Abstraction of Small Signal Equivalent Circuit Parameters of Enhancement-Mode InGaP/AlGaAs/InGaAs PHEMT*

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Abstract: An extraction method of the component parameter values of an enhancement-mode InGaP/AlGaAs/InGaAs PHEMT small signal equivalent circuit is presented, and these component parameter values are extracted by using the EEHEMT1 model of IC-CAP software. The extraction results are verified by ADS software, and the DC *I-V* curves and *S* parameters simulated by ADS are basically accordant with those of the test results. These results indicate that the EEHEMT1 model can be used for extracting the component parameters of an enhancement-mode PHEMT.

Key words: enhancement-mode; InGaP/AlGaAs/InGaAs PHEMT; small signal equivalent circuit; parameter extraction

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1 Introduction

GaAs PHEMTs have demonstrated excellent high frequency, high speed, and low noise performance, so they have been widely used in microwave and millimeter-wave circuits and high-speed digital circuits. Compared with conventional circuits based on depletion-mode GaAs PHEMTs, the advantages of direct-couple FET logic (DCFL) using enhancement/ depletion-mode GaAs PHEMTs (E/D GaAs PHEMTs) include high speed, low power consumption, design simplicity (no voltage level shift), and the need for only one positive power supply[1~3].

The realization of E PHEMT's positive threshold voltage is the key for fabrication of E/D PHEMTs. To obtain good selective etching, an InGaP/AlGaAs/InGaAs PHEMT structure is chosen[4]. While fabricating the gate recess of the E PHEMT, an InGaP layer is etched and an AlGaAs layer is used as the Schottky layer of the E PHEMT.

Exact extraction of E PHEMT device parameters is very important for optimizing E/D PHEMT devices and circuits. In this paper, we report the extraction of parameters of E PHEMT devices with the EEHEMT1 model of IC-CAP software, based on the normal extraction experiences of D PHEMT device parameters.

2 Extraction method

The HEMT small signal equivalent circuit model has a crucial function for analyzing circuits and judging device performances. A basic HEMT small signal equivalent circuit model is shown in Fig. 1, which is similar to a MESFET small signal equivalent circuit model[5]. Linear component values do not depend on bias conditions, including series inductance (L_s, L_d, and L_g), series resistance (R_s, R_d, and R_g), source drain additional capacitance (C_{ds}), and parasitic capacitance (C_{pg}, C_{pd}). On the contrary, non-linear component values depend on bias conditions, including non-linear current source $J_{ds}(V_d, V_g)$, non-linear capacitance (C_{gs}, C_{gd}), and R_i.

Yang Long's method[6] is used in the EEHEMT1 model of IC-CAP software for extracting end resistance R_s. The voltages used in his method must be optimized in the preview setup. The two drain currents, which differ within 10%, are cho-

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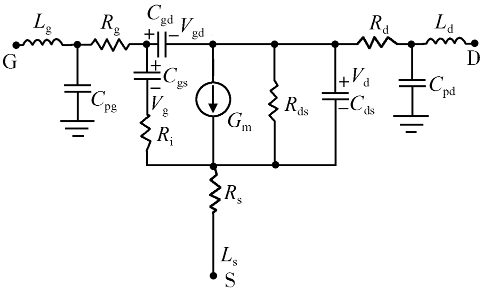

Fig.1 Topology of HEMT small signal equivalent circuit

sen in the linear *I-V* region. In general, V_{ds} is smaller than 0.25V to ensure that the channel resistance remains constant. R_s is computed using Yang Long's method from the alteration of V_{gs} due to the application of two drain currents that are 50～100 times greater than I_g.

When the positive bias is small, the gate junction can be treated as an ideal distributing Schottky diode, and the current is expressed as

$$I = I_s\left[\exp\left(\frac{qV}{kT}\right) - 1\right] \quad (1)$$

where I_s is the reverse saturation current of the Schottky diode and V is the positive bias.

Because the gate diode has a series resistance, when the current is big, the voltage across the resistance is too big to be neglected. Thus it can make the measured *I-V* curve deviate from the ideal curve, and then the actual *I-V* characteristic can be expressed as

$$V = \frac{kT}{q}\ln\left(\frac{I}{I_s} + 1\right) + IR \quad (2)$$

Contact resistances R_g and R_d are extracted with the cold FET method[7]. The device is strongly forward-biased in both the gate-drain and gate-source regions to simplify the linear equivalent circuit. A series of matrix operations are used in cold FET method for extraction. Because the value of R_s has been extracted with the above Yang Long's method, R_g and R_d can be respectively extracted.

After parasitic resistances (R_s, R_d, and R_g) were extracted, the values of other parasitic components were extracted by Arnold Golio's method[8] from S parameters measured across V_{gs} with V_{ds} at nominal operating points. It is particularly important to verify the nominal operating conditions that are used for extractions of contact resistance and parasitic parameters; otherwise errors are caused.

In this setup, S parameters are measured at the nominal V_{ds} bias point, while the value of V_{gs} varies from pinch-off to I_{dss}. This large scanning range of V_{gs} values allows the largest intrinsic model variations to increase the impact of parasitic components for making extraction easier in the later procedures.

3 Extraction and validation

The EEHEMT1 model of IC-CAP software and HP8510 network analyzer are used to extract the parameters of E PHEMT devices. Enhancement-mode InGaP/AlGaAs/InGaAs PHEMTs are fabricated by the compound semi-conductor craft line of the Institute of Microelectronics of the Chinese Academy of Sciences. The gate length, gate width, and source-drain distances are 1, 30, and 4μm, respectively.

Measurement scope is optimized in source resistance setup, and the value of R_s extracted by Yang Long's method is 39.84Ω.

A lower frequency is set to obtain better test curves for extracting R_g and R_d in the cold FET setup, and the frequency scope is from 0.1 to 2.5GHz. As a result, the extraction values of R_d and R_g are 24.44 and 9.444Ω.

In the opt_pkg item of the Package setup, all parameter values are adjusted, so simulation curves of S parameters keep almost consistent with their measurement curves.

Transfer characteristic and transconductance characteristic curves of the E PHEMT device are shown in Fig.2 and Fig.3 (Dashed and solid lines are measurement results and simulation results, re-

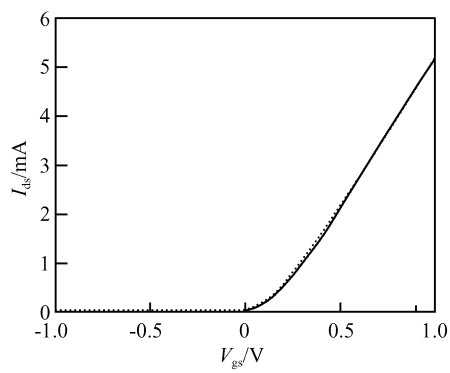

Fig.2 Simulation and measurement curves of transfer characteristic

spectively, in these and all following figures). From Fig. 2, the threshold voltage of the E PHEMT is about 0V. Figure 3 shows that G_m has a peak value when V_{gs} is 0.6V.

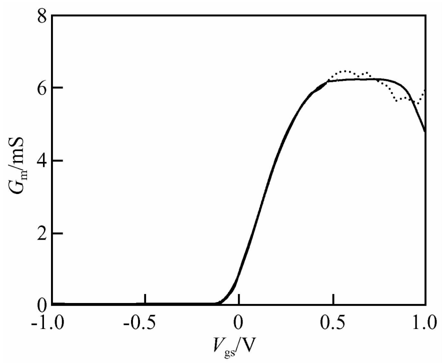

Fig.3　Simulation and measurement curves of transconductance characteristic

The DC *I-V* characteristic curve of the E PHEMT is shown in Fig. 4. The values of the DC parameters are alterable by executing opt_iv_hemt1. When the simulation curve is very close to the measurement curve, the ultimate values of the DC parameters are obtained.

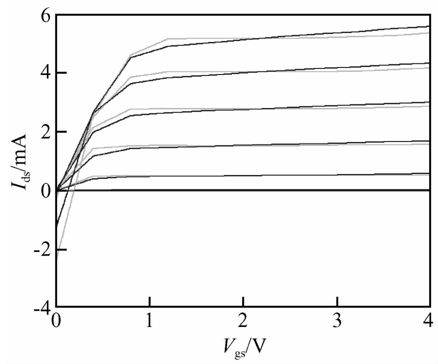

Fig.4　Simulation and measurement curves of DC *I-V* characteristic

In AC_at_VDSO/Meas_Spars and AC_all/Meas_Spars setup, the charge model and dispersion model parameters are extracted. File_Validate setup is used to verify whether simulation *S* parameter data is close to those of measurements at expected bias points. Simulated and measured curves of *S* parameters are shown in Fig. 5 and Fig. 6.

The extracted values of the EEHEMT1 model parameter are inputted into ADS software. The simulation results of ADS are used to verify the

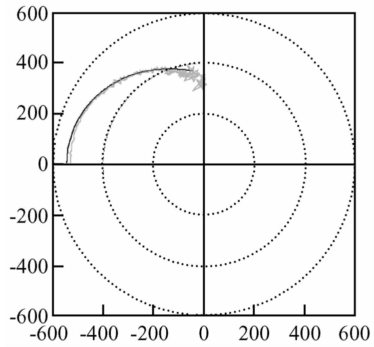

Fig.5　Simulated and measured curves of S_{21}

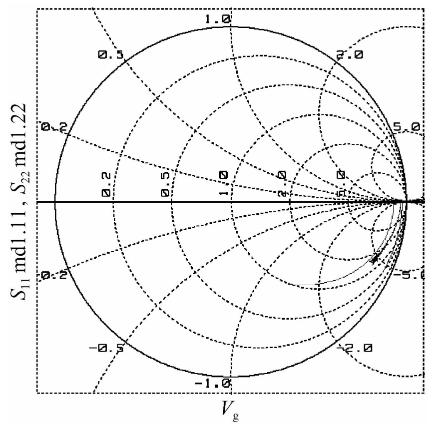

Fig.6　Simulated and measured curves of S_{22} and S_{11}

validity of the results, which are extracted by IC-CAP. Figure 7 shows the simulation curves of the DC *I-V* characteristic by ADS, and Figure 8 and Figure 9 show the simulation curves of S_{21} and S_{11}, respectively by ADS. The simulation results of ADS are similar to those measurement results, which verifies that the method of extracting component parameter values of enhancement-mode InGaP/AlGaAs/InGaAs PHEMT small signal equivalent circuit is correct.

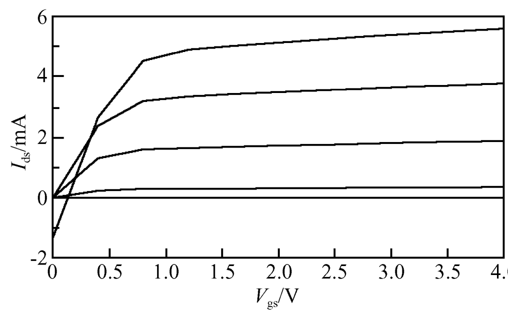

Fig.7　Simulation curves of DC *I-V* characteristic

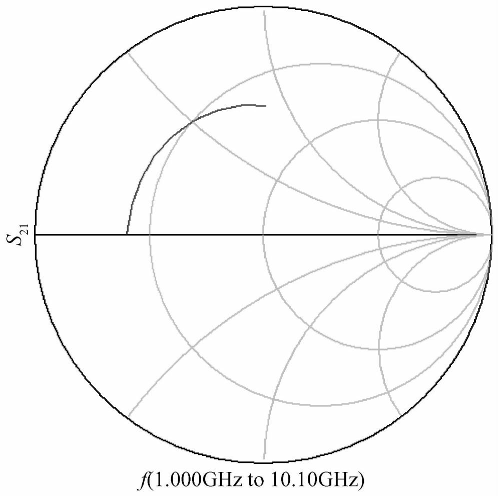

Fig. 8 Simulation curve of S_{21}

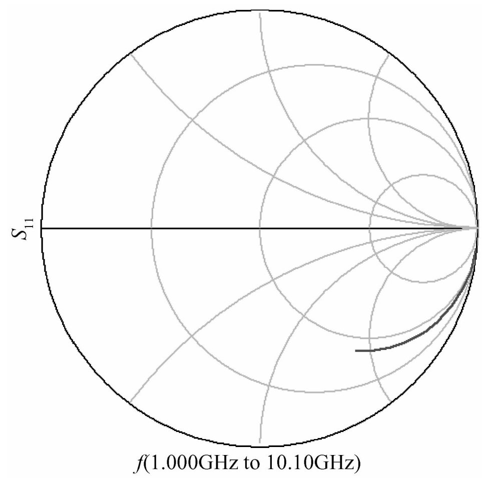

Fig. 9 Simulation curve of S_{11}

4 Summary

The component parameter values of an enhancement-mode InGaP/AlGaAs/InGaAs PHEMT small signal equivalent circuit are extracted. The extraction results are verified by ADS software, and the simulation results of ADS are similar to the measurement results, verifying that the extraction method is correct. The extracted component parameter values can be used in circuit design later.

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增强型 InGaP/AlGaAs/InGaAs PHEMT 小信号等效电路参数的提取*

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摘要： 介绍了增强型 InGaP/AlGaAs/InGaAs PHEMT 小信号等效电路中元件参数值的提取方法，并利用 IC-CAP 软件 EEHEMT1 模型提取了参数. 利用 ADS 软件验证了提参结果，ADS 仿真的直流 *I-V* 曲线和 *S* 参数与实测结果基本吻合. 结果表明 EEHEMT1 模型可以用于提取增强型 PHEMT 参数，并且具有可操作性.

关键词： 增强型；InGaP/AlGaAs/InGaAs PHEMT；小信号等效电路；参数提取
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