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GaAs HBT Microwave Power Transistor with On-Chip Stabilization Network

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Abstract: An InGaP/GaAs HBT microwave power transistor with on-chip parallel RC stabilization network is developed with a standard GaAs MMIC process. From the stability factor K, the device shows unconditional stability in a wide frequency range due to the RC network. The power characteristics of the device as measured by a load-pull system show that the large-signal performance of the power transistor is affected slightly by the RC network. P_{sat} is 30dBm at 5.4GHz, and P_{1dB} is larger than 21.6dBm at 11GHz. The stability of the device due to RC network is proved by a power combination circuit. This makes the power transistor very suitable for applications in microwave high power HBT amplifiers.

Key words: HBT; microwave power transistor; stability

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1 Introduction

High-power amplifiers (HPA) have been developed using advanced semiconductor processes such as GaAs FET or HBT technology. HPAs have multiple stages and large periphery with power combination in order to realize high power and high gain[1,2]. They often work under a high bias and strongly nonlinear state. These factors make power transistors very prone to generate diversified parasitic oscillations due to the presence of a multiple nonlinear feedback loop[2,3]. The port impedance variation of the transistors due to thermal dissipation can also bring instability. In order to design an HPA successfully, the designer must pay attention to the device's stability and use an effective structure to restrain the oscillation. For high-power MMIC amplifier design, the power transistors, the matching network, and the bias circuit are integrated onto a substrate with very small size. Then, if the transistors oscillate, it is difficult to debug the oscillation within the chip[4]. Therefore the stability design of power transistors is much more important for MMIC design. In this paper, an InGaP/GaAs HBT microwave power transistor with on-chip RC stabilization network is developed. The RC network is adopted to improve the stability of the device. The effect of the RC network for the HBT device's stability and power characteristics are evaluated and compared to a device with no RC network. The stability of the device is proved by a C band two-cell power combination circuit.

2 GaAs HBT power transistor with RC stability network

2.1 Stability analysis of the device with RC network

When oscillation occurs, the port reflection coefficient of the power transistor is larger than 1, and the negative resistor takes effect. An effective structure must then be used to offset the negative resistor of the power transistor and eliminate the oscillation. The resistor of the RC network can offset the negative resistor in the transistor, thereby suppressing any oscillations. At high frequencies the reactance of the couple capacitor becomes low and compensates the attenuation of the power gain due to the resistor. Thus a power transistor with a parallel RC network can achieve unconditional stability in a wide range of frequencies from several hundred MHz to several GHz. In particular, an RC network can restrain

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the oscillation that is relative to the frequency, input power level, and the DC bias of the transistor[6,7].

The effect of the RC network on the device's stability can be simply evaluated by a stability factor K and load or source stability circle. K is calculated from small signal S parameter data, which can be measured for the power device with a network analyzer. The equation is as follows[8]:

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|},$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21}$$

When K is larger than 1, the device is unconditionally stable. The load stability circle of different frequencies can be drawn based on the S parameter by an EDA tool, and generally the stable area is outside of the circle on the Smith chart when $S_{11} < 1$[9].

Generally, an RC network is placed at the input of the power transistor in order to eliminate the effect on output power level. The value of R should make K above 1 in a wide frequency range and be as small as possible. C is selected by the operational frequency of the transistor. As a rule, the capacitive reactance is equal to the resistance R at the low end of the operational frequency range[6].

2.2 Device fabrication

The developed GaAs HBT power transistor with RC stabilization network is shown in Fig. 1. The GaAs HBT epitaxial wafer grown by MBE was provided by the Shanghai Institute of Microsystem and Information Technology of the Chinese Academy of Sciences. The power transistor cell is composed of ten 2×30 emitter fingers and is manufactured using a self-alignment process[5] in the 100mm compound semiconductor process line of IMECAS. The RC network includes a 50Ω TFR and 0.8pF MIM capacitor and is placed at the input of the power transistor.

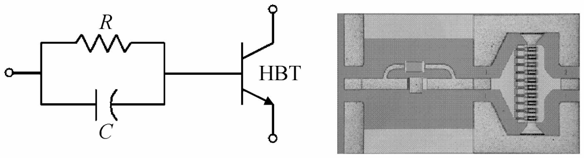

Fig. 1　Power transistor with RC stability network

3 Measurement results and discussion

3.1 S parameter measurement results

The small signal S parameter was measured from 0.1 to 15.1GHz by using HP8510 parameters network analyzer (PNA) system and Cascade probe station. With the EDA software ADS, the stability factor K was calculated and is shown in Fig. 2. The load stability circle is plotted in Fig. 3. The factor K and load stability circle of the power transistor with no RC network are also shown in Figs. 2 and 3. From the stability factor K shown in Fig. 2, the power transistor with the RC network is unconditionally stable in the entire frequency range, and then the load stable circles have no superposition on the Smith chart. On the contrary, the power transistor with no RC is no longer unconditionally stable when $f < 6$GHz, and the load stable circles have much superposition on the Smith chart. If the port impedance enters the superposition area, the transistor is prone to oscil-

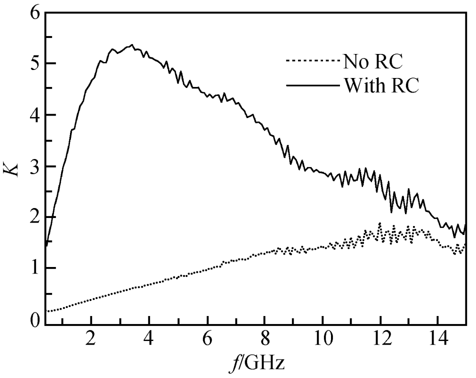

Fig. 2　Stable factor K of the power transistor

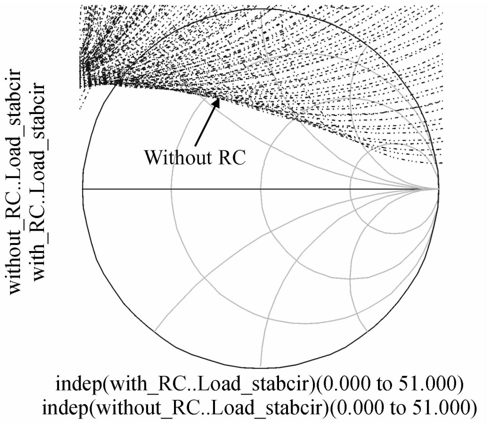

Fig. 3　Load stability circle of the power transistor

late. According to the factor K and the stability circle, the RC network improves the stability of the power transistor.

3.2　Load-pull measurement results

The on-chip load-pull measurement of the power transistor with or without RC network has been performed for the CW mode. The curves of power gain and output power level versus input power level at 5.4GHz are shown in Fig. 4. The curves at 11GHz are shown in Fig. 5. At 5.4GHz, the small signal power gain of the power transistor with RC is 6.5dB, P_{sat} is 30dBm, the small signal power gain of the power transistor without RC is 10dB, and P_{sat} is 30dBm. At 11GHz, the small signal power gain of the power transistor with RC is 3.6dB, P_{1dB} is larger than 21.6dBm, and the small signal power gain of the power transistor without RC is 4.2dB. From the above data, the stabilizing RC network reduces the small signal gain by 3.5dB at 5.4GHz, but due to the couple capacitor it only reduces the small signal gain by 0.6dB at 11GHz. We can predict that if the couple capacitor is larger than 0.8pF and the K factor is above 1, a high gain and high stability power transistor could be obtained at 5.4GHz. The values of the RC could be optimized according to the operational frequency. Furthermore, the larger signal performance of the power transistor is not affected much by the RC network. In addition, it is difficult to find an optimum impedance for the power transistor without RC because the transistor is oscillating in some area of the Smith chart. But no oscillation was found for the stable power transistors in the whole area of the Smith chart. The test is quick and effective due to the RC stabilization network.

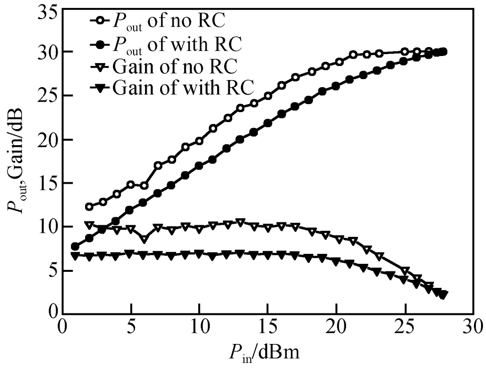

Fig. 4　P_{out} and gain versus P_{in} at C band

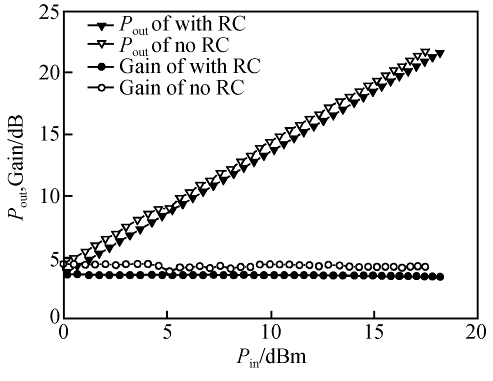

Fig. 5　P_{out} and gain versus P_{in} at X band

3.3　Circuit validation of stability

A C band internal match power amplifier with two power transistor chips is shown in Fig. 6. The circuit is mounted on a copper-tungsten carrier and tested using a fixture with a bias network. Though the circuit does not oscillate with one power transistor mounted at the DC test with no RF drive, the circuit is found to oscillate with two power transistors mounted. The oscillation is shown in Fig. 7, and the abnormal DC I-V curve is shown in Fig. 8. The oscillation is strong and not eliminated by modifying the bias decouple network. Therefore the performance of the circuit with RF drive cannot be tested. The circuit does not work due to the oscillation. Then a power transistor with RC network is used in the same oscillating circuit. With high mismatch and simple bias decouple network, the new circuit is perfectly stable at all DC bias points. The normal DC I-V

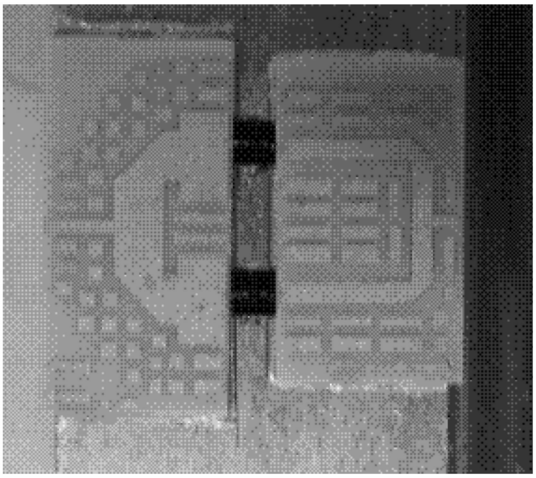

Fig. 6　Internal match power amplifier circuit

curve of the stable circuit is shown in Fig. 8. The power transistor with RC network saves the time of eliminating the oscillation and makes the circuit functional.

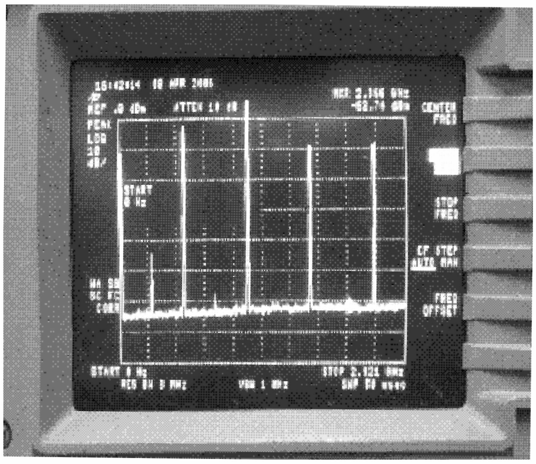

Fig. 7 Oscillation spectrum

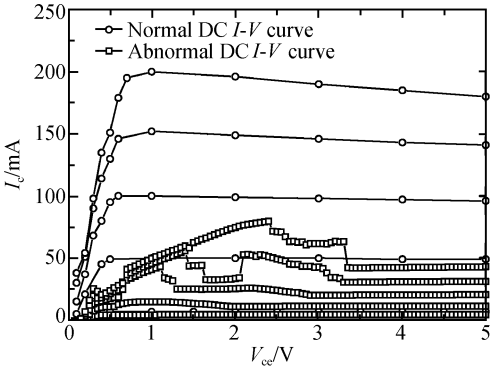

Fig. 8 Normal and abnormal DC *I*-*V* curve

4 Conclusion

A GaAs HBT C/X band microwave power transistor with RC stabilization network was developed successfully. According to the analysis of the stability factor K, the power transistor is unconditionally stable through a wide frequency range, especially at low and medium frequencies. The stability of the power transistor is improved by an RC network. The large signal performance of the power transistor is not affected much by the RC network. At 5.4GHz, the stable P_{sat} is 30dBm. At 11GHz, P_{1dB} is more than 21.6dBm. The high stability of the power transistor was demonstrated by the load-pull test and a C band internal match power combination circuit. This makes the power transistor very suitable for applications in high-power HBT amplifiers.

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具有在片稳定网络的 GaAs HBT 微波功率管

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摘要：采用 GaAs 标准 MMIC 工艺制作了具有片上 RC 并联稳定网络的 InGaP/GaAs HBT 微波功率管单胞. 依据 K 稳定因子，RC 网络使功率管在较宽的频带内具有绝对稳定特性. Load-pull 测试表明 RC 网络没有严重影响功率管的大信号特性，在 5.4GHz 饱和输出功率为 30dBm，在 11GHz 1dB 压缩点输出功率大于 21.6dBm. 功率合成电路验证了该功率管具有高稳定性，非常适合制作微波大功率 HBT 放大器.

关键词：HBT；微波功率管；稳定性

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