An 8–18 GHz broadband high power amplifier*

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Abstract: An 8–18 GHz broadband high power amplifier (HPA) with a hybrid integrated circuit (HIC) is designed and fabricated. This HPA is achieved with the use of a 4-fingered micro-strip Lange coupler in a GaAs MMIC process. In order to decrease electromagnetic interference, a multilayer AlN material with good heat dissipation is adopted as the carrier of the power amplifier. When the input power is 25 dBm, the saturated power of the continuous wave (CW) outputted by the power amplifier is more than 39 dBm within the frequency range of 8–13 GHz, while it is more than 38.6 dBm within other frequency ranges. We obtain the peak power output, 39.4 dBm, at the frequency of 11.9 GHz. In the whole frequency band, the power-added efficiency is more than 18%. When the input power is 18 dBm, the small signal gain is 15.7 $\pm$ 0.7 dB. The dimensions of the HPA are 25 $\times$ 15 $\times$ 1.5 mm^3.

Key words: wideband; Lange coupler; hybrid integrated circuit; power amplifier
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1. Introduction

Broadband high power amplifiers (HPAs) play an important role in wireless communication, such as in telecommunications, phase-array radars and aerospace systems[1]. The best performance is found in MMIC broadband power amplifiers, but their output power is restricted. Due to higher requirements of output power, the demand of the user cannot be satisfied by the power of a single MMIC broadband power amplifier. This problem is solved effectively by the power combining of two or more MMIC broadband power amplifiers, which has become a new direction of development. Generally speaking, there are two fundamental types of power combining using two or more power amplifiers, namely same-phase-power combining (such as in a Wilkinson power divider) and orthogonal phase-power combining (such as in a Lange coupler).

2. Four-fingered Lange coupler design

Both the Wilkinson power divider/combiner and the Lange coupler can be operated in broadband with a low insertion loss. The structure of a Wilkinson power divider/combiner is simple and has the same output phase. However, the design of a multilevel structure is required to expand the bandwidth of the method and more space is needed as compared to a Lange coupler. The range of applications of a Wilkinson power divider/combiner is restricted by the multilevel structure. In addition, compared with a Wilkinson power divider/combiner, the structure of a Lange coupler is more compact.

A broadband power amplifier based on a Lange coupler has been reported in some literature. In 1991, Gat reported a 8 W Ku-band module using Lange couplers[3]. Power combining using two 1-W 6–18-GHz MMIC power amplifiers using Lange couplers was reported by Platzker Aryeh in 1992[2]. In 1993, D'Agostino reported an innovative power distributed amplifier based on interdigital combiners[3]. In 2007, a 4–12 GHz broadband balanced integrated power amplifier was reported by Yao[4]. An UHF balanced broadband 20 W power amplifier was reported by Huang in 2008[5]. In 2009, Chen reported a 4–9 GHz 10 W broadband power amplifier[6]. In these literatures, all the power of the power amplifier was combined by Lange couplers based on an Al_2O_3 material substrate. Lange couplers based on an Al_2O_3 material substrate are cheap, fast and easy to manufacture. In 1990, Le reported a power amplifier which could produce 2.4 to 2.8 W of output power at 26% to 29% power-added efficiency across the 40% bandwidth from 8 to 12 GHz[7], the Lange coupler of which is based on the GaAs MMIC process. In this paper, an 8–18 GHz broadband HPA with hybrid integrated circuit is designed and developed. The Lange coupler of the power amplifier is also based on the GaAs MMIC process. Compared with the Al_2O_3

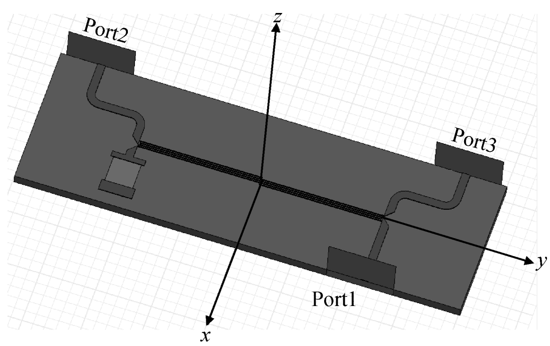

Fig. 1. Lange coupler's three-dimensional model of Ansoft HFSS.

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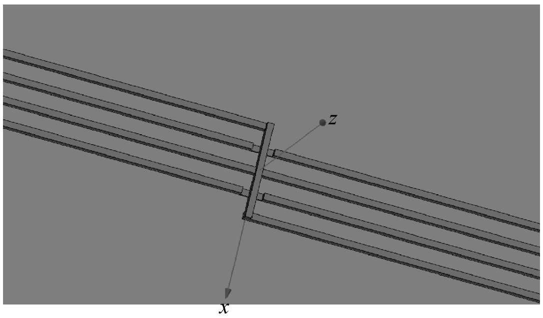

Fig. 2. Finger-to-finger structure of the Lange coupler.

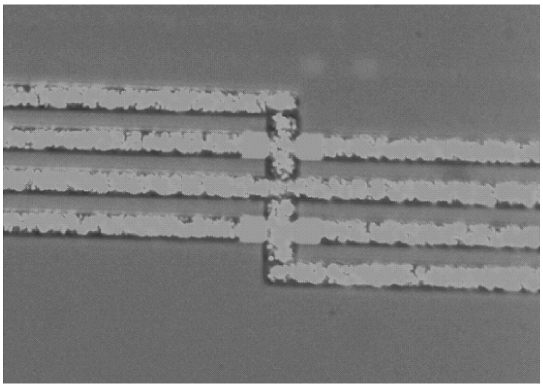

Fig. 3. Photograph of the finger-to-finger structure of the Lange coupler.

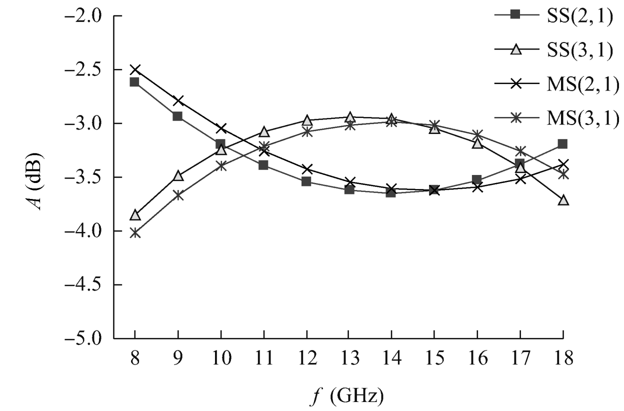

Fig. 4. Simulation and measurement results of amplitude imbalance.

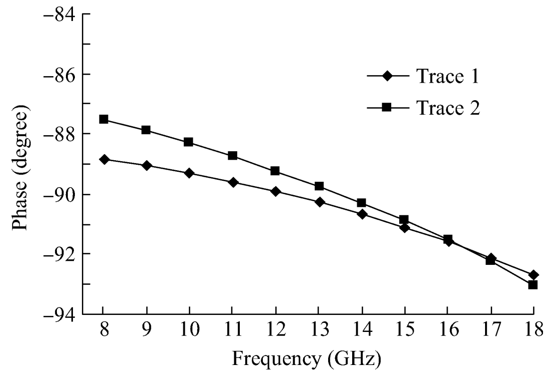

Fig. 5. Simulation and measurement results of phase imbalance.

material process, the Lange coupler produced with the GaAs MMIC process has many advantages, including high precision of the process, small dimension, good consistency, high reliability and suitable for volume production, etc.

A GaAs substrate with a thickness of 0.1 mm is selected for the Lange coupler. The relative dielectric constant of the GaAs substrate is 12.2. The initial design parameters of the coupler are obtained with the LineCalc tool of ADS2008 software, namely L_1, the length of the finger is 2.2 mm; W_1, the width of finger, is 0.0076 mm; S_1, the space between the fingers, is 0.01 mm. As shown in Fig. 1, a three dimensional model of the Lange coupler is established by HFSS software simulation of the three-dimensional electromagnetic field with the group of initial values. Figure 2 is the connection diagram among the fingers, in which traditional gold wire bonding is replaced by an air bridge. W_1, the width of the finger, and S_1, the space between the fingers, of the Lange coupler are taken as optimized variables, by which the Lange coupler is optimized. When W_1 is 0.008 mm and S_1 is 0.013 mm, the most optimized result of the Lange coupler is obtained.

The Lange coupler is produced in a GaAs MMIC process at the Hebei Semiconductor Research Institute. Figure 3 shows a photograph of the finger-to-finger structure of the Lange coupler. Figure 4 shows a comparison of the simulated and measured results of amplitude imbalance for the Lange coupler. SS(2,1) and SS(3,1) are the simulation results of amplitude imbalance for the Lange coupler. MS(2,1) and MS(3,1) are the measurement results of amplitude imbalance for the Lange coupler. From the figure, good fitting can be found between the simulation and measurement results. In the measurement result, the Lange coupler exhibits an amplitude imbalance of 1.5 dB with the frequency of 6 GHz. Figure 5 shows the comparison of the simulation and measurement results with Lange coupler phase imbalance. Trace 1 is the simulation result of phase imbalance for the Lange coupler. Trace 2 is the measurement result of phase imbalance for the Lange coupler.

3. Broadband HPA design and fabrication

As can be seen in Fig. 6, the broadband HPA is made up of two Lange couplers and two 5 W GaAs MMIC power amplifiers researched and developed independently by the Hebei Semiconductor Research Institute. The gain of the GaAs MMIC power amplifier is 19 dB and the Lange coupler adopted is that designed above with a GaAs MMIC process.

In order to decrease electromagnetic interference, a multilayer AlN material with good heat dissipation is adopted as the HPA carrier. The leak voltage V_d and the grid voltage V_g supply voltage to the GaAs MMIC power amplifiers through an inlayer of AlN substrate. During assembly, the GaAs MMIC power amplifier and Lange coupler are first sintered on the AlN substrate with Gold/Tin solder. Then the AlN substrate is sintered on the carrier of oxygen-free copper with Gold/Tin solder. Rogers 5880 microwave material is affixed on the AlN substrate with conducting resin. Finally, gold wire bonding is applied. The dimension of the HPA is 25 × 15 × 1.5 mm^3, as shown in Fig. 7.

The HPA is measured both by the small signal performance

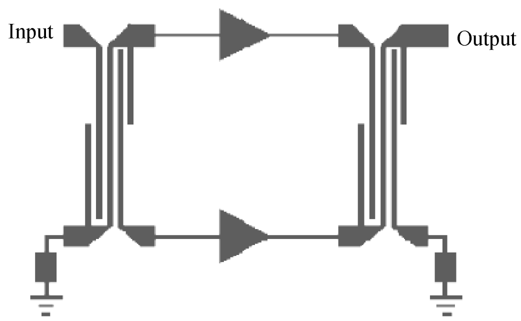

Fig. 6. Configuration of the broadband HPA.

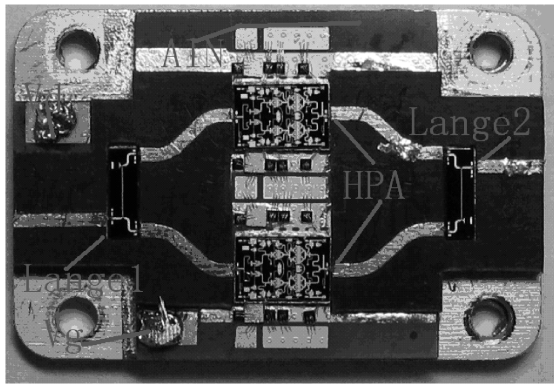

Fig. 7. 8–18 GHz broadband MIC HPA.

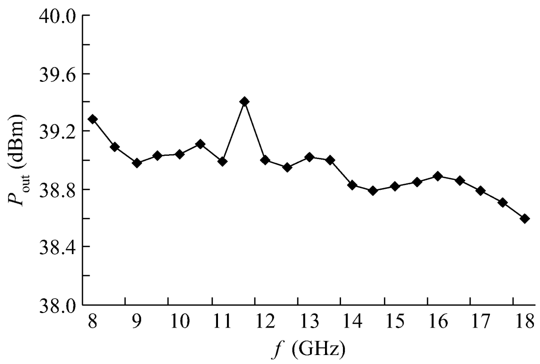

Fig. 8. Saturated output power ($V_d = 8$ V, $P_{in} = 25$ dBm).

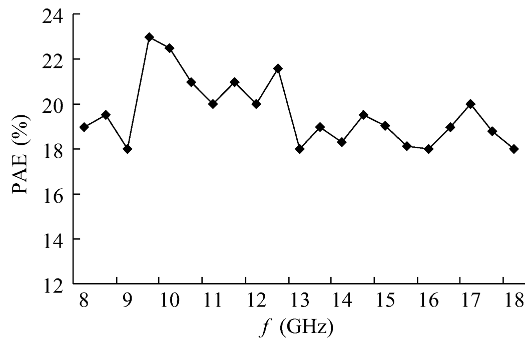

Fig. 9. Power-added efficiency ($V_d = 8$ V, $P_{in} = 25$ dBm).

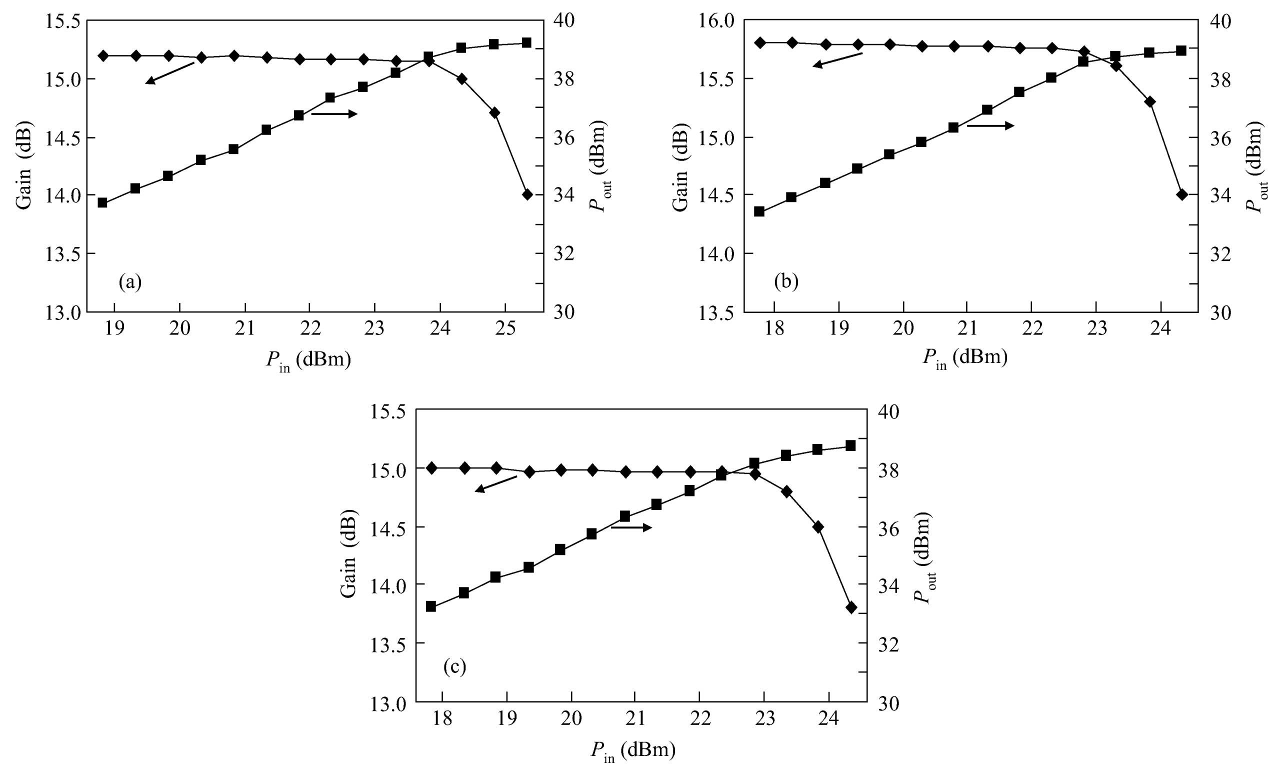

Fig. 10. Gain and power performance at (a) 8 GHz, (b)12 GHz, (c) 18 GHz.

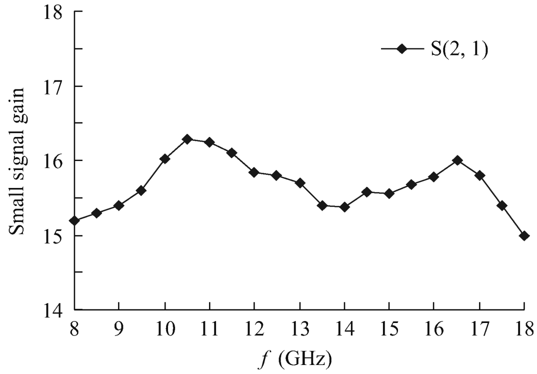

Fig. 11. The measured small signal gain ($P_{\rm in}$ = 18 dBm).

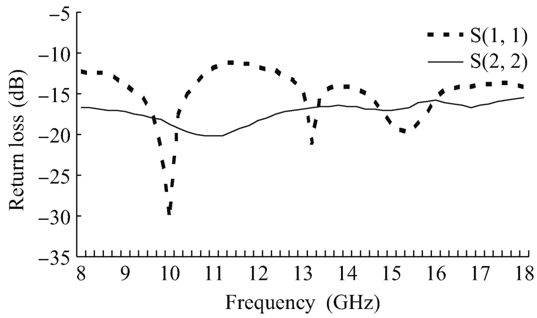

Fig. 12. The measured small-signal return loss of the amplifier.

and the power characters at a bias point of $V_{\rm ds}$ (leak voltage) = 8 V, $I_{\rm d}$ (quiescent current) = 2.5 A. Anritsu HP8350B is adopted as the signal source. A continuous wave input signal of 25 dBm is given to the amplifier. The output power is attenuated by 40 dB attenuate apparatus and then measured by Agilent E4416A power apparatus. The measurement results of output power are given in Fig. 8. The saturated power of the continuous wave (CW) outputted by the HPA is more than 39 dBm within the frequency range of 8–13 GHz and is more than 38.6 dBm within other frequency ranges. We get the peak power output, 39.4 dBm, with the frequency of 11.9 GHz. Within the frequency range of 8–18 GHz, the power-added efficiency (PAE) is above 18%, as shown in Fig. 9. The gain and the power performance at 8 GHz, 12 GHz and 18 GHz are shown in Fig. 10. The measured small signal gain is about 15.7 dB with ±0.7 dB gain flatness within the frequency range of 8–18 GHz when the input power is 18 dBm, as shown in Fig. 11. The measured small signal input and output return loss of the amplifier is shown in Fig. 12. The input return loss is less than –10 dB and the output return loss is less than –15 dB within the frequency range of 8–18 GHz.

4. Conclusion

An 8–18 GHz broadband hybrid integrated circuit HPA, using a four-fingered Lange coupler based on GaAs MMIC process, is designed and fabricated. The dimensions of the power amplifier are $25 \times 15 \times 1.5$ mm^3. When the input power (CW) is 18 dBm, the CW saturated power outputted by the HPA is more than 39 dBm within the frequency range of 8–13 GHz and more than 38.6 dBm within other frequency ranges. We obtain the peak power output, 39.4 dBm, with a frequency of 11.9 GHz.

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