Highly Consistent FET Model Parameter Extraction Based on Broadband S-Parameter Measurements

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ABSTRACT

A new FET model parameter extraction procedure is proposed which yields highly consistent model element values of a widely used 15-element model. For unique extraction of the elements from hot scattering parameters, the gate resistance R_g is previously derived from cold S-parameter coefficients measured at gate-voltages lower then the pinch-off voltage.

INTRODUCTION

The determination of the values of the model elements of an equivalent circuit of a microwave FET from measured data has been discussed since years. Numerous approaches have been published. In Ref. [1] e.g. additional test-structures are necessary for the performance of the proposed extraction procedure. This, however, supposes in-home technology facilities, which are not generally available. In many cases, the parasitic bulk resistance values of R_d and R_s are derived from DC measurements under forward-bias conditions, which generally differ from the typical operating point with reverse-biased gate [2]. For simplicity, the parasitic series resistances are mostly assumed to be bias-independent. Other authors use the scattering parameters at different bias points, e.g. under zero drain and forward gate bias voltage condition, and gate-voltage lower then the pinch-off voltage [3].

In this paper a new, efficient, and robust extraction procedure is presented which delivers highly consistent model element values from measured S-parameter data up to 40 GHz. It uses only one additional bias-point for the separate determination of the high-frequency value of R_g. With R_g known, all other elements can be extracted from hot S-parameters. Especially R_i, R_s and R_d are found as bias-dependent elements. The attained consistency in the extracted results makes investigation on model topology mismatching to the measured scattering parameters possible.

THE EXTRACTION PROCEDURE

The extraction procedure is based on a statistically working optimizer similar to that reported in Ref. [4]. To minimize the local minimum problem the used Simplex algorithm [5] is newly initialized always after 10 iteration steps. For increased sensitivity of the error-function and time-saving reduction of required number of frequency-dependent sets of scattering parameters raw-data processing of the measured S-parameters is applied. Fig. 1 shows e.g. the measured magnitude and phase of S_{12} of a FSX 03X device. Residual measurement errors appear as 'high-frequency' ripples in both curves. By an adapted curve fitting procedure with MATLAB [6] based on a polynomial of 5th order the smoothed 'error-corrected' solid curves are attained.

Fig. 2 demonstrates the local minimum problem generally involved with optimizers. In this case all elements of the 15-element model (Fig.3) have been defined as variables during optimization. It is shown, that the resistances R_i, R_g and R_s are converging to different values under different starting conditions. Nevertheless, the sum of all resistances, and the sum of R_i and R_g is obtained approximately equal. As has been discussed earlier in Refs. [7,8], all elements could be found consistently, if R_g would be known.

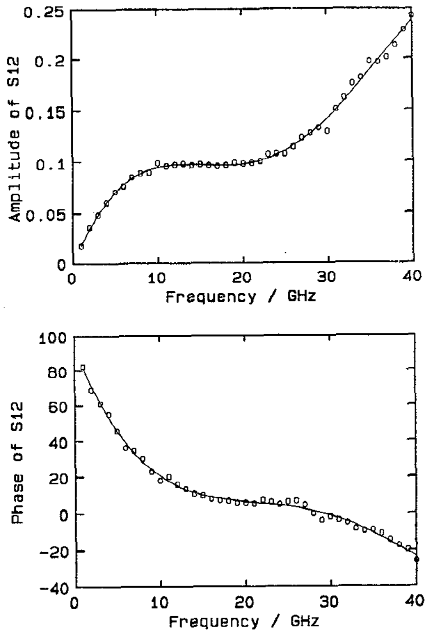

Fig.1: Raw-data processing of measured S-parameters by curce-fitting procedure.

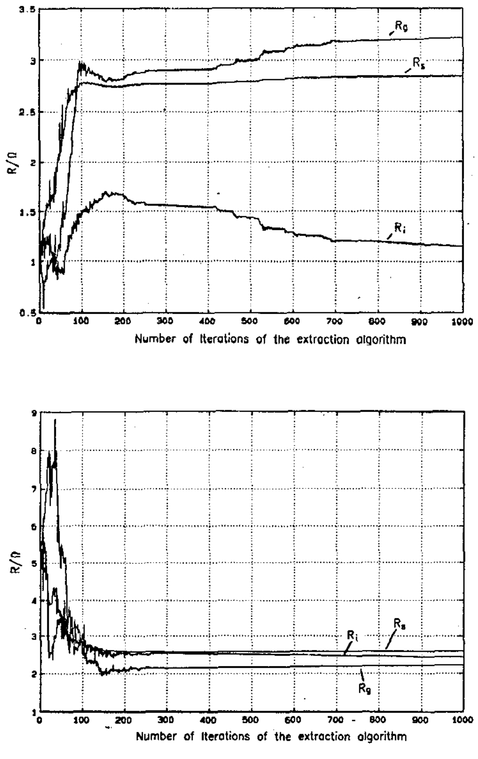

Fig.2: Extracted results R_i, R_s, R_g under different starting conditions of the optimizer indicating local minimum problem.

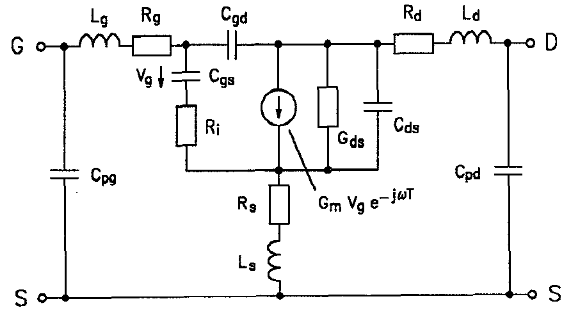

Fig.3: The 15-element FET model under discussion.

Regarding gate-voltages lower then the pinch-off voltage of the FET, the intrinsic resistance R_i is assumed to become zero which agrees with the results extracted in Ref. [9]. It should be noticed that this experience has been made in all cases of short-channel FETs, and is contradictory to the results for long-channel FETs in which cases R_i is extremely increasing against pinch-off (e.g. [10],[11]). Fig. 4 shows the FET model used for extraction under pinch-off condition. Fig.5 indicates the extracted optimizer based series resistances for a wide range of negative gate-voltage. It can be seen that the resistances have been determined with constant values for voltages lower than -2V (pinch-off). Thus, R_g has been chosen 2.175 Ω for the further extraction procedure.

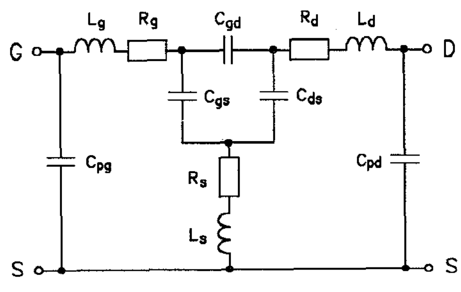

Fig.4: Equivalent circuit for the FET under pinch-off condition.

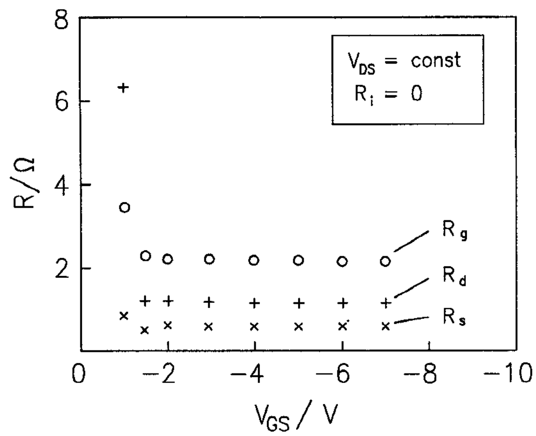

Fig.5: Extracted series resistances R_g, R_d, R_s.

RESULTS

As an example for extraction-consistency Table I shows the extracted results for the operating point (V_{gs}=-0.2V, V_{ds}=3.0V) for the investigated FET FSX 03X with R_g=const. P_0 and ΔP are defined as given in Ref. [12]. Although the 100 starting element values are varied in a wide-spread region, excellent consistence can be observed for all elements. For comparison, Table II shows the result, if all elements are assumed as variables, i.e. R_g included. In this case, the extracted values for each model element, especially the resistive ones, show rather large uncertainties.

As can be seen from Table I, the resistance value of R_d is rather low. To check the sensitivity of the extraction procedure we repeated the extraction cycle with fixed R_g and increased constant value of R_d being now 1Ω. It can be seen (Fig. 6) that this small change of R_d leads to a slightly worse agreement between smoothed and simulated frequency-dependent S_{22} coefficient, involving a higher residual value of the error-function of the optimizer.

Circuit	P_0	ΔP(%)
C_{gs}/pF	0.3638	0.0301
R_i/Ω	3.6795	0.2325
G_m/mS	50.7884	0.0355
G_{ds}^{-1}/Ω	261.3084	0.0670
C_{ds}/pF	0.0791	0.0285
C_{gd}/pF	0.0312	0.0238
R_g/Ω	2.1750	---
L_g/nH	0.2047	0.0275
R_d/Ω	0.0023	(*)
L_d/nH	0.2047	0.0265
R_s/Ω	2.0579	0.1429
L_s/nH	0.0380	0.0463
C_{pg}/pF	0.0398	0.0895
C_{pd}/pF	0.035	0.1165
T/ps	2.7537	0.0584

(*) uncertainty in the first significant digit

Table I: Uniquely extracted element values with Rg known from S-parameters under pinch-off operating conditions.

Circuit Element	P_0	ΔP(%)
C_{gs}/pF	0.3483	1.2966
R_i/Ω	6.3060	10.8963
G_m/mS	48.5089	1.3415
G_{ds}^{-1}/Ω	267.8629	0.8106
C_{ds}/pF	0.0769	0.9743
C_{gd}/pF	0.0323	1.0169
R_g/Ω	0.4194	97.9531
L_g/nH	0.2059	0.2146
R_d/Ω	0.0412	92.4485
L_d/nH	0.2065	0.4010
R_s/Ω	1.2096	20.1402
L_s/nH	0.0384	0.6019
C_{pg}/pF	0.0393	0.5756
C_{pd}/pF	0.0359	1.0208
T/ps	2.7073	0.4516

Table II: Extracted element values with R_g unknown.

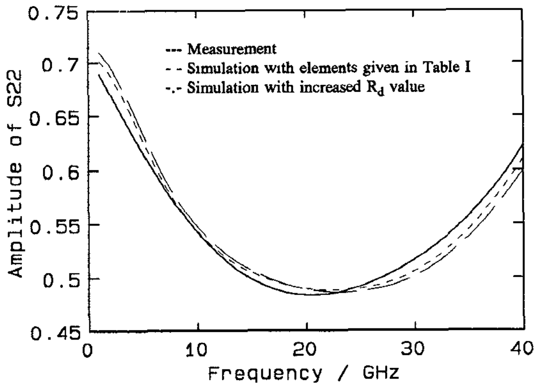

Fig.6: Influence of small value change of R_d on the extraction result.

CONCLUSION

The proposed extraction method yields highly consistent model elements (with R_i included) from measured broadband scattering-parameters. This result opens for the first time further investigations on potential mismatching of a defined model topology to a given FET device. Furthermore, investigations can be started which prove correlations between model elements and device physical parameters, such as geometry and material characteristics.

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