PLANAR BALUN DESIGN WITH ADVANCED HEAT DISSIPATION STRUCTURE FOR kW LEVEL SOLID-STATE AMPLIFIER MODULE DEVELOPMENT

T. C. Yu#, Ch. Wang, L. H. Chang, M. S. Yeh, M. C. Lin, F. T. Chung, T. T. Yang, C. H. Lo, M. H. Tsai, Y. H. Lin, M. H. Chang, L. J. Chen, Z. K Liu, NSRRC, Hsinchu Taiwan

Abstract

The power level of solid-state amplifier is continuously growing for advanced accelerator application as the RF power source. Huge amount of solid-state power amplifier (SSPA) modules can contribute several hundreds of kW RF power with high redundancy and reliability. However, with the increasing desire of RF power in single RF station, too much power modules would adversely cause larger area occupation and higher maintenance cost and complexity. Therefore, with the advancement of the RF power on single module, the overall system design and configuration would become much simple and compact. However, the increasing RF power of single SSPA module would also bring the thermal problem at its chip as well as the output power combining balun. In this article, 1kW SSPA is developed with the novel planar balun structure with better thermal distribution property. With such new planar balun design, the SSPA can operate more stable with 1kW CW output RF power.

INTRODUCTION

After the success of solid-state power amplifier transmitter at SOLEIL [1] for its excellent energy efficiency, highly reliability and redundancy, much collaboration with SSPA technique transferring was carried out in many accelerating facility such as LNLS and ESRF as their new RF power source [2-3] to replace the klystrons. For SOLEIL, the storage ring SSPA takes 330W, 724 modules for four towers, 190kW RF power and each tower for 50kW with 181 amplifier modules in average. Later, the ESRF has the upgraded version SSPA module with 650W 1-dB power for 75kW, 128 modules per tower. Obviously, the highly reliability and highly redundancy is achieved by several hundreds of modules for 100-200 kW RF power. For higher output power with fewer modules number for simplifying control complexity and reducing space occupation, increasing the unit power is the only way. The effort for promote SSPA unit power is also under going in APS, USA [4] for 352 MHz, 1kW CW SSPA study. The adopted chip (MRF6VP41KH) is able to generate more than 1kW in pulse without problem. However, in CW operation, much effort is needed for proper cooling of the transistors.

Besides the above progress in SSPA technology, other efforts are also made for reducing the manufacture complexity of balun design. The typical baluns are formed by semi-rigid coaxial cables [1-4] which need special bending and cutting tools for precise length control. Hence, the printed planar baluns are also emerging for easier mass production and tolerance control [3,6]. In the power level above 500Watts, the printed balun and the matching ceramic capacitors would start to get hot due to poor thermal transmission path. The reliability tests of the prior SSPA units design in NSRRC has been done and found the heat situation would degrade the output power as temperature rising. Many modification of the planar balun has been reported in this article while a moderate cooling method is proposed on the planar balun for reducing its heat loss as well as no sacrificing its RF property

*Work supported by National Science Council
#yu.tc@nsrrc.org.tw

THE BASIC PROPERTY OF THE PROPOSED PLANAR BALUN

The proposed printed planar balun is actually a modification version of Marchand balun by bending the shorting-to-ground ends together for size reduction as shown in Fig. 1. The initial version of this balun has the open stub on one arm for balance tuning. Also, the shorted ends aside input section of port 1 can also be used for balance and impedance control. With only total quarter wavelength forming a circle, the single end signal at port 1 can be transferred to differential signals at port 2 and 3 with equal amplitude and 180 degree out of phase.

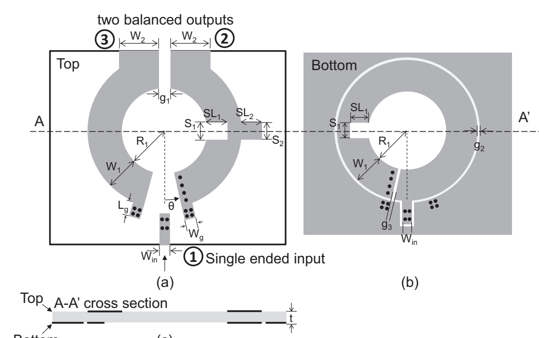

Figure 1: The planar balun design for 500MHz compact SSPA development.

Electromagnetic Field and Current Distribution

The basic working principle of the planar balun has been discussed in detail in prior article [5]. However, in order to deeply and visually capture the operation behaviour of electromagnetic wave, theoretical visualization the electrical, magnetic fields and surface current distribution is thus a better manner. The theoretical behaviour is simulated by HFSS of ANSYS.

E-field

The planar balun is a kind of broadside strong coupling for low leakage field and thus high coupling efficiency as shown in Fig. 2. In order to realize broadside coupling, the coupling area shall be as large as possible while the coupling distance shall be as small as possible. In general, the coupling distance is determined by the thickness of substrate; thus what we can control is to design the width of coupling microstrip line for impedance and frequency control. Although the balun shall be realized by three layers of coupling metals, we found with only top and bottom side metal on substrate can still efficient achieve balance transformation. Since the input line goes through via to bottom layer and get shorted to ground at the other end of bottom line, the field distribution would be like one quarter wavelength standing wave with zero voltage at shorted end and peak voltage at the input end.

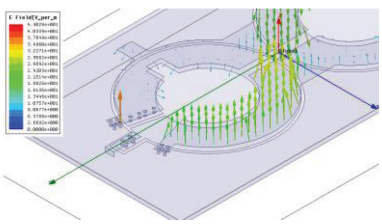

Figure 2: Electrical field on the surface.

H-field

Magnetic field would be perpendicular to E-field as shown in Fig. 3. Contrary to E-field, the H field would distribute surrounding the microstrip line and have it peak value at the shorted end of input coupling line. In Fig. 3, the open stub section will have larger magnetic field density than the other portion.

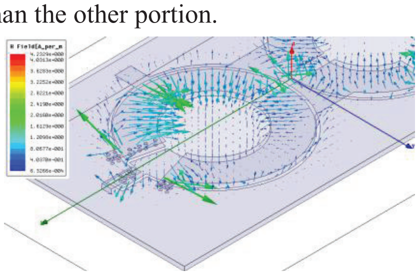

Figure 3: H-field distribution of the planar balun.

Current Flow

RF current will flow on the surface of microstrip line as shown in Fig. 4. Larger arrow indicating larger current value. Hence, the current value will change as it facing varying section size of the microstrip line. The discontinuity on microstrip line in Fig. 4 shows larger current value indicating that larger loss would happen over there. In fact, those portions with high current accompanying higher temperature rising during high power will be discussed in next section.

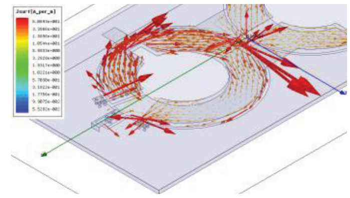

Figure 4: RF current on the planar balun.

Thermal Distribution under High RF Power

The designed planar balun will then be integrated with the output matching network to achieve 1kW output power. However, the output power will continuously degrade as time passing by. In order to keep the output power level to be constant, we have to apply a little more drive power to remain constant output power. As infrared camera was used, the extreme high temperature was found at those discontinuity sections on the planar balun. Thus, with infrared radiation view, the modification of the planar balun shall then be started.

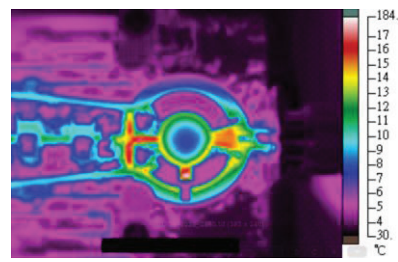

Figure 5: The Infrared view the planar balun on solid state amplifier with 900W output power.

Geometry Modification #1

Just before the modification of the planar balun, two kinds of transmission line are integrated together for infrared test with 1kW RF power passing through as shown in Fig 6. From this picture, the ground metal approximating signal line could help the heat dissipation. Thus, the substrate shall be covered by metal as much as possible. Therefore, the planar balun shall be built by coplanar waveguide structure as the physical view of right picture.

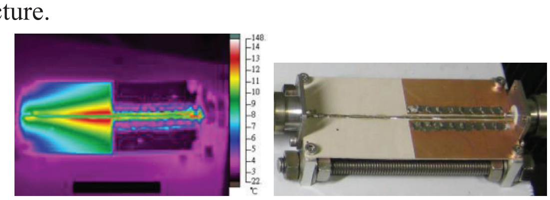

Figure 6: Infrared view of microstrip line and coplanar waveguide with 1kW power passing through.

With the above advantage of coplanar waveguide structure, the planar balun is modified to cover the metal at the output. With 1kW output power, the highest temperature would then be decreased by about 10 °C. This does help but not enough since the phase tuning stub still generates hot spot in Fig. 7.

ISBN 978-3-95450-122-9

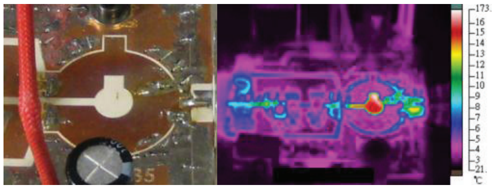

Figure 7: Modification #1 of the planar balun.

Geometry Modification #2

This modification excludes the balun from amplifier to be tested alone. Additional fan cooling from bottom side of the microstrip line is applied. With 900W passing through, the center of the balun still have high temperature.

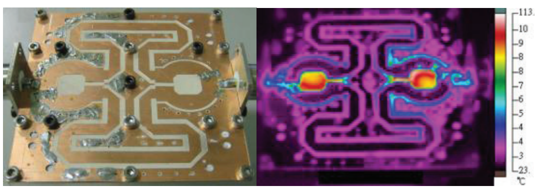

Figure 8: The back-to-back connection of the 2nd modification of planar balun.

Latest Geometry Modification

The above experiments tells that the center of the planar could also generate heat. The possible reason for this is that the high magnetic field passing through the centre could introduce high temp. Therefore, the substrate at the centre was cut down while the air cooling fins were added on the balun top and the surrounding ground. Thus the dielectric loss at centre is gone while the balun loss can also be cooled down by the added fin.

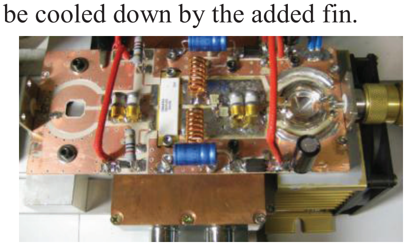

Figure 9: The SSPA using center slotted planar balun with air cooling fins added.

The planar balun with additional cooling structure can greatly improve its heat dissipation capability. The infrared view with 1kW output power is shown in Fig. 10. The maximum temp is about 120 °C at the input differential ports of the balun. Modification of the balun will be continued for lower temperature with 1kW output power.

Performance Comparison

With the lastest version of the planar balun, the maximum temperature of newly designed 1kW SSPA is then compared with the modification#1 SSPA in Fig. 8. The efficiency has improved to be about 4% while the temperature also gets lower to be about 80°C at 900W.

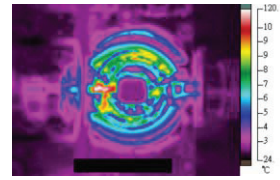

Figure 10: The thermal distribution of the latest planar balun.

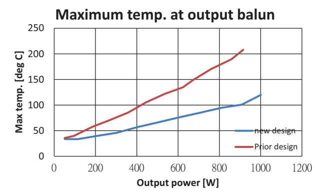

Figure 11: Temperature has deceased to be about 80°C or more at higher than 900W output power.

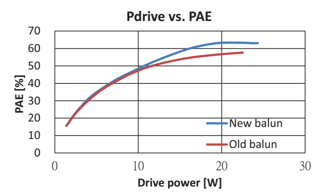

Figure 12: The efficiency has improved to be about 4% due to lower loss at the output balun.

CONCLUSION

The theoretical EM behaviours of the planar balun is analysed for the possible hot spot diagnosis. After several modification of the proposed balun, the hot spot temperature has decreased a lot by 80°C or more. Continuous improvement shall be carried out for highly reliable SSPA design with printed planar balun.

REFERENCES

[1] P. Marchand, R. Lopes, F. Ribeiro, T. Ruan etc, “Development of high RF power solid state amplifiers at SOLEIL,” IPAC2011, San Sebastian, Spain, pp. 376-378.

[2] C. Pardine, J.F.F. Ferrari, F. Santiago and R. H. A. Farias, “Commissioning and one year operation of the 50kW solid state amplifiers of the LNLS storage ring RF system,” IPAC2012, New Orleans, Louisiana, USA, pp. 3404-3406.

[3] J. Jacob, J.-M. Mercier, M. Langlois, G. Gautier, “352.2 MHz -150kW solid state amplifiers at the ESRF,” IPAC2011, San Sebastian, Spain, pp. 71-73.

[4] D. Horan, G. Waldschmidt, “Performance of the 352-MHz 4-kW CW solid state RF power amplifier system using 1-kW push-pull devices,” IPAC2011, New York,, USA, pp. 1-3.

[5] T.C. Yu, Ch. Wang, L.H. Chang, M.S.Yeh, M.H. Lin, etc, “A novel planar balun structure for continuous wave 1kW, 500MHz solid-state amplifier design,” IPAC2012, New Orleans, Louisiana, USA, pp. 2699-2701.