orthogonally to the output port direction. Also the E-field between the silver-plated plates has a quasi-TEM mode. Figure 5 shows the E-field between two silver-plated plates.

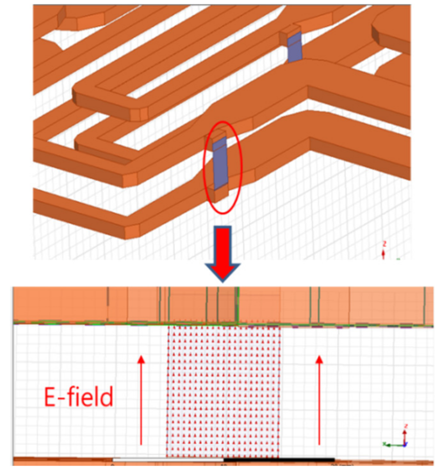

Figure 5: E-field between two silver-plated plates.

As shown in Fig. 5, the direction of the E-field is vertically distributed from the lower plate to the upper plate.

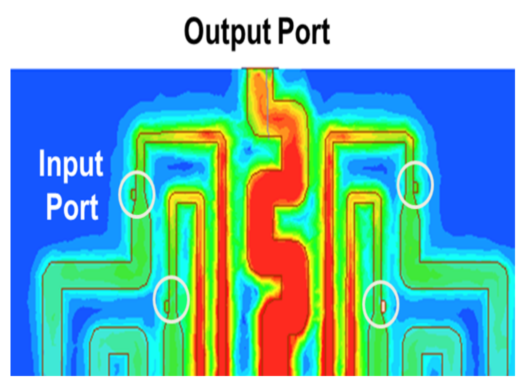

Figure 6 : E-field distribution of 4way Gysel combiner.

In the HFSS simulation, RF power was applied to four input ports and the distribution of the overall E-field was confirmed. Figure 6 shows the E-field distribution when RF power is applied to the input port. The RF power entering the input port is synthesized at the output port. It can be confirmed that the E-field intensity is increasing in the red part through HFSS simulation. EM-Simulation of combiner was performed by using HFSS-code.

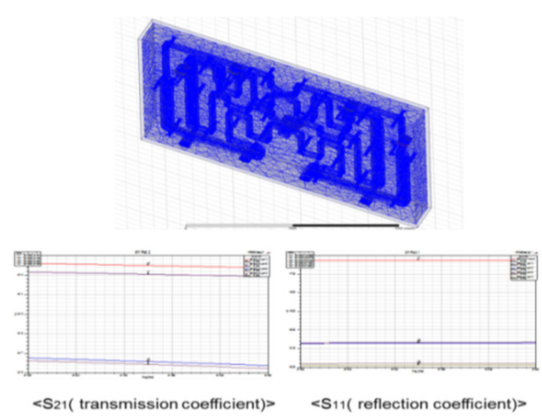

Figure 7: EM simulation of Gysel combiner.

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Table 1: Coefficients of S_{21}, S_{11}

Input port	S_{21}(dB)	S_{11}(dB)
1 port	-6.12	-21
2 port	-6.18	-20.7
3 port	-6.18	-20.6
4 port	-6.12	-21.8

The values of S_{21} (transmission coefficient) and S_{11} (reflection coefficient) were confirmed through EM simulation. Table 1 summarize the simulation values. The loss value of S_{21} was simulated between 0.1 and 0.2 dB, and S_{11} for four input ports are simulated below -20dB. A trace pattern and a cover mechanism were designed by using a 3D drawing tool with the simulation values [4]. Figure 8 shows the structure of combiner using the 3D drawing tool.

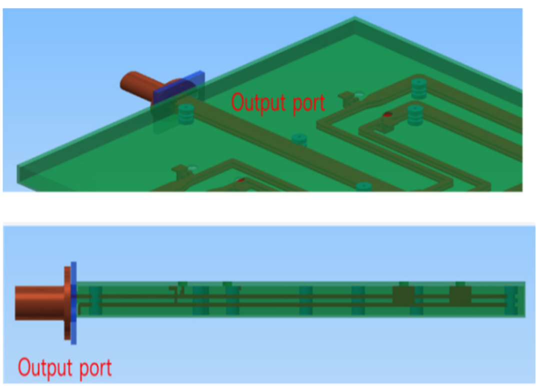

Figure 8: Twenty kW combiner drawing.

The inner plate of the combiner was made of silver-plated plate to improve the conductivity. An insulator was used to fix the gap between the silver-plated plates. The outer cover is made of aluminum plate and the output inner diameter is 3-1 / 8 inches EIA flange type. Based on the simulation results, S_{21} (transmission coefficient) and S_{11} (reflection coefficient) were measured by VNA (vector network analyzer). Figure 9 below shows the fabricated high power combiner shape.

Figure 9: 4-way Gysel Combiner.

The 4-way Gysel combiner was cold-tested by using a VNA (vector network analyzer).The experimental frequency was set to 81.25 MHz, the RFQ cavity resonance frequency, and the signal source was CW (continuous-wave). The tables 2 summarize the comparison between the simulation values for S_{21} and values for S_{21} of the fabricated combiner. The theoretical value of S_{21} (transmission coefficient) for 4 ports combiner is -6 dB. The measured S_{21} (transmission coefficient) of the fabricated combiner was similar to the simulation value as listed in Table 2. The combiner verified in the cold-test was applied to the SSPA system to provide the E-field to the RFQ cavity [5].

Table 2: Simulation and Fabricated Combiner S_{21}

Input port	Simulation(dB)	fabricated(dB)
1 port	-6.12	-6.14
2 port	-6.18	-6.21
3 port	-6.18	-6.1
4 port	-6.12	-6.11

CONCLUSION

In recent RAON project, the 4 way combiner was designed by using the Gysel structure and worked on the drawings by using the 3D modeling tool and then is fabricated the combiner. Also the cold-test was performed and we observed that the measured values are similar to those of HFSS simulation. Finally, high power 4-way combiner is applied to HPRF system for RAON RFQ cavity.

ACKNOWLEDGEMENT

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