DUAL CHIP IN SINGLE MODULE SOLID-STATE POWER AMPLIFIER DESIGN FOR COMPACT TRANSMITTER ARCHITECTURE

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Abstract

At present, the high power solid-state technique transmitter design are composed of hundreds parallel combined single chip for hundreds Watts power modules to achieve enough output power. Although the large numbers can bring high redundancy during system operation, the power hungry of next generation RF system of accelerator would need much more modules to satisfy its power requirement. Huge amount of power modules would bring the complexity and difficulty in power combining, system construction, management and maintenance. To overcome this disadvantage, upgrading the power level of a single module could be the solution. Besides depending on the power level growing with technology advancement in semiconductor industry, a circuit level solution to combine dual chip in advance in a single PCB board is proposed to produce twice power of single chip. Four power dividing/combining methods are designed and measured in this article.

INTRODUCTION

In accelerator field, the solid-state RF power sources are becoming popular for accelerating sub-systems, such as storage ring of LNLS and SOLEIL [1], booster of SOLEIL [2], LINAC of ELBE [3] and even beam chopper of J-PARC [4]. The basic working principle of the above solid-state amplifier circuits are adopting coaxial balun in CW [1-2] and printed Marchand balun in pulse [4] for push-pull operation. The adopted solid-state technology can extend from VHF to L-band in accelerator application.

The power level available from basic solid-state power amplifier (SSPA) unit is mainly determined by single chip module for continuous wave (CW) operation. However, two or more chips in single module can be found for pulse operation [4]. The possible reason for this is that the size of multi-SSPA units for CW operation is not small enough to be integrated together within one module. The other could be the cooling structure during development procedure is not intended for multi-amplifiers within one module. Since the compact round planar balun at 500MHz has been proposed by NSRRC in 2012 [5]. The integration of dual power transistor chips within one module without expanding too much area becomes applicable (less than 3U/133.3mm in width). In Fig. 1, without sacrificing the accessory bias components, the estimated size reduction using planar balun (139*108mm^2) can reach 50% when comparing to that using coaxial type balun (175*180mm^2).

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Thus, with the compact planar balun, dual or more chips integrating within one SSPA module become attractive. This article will discuss four planar two-way power splitting/combining methods for their characteristics as a basic study for dual chip combination within one SSPA module for double output power. With double output power, the total number of solid-state transmitter could be reduced in half for the same power level or twice the output power with the same module numbers.

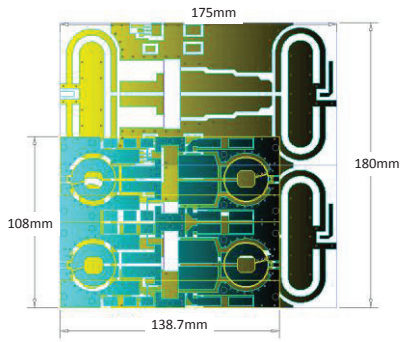


Figure 1: Dual SSPA using coaxial and planar balun in parallel for size comparison.

POWER COMBINING METHODS ON MICROTRIP CIRCUITS

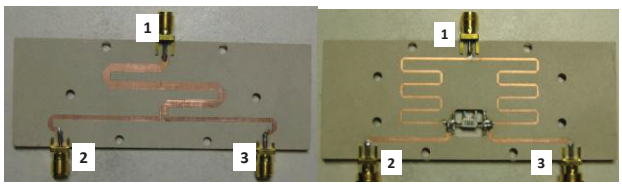
There are various ways for microwave power splitting and combining. In general, they are called hybrid power divider or combiner. The methods suitable for printed circuits are chosen as Y-junction, Wilkinson, Gysel and balance power dividers/combiners for investigation [6]. Each of them can be used as power divider as well as combiners and are designed at 500MHz. The properties such as input return loss, bandwidth, isolation and insertion are analysed and measured in detail. After these practical tests, their actual property can be obtained for optimum power division/combination in dual-chip combination.

Method I: Y-Junction Divider/Combiner

Y-junction is simply a two parallel 50Ω characteristic impedance transmission line connecting with a quarter wave length impedance transformer for matching 50Ω. This kind power division/combination is widely adopted in multi-ports application such as SSPA in SOLEIL [1-2]. The layout is shown in Fig. 2 (a). For efficient power combination; the input signal at port 2 and 3 shall be in-phase and equal amplitude. To be compact, the quarter wavelength transmission line is bent.

Method II: Wilkinson Divider/Combiner

This is the basic power divider with a centre positioned 100 Ω ballast resistor as shown in Fig. 2 (b). The 20 dB isolation between port 2 and 3 is available. However, this resistor would degrade the RF property when its size becomes large for high power application. For two 1kW power source combining, this ballast 100Ω shall withstand 500W power loss when one of the power sources fails. This brings the disadvantage for good RF performance for high power application due to large size of the ballast resistor.



(a) (b)

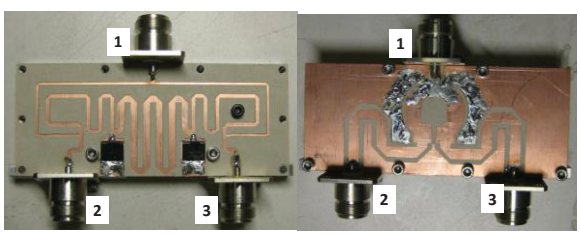
Figure 2: The designed 500MHz two-way (a) Y-junction and (b) Wilkinson power divider/combiner.

Method III: Gysel Divider/Combiner

To overcome the size problem of resistor in high power application, Gysel divider/combiner replaces the ballast resistor by two grounding 50 Ω resistors with a half wavelength transmission line as shown in Fig. 3(a). The isolation between port 2 and 3 is also better than 20dB. The two external terminated resistors can avoid degrading RF characteristic in high power application. By the way, two resistors can also share the power loss when one of the combining power sources fails. For two 1kW power sources combination, two 250W power resistors can absorb 500W power loss and the left 500W is sent out to port 1 ideally.

Method IV: Planar Balun Divider/Combiner

Since the proposed planar balun is quite compact, the investigation of this structure is also included. One quarter wavelength transmission line is added at the balance ports for 50 Ω matching in Fig. 3(b) since the balun itself is originally designed for low impedance of power transistor. Balance combination can bring the advantage of insensitive to load variation [6]. Also, no additional ballast resistor is required. However, the isolation between port 2 and 3 is still not good enough.



(a) (b)

Figure 3: The designed 500MHz two-way (a) Gysel and (b) balance power divider/combiner.

PROTOTYPE COMPARISON OF THE ABOVE DIVIDERS/COMBINERS

The designed and fabricated prototypes of the above four power dividers/combiners are measured for characteristic analysis. Figure 4 shows the input return loss with the other two ports terminated. Their centre frequency is simulated at 500MHz although the measured results have some variation.

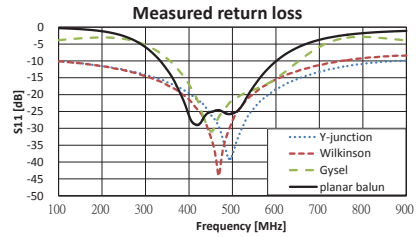


Figure 4: The input return loss of the four fabricated power dividers/combiners.

The isolation between port 2 and 3 are also verified in Fig. 5. Obviously, Gysel shows the best isolation with minimum frequency shift.

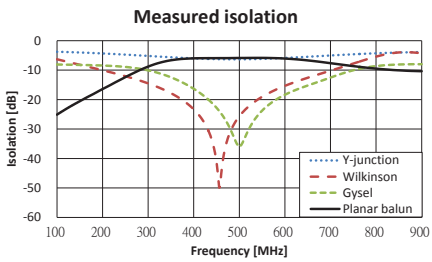


Figure 5: The measured isolation between port 2 and 3 of the four power dividers/combiners.

Although their insertion losses are quite low in general usage, however, in high power application up to kW range, little insertion loss will bring several tens of Watts power loss on the power combiner. Without proper cooling mechanism, the temperature would arise to above hundred °C. The insertion loss measurement is applied by connecting the above devices back-to-back as shown in Fig. 7. In Fig. 6, back-to-back connected dividers/combiners all have lower than 0.3dB insertion loss. When the back-to-back ones are divided in half, their insertion loss shall be lower than 0.15dB which is equivalent to lower than 34Watts power loss under 1kW power. Gysel combiner shows the highest lost.

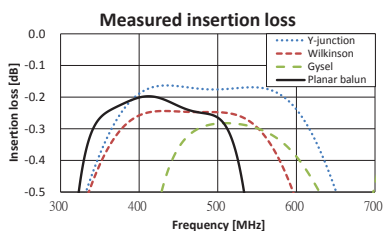


Figure 6: The insertion loss investigation by back-to-back connection of the four methods as in Fig. 9.

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The power combination seems to be straightforward while the measured results are good enough between simulation and measurement. However, the power loss on these passive components cannot be ignored while applying high enough RF power on them. Figure 7 shows the Y-junction power divider/combiner under 1kW power transmission without any cooling structure. The temperature would be risen to be higher than 190 °C in thermal stable condition. Proper cooling mechanism for microstrip lines must be added in actual high power usage..

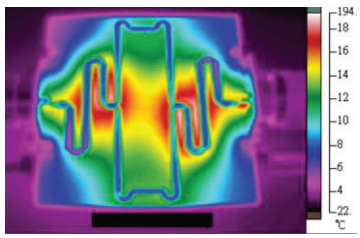

Figure 7: The back-to-back connection of Y-junction power divider/combiner for insertion loss and temperature distribution measurement.

COMBINING EFFICIENCY TESTS OF THE DIVIDERS/COMBINERS

Although the basic function of these power dividers/combiners are all tested individually, the actual operation efficiency shall be tested by real amplifiers. Since, the proper cooling structure for two 1kW SSPA transistors and power combiners are still in design step, the 50W commercial available power amplifiers (from mini-circuits) are used for power combining efficiency tests. The setup is shown in Fig. 8. The combination for Y-junction and balun type combiner need isolator at SSPA output for amplifier VSWR protection while the other two methods with good isolation do not need additional isolator. The combiner with the best efficiency would need the lowest driving power to have 100Watts output power. In Fig. 9, the Gysel and Wilkinson has similar performance due to no circulator losses are added for successful power combination. Although Gysel has the highest insertion loss in low power tests, it reaches 100W with minimum input power. However, the efficiency difference between Gysel and Wilkinson power combiner is not obvious.

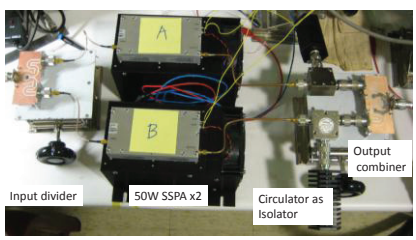

Figure 8: The setup for power combining efficiency using two idental 50W SSPAs.

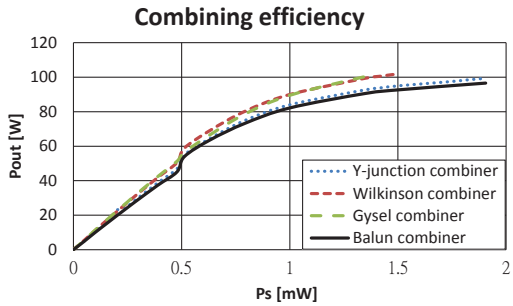

Figure 9: The combining efficiency of the four dividing/combining methods.

CONCLUSION

In order to find out the most proper method for dual-chip combination within single module, four two-way power dividing/combining methods are investigated in detail from low power measurement to actual 50Watt power combination. The back-to-back connections are also applied for their insertion loss in low power and thermal distribution under 1kW CW power. The Gysel power combiner has the best combining efficiency while the proper cooling mechanism is needed for the power loss on microstrip lines under high RF power. Further study is still needed while the protection circuits shall be included in case there is high reflection CW power.

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