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A Radial Stub Test Circuit for Microwave Power Devices *

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Abstract: With the principles of microwave circuits and semiconductor device physics, two microwave power device test circuits combined with a test fixture are designed and simulated, whose properties are evaluated by a parameter network analyzer within the frequency range from 3 to 8GHz. The simulation and experimental results verify that the test circuit with a radial stub is better than that without. As an example, a C-band AlGaN/GaN HEMT microwave power device is tested with the designed circuit and fixture. With a 5.4GHz microwave input signal, the maximum gain is 8.75dB, and the maximum output power is 33.2dBm.

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1 Introduction

Radio frequency high power devices are key components in radar and wireless communication systems that directly influence the communication quality[1]. However, due to their high operating frequency, it is quite difficult to characterize a microwave device's performance, especially a packaged device. Since a device needs not only an on-wafer test during the processing, but also to be packaged and tested again before being incorporated into a system, a test circuit with a fixture for the packaged device is absolutely necessary. It acts as an electrical and mechanical interface from the microwave signal test system to the device under test (DUT). In microwave circuits, since it is not always desired that a DC connection transmit RF signals, surface mounted (SMT) capacitors are often used to block microwave signals in the DC bias circuits of the test circuit. At high frequencies, however, SMT capacitors tend to have a large parasitic resistance, capacitance, and inductance. These parasitics are often the origin of loss, reflection, and the excitation of harmonics, resulting in the failure of the test circuits. In addition, the soldering of the SMT capacitors may also cause the same problem at high frequencies.

In order to evaluate performance of a packaged microwave high power device, it is necessary to consider the loss, reflection, oscillation prevention, and other characteristics of the test circuit. This paper concentrates on the use of a radial stub to bias the microwave power device in a printed circuit board (PCB) test circuit. With the example of an AlGaN/GaN HEMT[2] microwave power device, this paper analyzes the measuring principle and methods of the main parameters of the device. The influential factors during the device testing are also discussed.

2 Design and evaluation

2.1 Radial stub

A radial stub is a useful microstrip line[3]. It is used in many microwave circuits, such as amplifiers, filters, and mixers, to realize impedance matching or an RF ground. An RF ground connection is usually defined by its resistance at the observed

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frequency toward the ground potential and should be as low as possible. Usually, a resistance below 5Ω is seen as an RF ground. As depicted in Fig. 1, a radial stub has three characteristic parameters: the radius R_L, the angle α, and the inner radius R_i. The reactance of the radial stub is[4]

$$X_1 = \frac{h}{2\pi r_1} Z_0(r_1) \frac{360}{\alpha} \times \frac{\cos(\theta_1 - \psi_2)}{\sin(\psi_1 - \psi_2)}$$

where

$$Z_0(r_1) = \frac{120\pi}{\sqrt{\varepsilon_r}} [J_0^2(kr_1) + N_0^2(kr_1)]^{1/2} \times [J_1^2(kr_1) + N_1^2(kr_1)]^{-1/2}$$

$$\tan\theta_i = \frac{N_0(kr_i)}{J_0(kr_i)}, \tan\psi_i = -\frac{J_1(kr_i)}{N_1(kr_i)}, \quad i = 1,2$$

$$k = 2\pi \sqrt{\varepsilon_{re}} / \lambda_0$$

where Z_0 is the wave impedance of a radial transmission line, and h is the metal thickness. The variables α, r_1, and r_2 represent the angle, inner radius, and radius, respectively. J_n is the Bessel function of the first kind of order n, and N_n is the Bessel function of the second kind of order n. Finally, k is the wavenumber, and ε_{re} is the dielectric constant.

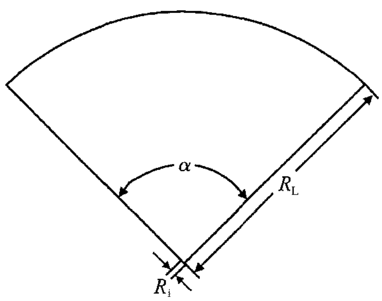

Fig. 1 Characteristic parameters of radial stub

Many microwave circuits require shunt stubs with low characteristic impedance to realize a matching condition or DC bias. However, the width of these shunt stubs is often a significant fraction of the wavelength at high frequencies. The result is that larger harmonic modes are excited by the distributed tee-junction effect, which is not contained in simulation but introduces the possibility of oscillation. Then the circuit will not work as expected. The radial stub is proposed to solve this problem. It can behave as a low impedance stub, creating a precise insertion point that can escape from the tee-junction effect. Then larger harmonic modes will not be excited. Therefore the oscillation, which may result in severe damage to the DUT, can be well prevented, and a smaller reflection can be obtained as well[5,6].

In addition, planar circuits often need a microwave short through an extra means such as metal via hole, which often produces parasitic inductance. The radial stub will realize a short circuit at the point where it is placed, making the metal via hole in the planar circuit unnecessary. Thus the parasitic, which often produces loss and oscillation at high frequencies, will be decreased. Furthermore, a radial stub has a wider bandwidth due to its larger fringing capacitance at the open end, which makes it possible to have little loss and reflection at high frequencies[6~8].

2.2 Design and simulation

With EDA software, we designed two kinds of PCB test circuits. As can be seen from Fig. 2, they mainly consist of the microwave main line and the DC bias network. The characteristic impedance of the main line is 50Ω. SMT capacitors are used as a DC block. The quarter wave micro-strip line, the radial stub, and the DC pads constitute the bias network. The quarter wave micro-strip line's characteristic impedance is 125Ω, which is intended to be an RFC of the microwave signal. The difference between the two kinds of circuits is that the right one uses a radial stub, with its optimized parameters being the radius R_L = 6.6mm, the angle α = 90°, and the inner radius R_i = 1mm to ground the microwave signal, while the left one uses SMT capacitors to substitute the radial stub. The radial stub realizes a microwave short. After the series with the quarter wave microstrip line, however, they realize a microwave open state together, and then they produce little reflection and loss to the microwave signal on the main line. Hence they can be used as a DC bias network. The same is true for the SMT capacitor in series with the quarter wave line[7].

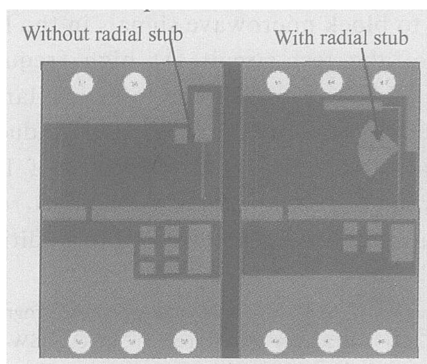

Fig. 2 Two kinds of PCB test circuits

The simulation of the PCB test circuits is carried out with EDA software. After optimization, the simulated S parameters are given in Fig. 3. At the frequency of 5.4GHz, the circuit with the radial stub has $S_{11} = -47.6$dB and $S_{21} = -0.08$dB. The corresponding results of that without the radial stub are $S_{11} = -26.1$dB and $S_{21} = -0.095$dB. These results indicate that the test circuit with the radial stub has good reflection and loss characteristics. The reason is that the radial stub creates a microwave short at a precise point, which means little reflection and loss of the microwave signal. Furthermore, there is no effect of soldering by using a radial stub, compared with using SMT capacitor.

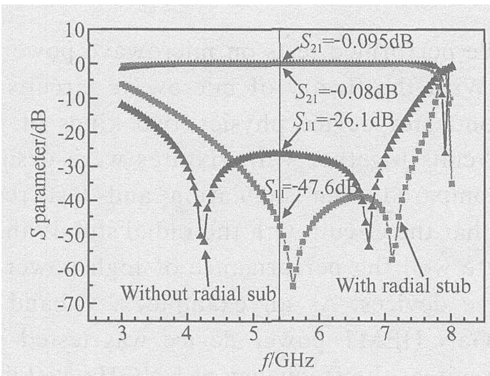

Fig. 3 Simulation results of two kinds of PCBs

In addition to the PCB test circuit, the test fixture is also designed. The PCB test circuit is fixed on the fixture that is connected with the microwave signal as well as the DC power. The packaged device under test is to be mounted between the two PCB test circuits, with the pins of the package connected to the microstrip line on the PCB.

2.3 Circuit evaluation

Before testing the device, small signal evaluation of the passive fixture including the PCB test circuit was carried out with a parameter network analyzer (PNA). The frequency range is from 3 to 8GHz. The S parameters of the two PCB test circuits measured are shown in Fig. 4. It is clear that both the reflection and loss of the circuit with the radial stub are better than that without the radial stub, which is in accordance with the simulation results. To quantify the benefit of using a radial stub, the corresponding results are $S_{11} = -26.56$dB, $S_{21} = -0.90$dB; $S_{11} = -18.19$dB, $S_{21} = -1.44$dB. The reason may be that by using the capacitors to ground the microwave signal, the DC bias line is neither shorted nor opened to the signal of 5.4GHz very well. This causes loss and reflection to the microwave signal of 5.4GHz. The soldering of the SMT capacitor has bad effects as well. In addition, it can be seen from Fig. 4 that the bandwidth of the radial stub test circuit is larger than that with the SMT capacitor.

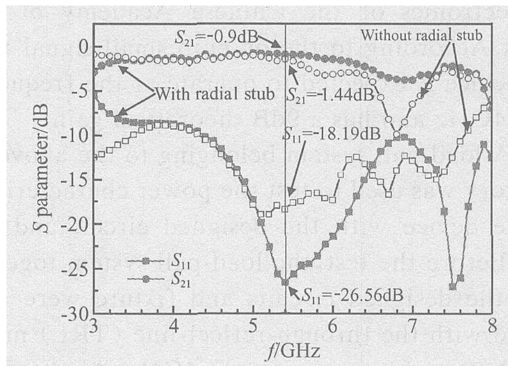

Fig. 4 Small signal test results of two kinds of PCBs

Figure 5 shows the measured and simulated results of the circuit with the radial stub. At the frequency of 5.4GHz, both the reflection and loss of the measured results are worse than those of the simulated results. The degradation is due to the parasitic capacitance and inductance of the DC block, the SubMiniature A (SMA) connector, the coil inductor of the fixture, etc., all of which cannot be accounted for in the simulation. Regardless, according to the measured results, the reflection and loss of the circuit are acceptable. Therefore, the test circuit with the radial stub can be used to test microwave devices together with the designed fixture.

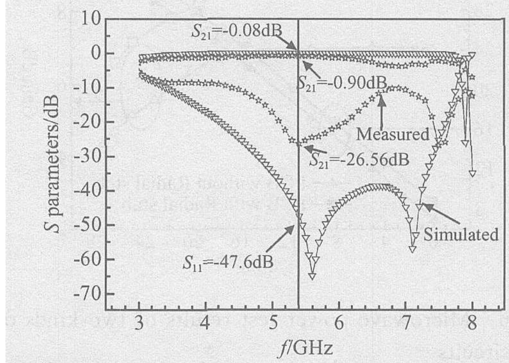

Fig. 5 Simulation and test results of test circuit with radial stub

3 Device test and discussion

In our work, the packaged C-band AlGaN/GaN HEMT power device is tested with the designed fixture, which has a promising application under conditions of high frequency and high power. The device is provided by the Microwave Device and Circuit Laboratory of the Institute of Microelectronics of the Chinese Academy of Sciences. According to the on-chip small signal test, the device is expected to operate at the frequency of 5.4GHz and has a 9dB theoretical gain.

A load-pull system belonging to the above laboratory was used to test the power characteristics of the device with the designed circuit and fixture. Before the test, the load-pull system together with the designed circuits and fixture were calibrated with the through-reflect-line (TRL) method. The test frequency was 5.4GHz. As shown in Fig. 6, the test results of the DUT are a maximum gain of 8.75dB and a maximum output power of 33.2dBm. The corresponding results of that using the SMT capacitor are 7dB and 31.85dBm. Both the measured gain and the maximum output power of the DUT through the PCB test circuit with the radial stub are better than that without, a finding that agrees well with the simulation and PNA test results. Compared with the 9dB theoretical gain, the result of the radial stub test circuit is very close to the theoretical value. The measured gain error percentages of the two test circuits are 2.78% and 22%, respectively.

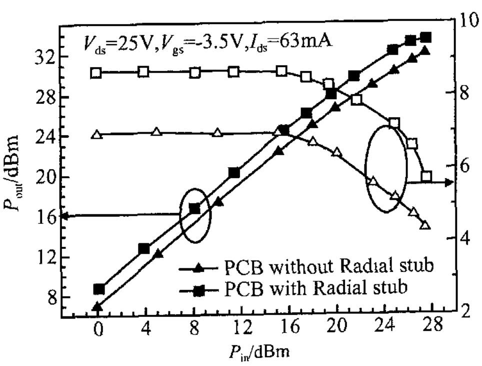

Fig. 6 Microwave power test results of two kinds of test circuits

In addition, the experiment was repeated with several other C-band AlGaN/GaN HEMT power devices. The results, given in Table 1, also show that the designed PCB with the radial stub is better than that without. Therefore, the designed test circuit with the radial stub can test microwave power devices.

Table 1 Results of several other samples tested with two kinds of circuits

	Sample one		Sample two		Sample three	
	Gain / dB	P_{outmax} / dBm	Gain / dB	P_{outmax} / dBm	Gain / dB	P_{outmax} / dBm
With radial stub	8.69	33.06	8.52	32.88	8.48	32.75
Without	8.02	31.68	7.35	31.05	7.15	31.15

4 Conclusion

We performed tests on microwave power devices. With the theory of microwave circuits and semiconductor device physics, two kinds of PCB test circuits together with fixtures were designed and compared. The simulation and test results show that the circuit with the radial stub is able to evaluate well the performance of high power microwave devices. As an example, a C-band AlGaN/GaN HEMT power device was tested with the circuit, at the frequency of 5.4GHz, yielding a maximum gain of 8.75dB, within an error of 2.78%, and a maximum output power of 33.2dBm. The test results are very close to the theoretical values, verifying the success of the designed test circuit together with the fixture.

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微波功率器件的扇形线测试电路 *

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摘要: 在微波电路原理和半导体器件物理的基础上,设计和模拟了两种用于微波功率器件的测试电路,并且设计了与之配套的测试夹具. 采用矢量网络分析仪对该测试电路和夹具在 3～8 GHz 范围内进行了小信号测试. 模拟和测试结果都表明,采用扇形线的测试电路性能较好. 最后采用该电路和夹具对 C 波段 AlGaN/GaN HEMT 微波功率器件进行了微波功率测试,测试频率为 5.4 GHz. 实验测得最大功率增益为 8.75dB,最大输出功率为 33.2dBm.

关键词: 扇形线; 测试电路; 氮化镓; 高电子迁移率晶体管
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