DIRECT EXTRINSIC PARAMETER EXTRACTION FROM COLD MEASUREMENTS

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I. INTRODUCTION

An approach to direct extraction of extrinsic parameters for MESFETs and HEMTs from cold measurements ($V_{DS} = 0$) is implemented in HarPE [1]. The extrinsic parameters are analytically extracted from the unbiased ($V_{GS} = 0$, $V_{DS} = 0$) and pinched-off ($V_{GS} < V_P$, $V_{DS} = 0$, where V_P is the pinched-off voltage) measurements. No optimization is involved. It provides a fast way of determining the parasitic elements. It is very useful in two-stage parameter extraction of MESFET and HEMT devices. First, the extrinsic parameters are analytically extracted from the cold measurements. Then, the intrinsic parameters are extracted from the hot measurements while keeping the pre-extracted extrinsic parameters fixed.

II. PARAMETER EXTRACTION

In general, an equivalent circuit of a MESFET or HEMT model can be decomposed into two parts: the intrinsic circuit and extrinsic circuit as shown in Fig. 1. The intrinsic circuit consists of nonlinear elements such as nonlinear capacitors and controlled sources which model the nonlinear characteristics of the device. The extrinsic circuit contains all the parasitic elements which represent the parasitic property of the device.

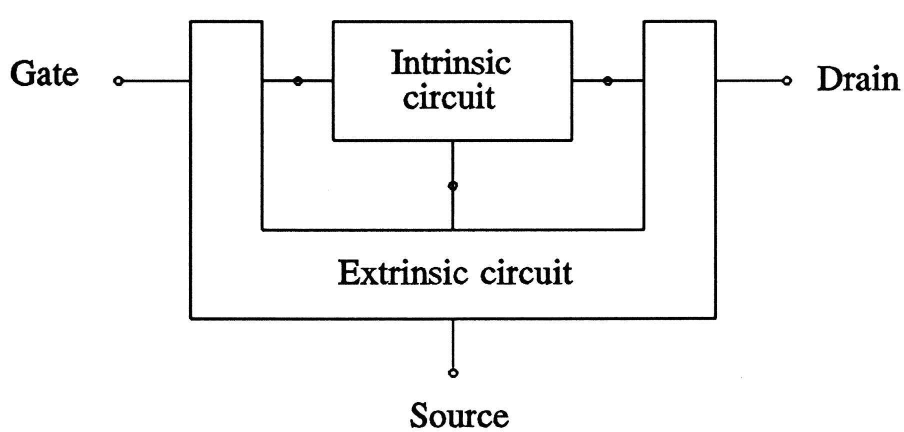

Fig. 1 The equivalent circuit of a MESFET or HEMT device.

Usually, all the parameter values of the equivalent circuit are obtained through optimization by fitting the model responses to the corresponding measurements such as DC, small-signal and large-signal measurements. Parameter extraction using optimization method can provide accurate models to fit DC/small-signal/large-signal measurements simultaneously [1]. It is a general method used in device modeling. However, the parameter values may varies for different optimizers and starting points, particularly with a large number of optimizable variables. It is also time consuming comparing to the direct analytical parameter extraction.

When a MESFET or HEMT is biased at V_{DS} = 0 the intrinsic circuit of the model can be significantly simplified. This makes it possible to extract the extrinsic circuit parameters analytically. There are a number of advantages of analytical parameter extraction such as fast, accurate and independent of initial values.

Two types of cold measurements are used in the current implementation of the cold parameter extraction method. Either of the four extrinsic circuits (EXTRINSIC1, EXTRINSIC2, EXTRINSIC3 and EXTRINSIC4) provided in Harpe [1] can be employed. In the following discussion, we use EXTRINSIC1 as shown in Fig. 2. The results are applicable to other extrinsic circuits.

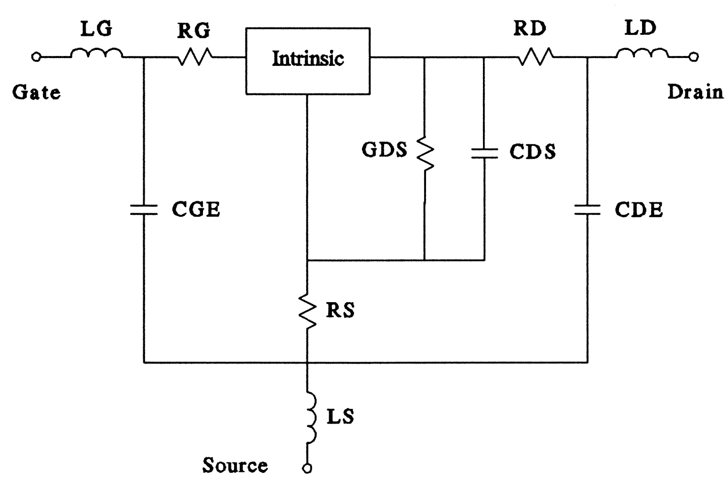

Fig. 2 Schematic of extrinsic circuit EXTRINSIC1 with its associated intrinsic circuit.

A. Unbiased FET

The equivalent circuit of the unbiased MESFET or HEMT can be simplified as the circuit shown in Fig. 3 [2-4] by neglecting the influence of capacitances C_{GE}, C_{DS}, C_{DE} and conductance G_{DS} on the Z parameters of the overall circuit.

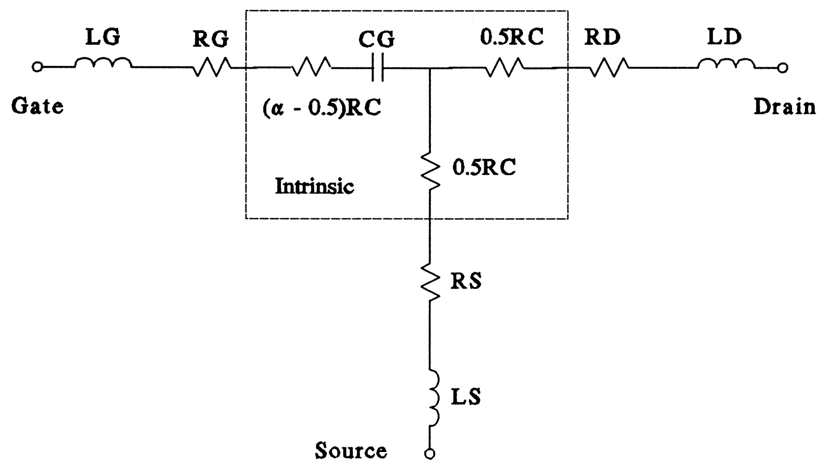

Fig. 3 Simplified equivalent circuit under unbiased condition.

The Z parameters of this circuit can be written as [2]

$$Z_{11u} = R_G + \alpha R_C + R_S + j[\omega(L_G + L_S) - 1 / (\omega C_G)] \tag{1a}$$

$$Z_{12u} = Z_{21u} = R_S + 0.5R_C + j\omega L_S \tag{1b}$$

$$Z_{22u} = R_D + R_C + R_S + j\omega(L_D + L_S) \tag{1c}$$

The real parts of the Z parameters can be written as

$$Re\{Z_{11u}\} = R_G + \alpha R_C + R_S \tag{2a}$$

$$Re\{Z_{12u}\} = Re\{Z_{21u}\} = R_S + 0.5R_C \tag{2b}$$

$$Re\{Z_{22u}\} = R_D + R_C + R_S \tag{2c}$$

The imaginary parts of the Z parameters can be represented by

$$Im\{Z_{11u}\} = \omega(L_G + L_S) - 1 / (\omega C_G) \quad (3a)$$

$$Im\{Z_{12u}\} = Im\{Z_{21u}\} = \omega L_S \quad (3b)$$

$$Im\{Z_{22u}\} = \omega(L_D + L_S) \quad (3c)$$

B. Pinched-off FET

The equivalent circuit of the pinched-off MESFET or HEMT can be simplified as the circuit shown in Fig. 4 [3,4].

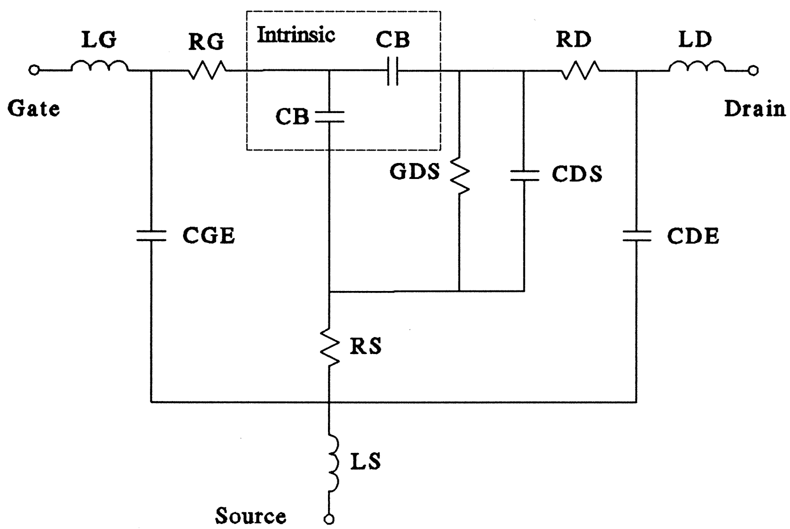

Fig. 4 Simplified equivalent circuit under pinched-off condition.

By neglecting the effect of G_{DS}, capacitances and inductances on the real parts of Z parameters, the real part of Z_{11} under pinched-off condition can be written as [2,4]

$$Re\{Z_{11p}\} = R_G + R_S \quad (4)$$

For frequency up to a few gigahertz, the influence of the resistances and inductances on the imaginary part of the Y parameters can be ignored. Then, the imaginary parts of the Y

parameters under pinched-off condition can be written as [3,4]

$$Im\{Y_{11p}\} = \omega(C_{GE} + 2C_B) \tag{5a}$$

$$Im\{Y_{12p}\} = Im\{Y_{21p}\} = -\omega C_B \tag{5b}$$

$$Im\{Y_{22p}\} = \omega(C_{DS} + C_{DE} + C_B) \tag{5c}$$

C. Analytical Parameter Extraction

From Eqs. (1) - (5), the parameter values can be solved for analytically under the unbiased and pinched-off conditions.

a. Solving for Resistances

Subtracting Eq. (4) from Eq. (2a) gives

$$R_C = (Re\{Z_{11u}\} - Re\{Z_{11p}\}) / \alpha \tag{6}$$

Following [2], a value of 0.3 is chosen for α. Once R_C is known, R_G, R_D and R_S can be obtained by solving Eqs. (2a) - (2c). The results are

$$R_S = Re\{Z_{12u}\} - 0.5R_C \tag{7}$$

$$R_D = Re\{Z_{22u}\} - Re\{Z_{12u}\} - 0.5R_C \tag{8}$$

$$R_G = Re\{Z_{11u}\} - Re\{Z_{12u}\} - (\alpha - 0.5)R_C \tag{9}$$

b. Solving for Inductances

The inductances L_D and L_S can be obtained by solving Eqs. (3b) and (3c).

$$L_S = Im\{Z_{12u}\} / \omega \tag{10}$$

$$L_D = (Im\{Z_{22u}\} - Im\{Z_{12u}\}) / \omega \tag{11}$$

In order to solve for L_G we use Eq (3a) at two frequency points ω_1 and ω_2 [4], i.e.,

$$Im\{Z_{11u}(\omega_1)\} = \omega_1(L_G + L_S) - 1 / (\omega_1 C_G) \quad (12a)$$

$$Im\{Z_{11u}(\omega_2)\} = \omega_2(L_G + L_S) - 1 / (\omega_2 C_G) \quad (12b)$$

Solving Eqs. (12a) and (12b) gives

$$L_G = [\omega_1 Im\{Z_{11u}(\omega_1) - \omega_2 Im\{Z_{11u}(\omega_2)] / (\omega_1^2 - \omega_2^2) - L_S \quad (13)$$

c. Solving for Capacitances

The capacitances C_{GE}, C_{DS} and C_{DE} are solved for using the pinched-off measurement. First, the S parameters are converted to Z parameters. The branch impedances of the parasitic inductances and resistances, which are already known, are subtracted from the Z parameters. Secondly, the new Z parameters are converted to Y parameters. Finally, the capacitances are obtained from Eqs. (5a) - (5c).

$$C_{GE} = (Im\{Y_{11p}\} + 2Im\{Y_{12p}\}) / \omega \quad (14)$$

$$C_{DS} + C_{DE} = (Im\{Y_{22p}\} + Im\{Y_{12p}\}) / \omega \quad (15)$$

Since C_{DS} and C_{DE} cannot be separated, the assumption of $C_{DE} = 0.25C_{DS}$ [4] is used to determine the values of C_{DS} and C_{DE}.

d. Parameter Value Averaging

All the parameters are calculated at each frequency supplied in the cold measurement data. The actual parameter values are taken as the average values over all frequencies.

III. MODEL VERIFICATION

Since there is no cold measurement available at the time when this project was finished. The method is tested against the simulated cold data (V_G: 0V, -5V and V_D: 0V) generated using the Materka model which are obtained by fitting the model responses to the measured S parameters at three bias points (V_G: 0V, -1.74V, -3.1V and V_D: 4V).

The extrinsic parameters are extracted from the simulated cold data using the aforementioned method. The result shows that the extracted inductances are very close to the original values used to generate the data but the extracted resistances and capacitances are quite different from the original values.

In order to fully evaluate the method the actual measurements should be used.

IV. CONCLUSIONS

A method for extracting extrinsic parameters from the cold measurements has been implemented in HarPE. It is very useful in two-stage parameter extraction where the extrinsic parameters are analytically calculated from the cold measurements while the intrinsic parameters are extracted from the hot measurements by optimization. There are two obvious advantages using this method. The extraction of the extrinsic parameters are very fast since they are calculated analytically. The number of variables for optimization to obtain the intrinsic parameters are significantly reduced since the extrinsic parameters are already known.

Accurate verification of the method should be carried out using the actual cold measurements. More sophisticated method may need to be developed to accurately extract the extrinsic parameters.

V. REFERENCES

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