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DESIGN AND MANUFACTURE OF 10 kW, 83.2 MHz 4-WAY POWER COMBINER FOR SOLID STATE AMPLIFIER

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Abstract

The purpose of this study is to improve the insertion loss of a 20 kW solid-state RF power amplifier and the power coupling efficiency by reducing reflected power. For this purpose, a power combiner, which is a core component of a solid-state RF power amplifier, was designed and fabricated. The 4-way power combiner employs the Wilkinson type, which has excellent power coupling efficiency and isolation, and operates at 83.2 MHz. This paper covers the design and cold test results.

INTRODUCTION

RF amplifiers for particle accelerators require high frequency, power and phase stability. Depending on the type of particle accelerator, the power requirement is 10 kW to 2 MW or more for continuous sources and a maximum of 150 MW for pulse sources.

These high frequency, power and phase safety requirements have led to the use of tube amplifiers as the source of particle accelerators. Tube amplifiers include Tetrode amplifiers, Inductive output tubes, Klystrons, Magnetrons and Gyrotrons. Tube amplifiers have been used as a power source for particle accelerators because they can supply frequencies up to 10 GHz and power up to 100 MW. Recently, however, limitations of tube amplifiers have begun to emerge. All tube amplifiers have the same problem, and typical problems include heat loss, voltage breakdown, output window failure, and multipactor discharge. Semiconductor amplifiers have emerged to solve impedance problems during beam loading and reflection problems during multipacing.

In the case of a semiconductor amplifier, the output power of a single amplifier is lower than that of a tube amplifier, but when sufficient power cannot be obtained, the output of several amplifiers can be combined to achieve a target output. In addition, semiconductor amplifiers have low voltage requirements and low maintenance costs. The cost of amplifiers (including replacement preamplifiers) in the total operating cost of a particle accelerator system is quite high. Therefore, the maintenance cost of a semiconductor amplifier with low voltage requirements is much lower than that of a tube amplifier because the power efficiency of an RF amplifier determines the power consumption and the power consumption soon determines the operating cost. In addition, the semiconductor amplifier is modularized, so that the failure of a single amplifier unit does not affect the whole system, and it is easy to find the fault part, so that maintenance is easy and cost is low. In the future, as the efficiency of MOSFETs, a key component of semiconductor amplifiers, increases, the amount of power available for output is expected to increase.

However, semiconductor amplifiers still have a lower maximum output power than tube amplifiers and have some disadvantages. Semiconductor amplifiers require a compact system that has high RF power per unit volume due to low acceleration efficiency per unit volume. In addition, the LDMOS device, a key component of the semiconductor amplifier, is sensitive to increased junction temperature, requiring a heat sink design with good thermal management efficiency.

There is also a problem of lowering power coupling efficiency due to unbalance of amplitude and phase. The semiconductor amplifier combines the power of single amplifier units to achieve the target power. When single amplifier units have different powers and phases and ignore them and combine them, there is a risk of damage to the equipment due to the reflected power generated by the phase and power difference. To solve this problem, amplitude and phase trimmers have been developed and individual PA phase adjustments have been used to compensate for phase imbalance, but no perfect solution has yet emerged. In this paper, we designed a power combiner that increases the power coupling efficiency and minimizes the reflection power to solve the problem of power coupling efficiency degradation due to the amplitude and phase imbalance of semiconductor amplifiers.

DESIGN FEATURE

The most suitable type for power combiners that must combine large powers of 10 kW is Gysel power combiners. Gysel power combiners are superior to Wilkinson power combiners in terms of thermal endurance and power handling, making them suitable for high power applications.

However, the proposed 4-way power combiner has the goal of improving insertion loss and reflected power. The advantages of Gysel power combiners, thermal endurance and power handling, have no direct impact on insertion loss and improved return power. Therefore, Wilkinson power combiner, which has low loss type, is more suitable for the target than Gysel power combiner. In addition, the

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matching frequency is distorted due to the slight characteristic change due to heat generated during power coupling. In order to minimize the loss caused by this phenomenon, a wide bandwidth Wilkinson power combiner is adopted.

Since it was difficult to ignore the heat generation problem of the resistive component, which is the disadvantage of Wilkinson's power coupler, the isolation resistor was directly coupled to the heat sink and a cooling fan was installed to improve thermal durability. Based on these considerations, the 4-way power combiner proposed in this paper is designed by adopting Wilkinson type.

Before designing a 4-way power combiner, a conceptual 4-way Wilkinson combiner was designed to verify the shape, impedance, and matching of circuit components and patterns. The Term was placed at 50 ohms for both input and output ports, with 100 ohms between the input ports for isolation, according to Wilkinson divider theory. The transmission line is set to 1/4 wavelength and the impedance is designed to 70.7 ohms. As a result, the 4-way power combiner was completed by combining three 3-way power combiners as shown in Fig. 1.

The S-parameter simulation results show that S (2,2) is about –100 dB at 83.2 MHz and S (1,2) is about –6 dB as shown in Fig. 2.

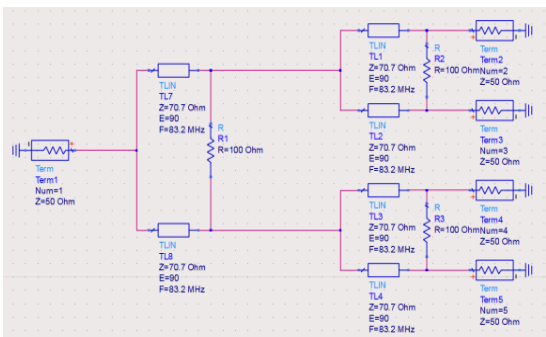

Figure 1: Ideal 4-way wilkinson power combiner matched at 83.2 MHz.

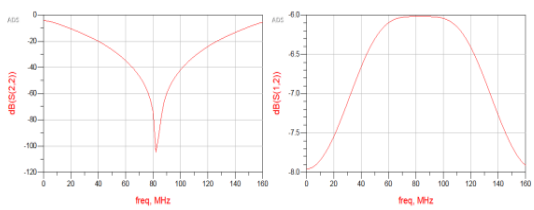

Figure 2: S-parameter simulation result S (2,2), S (1,2).

Considerations for circuit design include pattern width and pattern length, thickness of PCB board, thickness of gold foil, conductivity of gold foil, dielectric constant of Teflon and PCB dissipation factor. PCB board is adopted for accurate circuit design (Table 1).

Table1: Characteristics of Teflon Base PCB Board

Parameter	Value
Base Material	Teflon
Board Thickness	2.6 mm
Copper Thickness	2 OZ (0.07 mm)
Dielectric Constant	2.1
Dissipation Factor tan	0.0004
Conductivity	5.8E+7

After layout and simulation of the completed circuit diagram, it is possible to manufacture after checking the matching and S-parameter. After that, if you go into production without patterning, a pcb board about 1.2 m long is completed.

The already developed semiconductor amplifier of Sungkyunkwan University does not have enough space to mount a board about 1.2 m long. In addition, if the distance between the input port and the output port is 1.2 m away, the power coupling efficiency is expected to decrease due to the phase change depending on the position of the connector and the length of the transmission line. In order to prevent such reduction in power coupling efficiency, a patterning process is required.

Figure 3 shows the proposed 4-way power combiner circuit. Table 2 shows the main difference between the circuit design and the pattern design S-parameters.

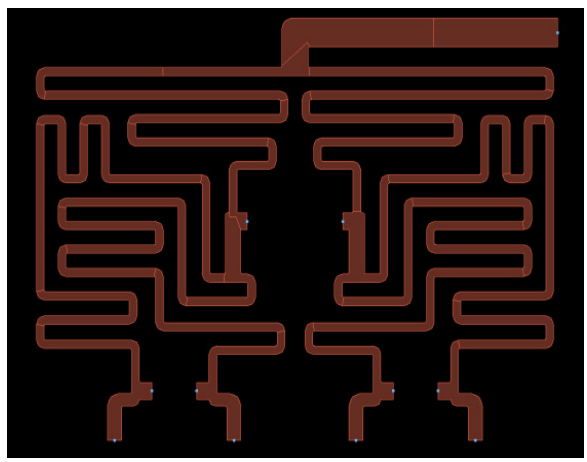

Figure 3: Pattern of the proposed 4-way power combiner circuit.

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Table 2: Difference between Circuit Design and Pattern Design S-parameter

S-Parameter	Circuit Design	Pattern Design
Insertion Loss	6.162 dB	6.241 dB
Input Return Loss	29.874 dB	25.144 dB
Output Return Loss	19.467 dB	13.319 dB
Near Isolation	25.241 dB	16.587 dB
Far Isolation	42.353 dB	38.646 dB

The measurement was performed in the 70 ~ 100 MHz section and the measurement equipment was used as a network analyzer (NA). Table 3 lists the S-parameters measured in the cold test in the order of Insertion Loss, Input Return Loss, Output Return Loss, Near Isolation, and Far Isolation. Figures 4 and 5 show the insertion loss and input return loss measured at ports 2 and 5, respectively. In the cold test of the fabricated power combiner, the characteristics of the S-parameter were many different from those of the designed value.

Table 3: Cold Test S-parameter versus Simulation S-Parameter

S-Parameter	Cold Test	Pattern Design
Insertion Loss	-6.17 dB	-6.241 dB
Input Return Loss	-25.738 dB	-25.144 dB
Output Return Loss	-13.659 dB	-13.319 dB
Near Isolation	-16.148 dB	-16.587 dB
Far Isolation	-35.245 dB	-38.646 dB

In the existing design, the frequency was precisely matched to the target frequency of 83.2 MHz, and the flat power did not differ by more than 5 dB even if the target frequency differed by up to 40 MHz. However, the actual measurements showed that the matching frequency was formed at about 87 MHz and the reflection power was as good as -30 dB when matched. At 83.2 MHz, the reflection power was about –25.6 dB, which is better than the simulation value. It is expected that the end part designed by wider line width has less influence than the simulation to protect the damage caused by current, so that the flat power is reduced and the reflection power which is reduced by widen the line width is expected to be higher than the design value.

In case of insertion loss, there was also a slight difference between the simulation value and the measured value. The simulation result was –6.241 dB and the insertion loss measured during cold test was –6.17 dB. It is expected that the characteristics of the actual measurement are better because the dielectric constant of the gold foil is higher than the value set in the simulation.

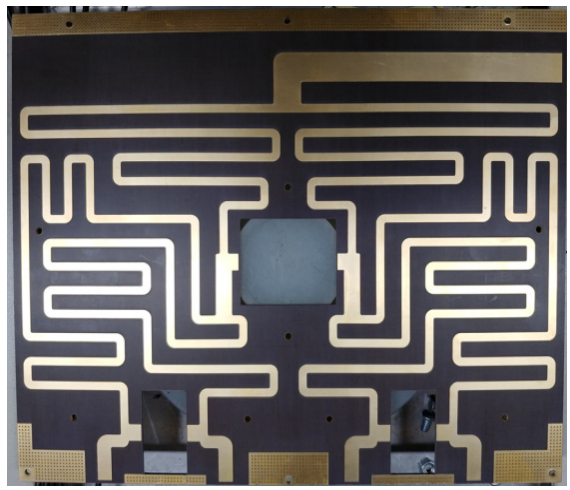

Figure 4: 4-way combiner.

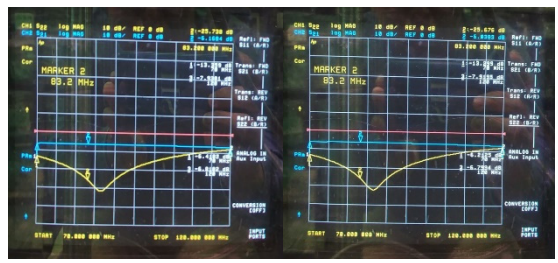

Figure 5: Cold test.

CONCLUSION

Cold test results showed similar trends with simulation values. In particular, the insertion loss and the Input Return Loss values were better than the simulation results. This is expected to be due to the lower conductivity of the gold foil, resulting in better actual conductivity and less impact on the end of the wider pattern width for overcurrent protection. As a result of the cold test, the values of Insertion Loss, Input Return Loss, Output Return Loss, Near Isolation, and Far Isolation respectively were -6.17, -25.144, -13.319, -16.587 and -38.646 dB.

These results confirm that the 4-way power combiner is designed in a way that meets the purpose. It is considered that the results of the study on the high power pcb combiner for semiconductor amplifiers are extremely rare.

ACKNOWLEDGEMENT

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