Development and Verification of a New Non-linear Mosfet Model

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Abstract — **A new non-linear model of SiMOSFET transistor based on a device characterization using DC and small-signal scattering parameter measurements is proposed. It is shown that interpolation of measured data and look up tables provide an extensive description of the extrinsic and intrinsic MOSFET non-linearities. Model verification is achieved by comparing simulations and on-wafer measurements of S parameters at a typical bias point.**

I. INTRODUCTION

Recent advances in robust and low cost SiMOSFET's using submicrometer gate length have made these devices an attractive candidate for RF designers. Accurate non-linear models are needed to design microwave integrated circuits. Several large-signal empirical were developed for MESFETs [1] in order to describe the device behavior within commercial frequency-domain simulators. The same effort has been made to find accurate non-linear models of MOSFET devices [2]. Such models are usually based on lumped equivalent circuits where the non-linear elements are empirical functions of the bias point (Vgso, Vdso).

This paper presents a SiMOSFET transistor and its specific non-linear model. The non-linear device model is extracted from measured data (DC, (S)) and empirical equations are used to represent the non-linear elements such as gm, Cgs, Cgd, Cds, and Rds. Usually, the extrinsic parameters Rg, Rd, Rs, are considered to be bias independent but it is difficult to separate these extrinsic parameters from intrinsic resistances. Therefore, more accurate non-linear models are proposed in this paper for these resistances.

II. RF MOSFET MODELLING

Non-linear modelling generally starts with a linear extraction. From measured S-parameters of a open pad structure without an active device, the pad parasitics are determined. S parameters of 0.25 μm Si n-MOSFET are measured at various bias conditions in the saturation region ($1.2\,V \leq Vgs \leq 2.5\,V$ and $1\,V \leq Vgs \leq 2.7\,V$) using on-wafer RF probes from 0.1 to 10 GHz. In our procedure, only extrinsic capacitors Cpg = 80 fF and Cpd = 150 fF which take into account the parasitic effects of the gate and drain feed pads are considered to be bias independent. They are obtained by suppressing the channel conduction Vds = 0 V and Vgs < Vp (pinch off voltage) [3]. The data set is measured at Vgs = 1.2 V, Vds = 1.8 V and Ids = 16 mA, corresponding to the saturation region of the transistor DC characteristics. The values of the extrinsic components (Rg = 10.6 Ω, Rd = 11.5 Ω, Rs = 6.1 Ω, Lg = 180 pH, Ld = 280 pH and Ls = 24 pH) are determined using the method described in [4]. Fig. 1 shows the measured data and fitting curves of real parts and imaginary parts of Z parameters for frequencies up to 10 GHz.

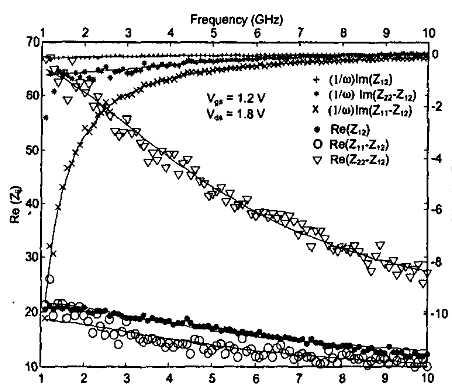

Fig. 1. The measured data and fitting curves of real parts and imaginary parts of Z parameters versus frequency.

Now that the extrinsic elements have been defined for any gate and drain bias voltage, the intrinsic small signal elements can be deduced from Y parameters using a deembeeding of the extrinsic parameter values [3].

III. NON-LINEAR MOSFET TRANSISTOR

Once the element values of the linear model are known for all bias points, the next challenge is to find equations that fit the extracted capacitances and resistances over all

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bias points. Our analytical non-linear MOSFET model can be described by the equivalent circuit shown in fig. 2. It consists of eight non-linear elements (intrinsic transconductance gm, capacitors Cgs, Cgd, Cds, output resistance Rds and extrinsic resistances Rs, Rd, Rg) which depend on bias voltages Vgs and Vds.

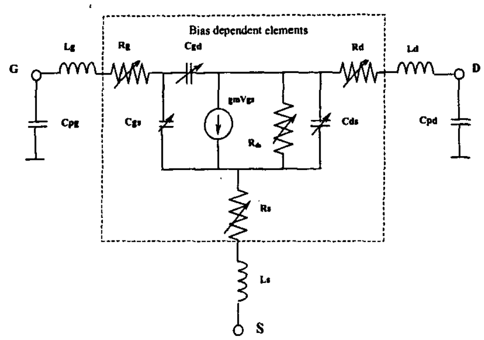

Fig. 2. Equivalent circuit model for n-MOSFET, including bias dependent elements.

The intrinsic non-linear elements of Cgs, Cgd, Cds, Rds are modelled by the equations (3)-(6) proposed in [2]. In contrast, we considered Rd and Rg as non linear in our model. In our work, we have considered the non linearity of gm (fig. 3) instead of the drain current source Ids [2].

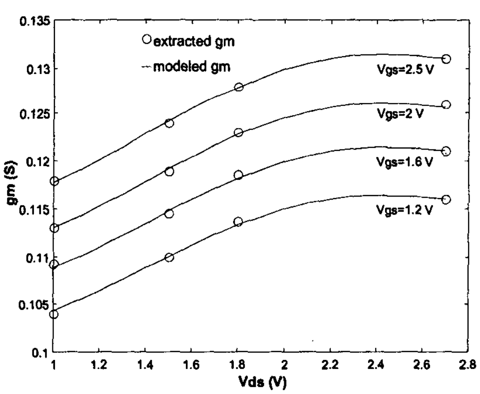

Fig. 3. Extracted and modelled gm.

This nonlinearity is described by the equation (1).

$$gm = \sum_{i=0}^{5} s_i Vds^i \times \sum_{i=0}^{2} t_i Vgs^i \qquad (1)$$

Rg and Rd are described by polynomial equations.

$$Rg = \sum_{i=0}^{4} u_i Vds^i \times \sum_{i=0}^{4} v_i Vgs^i \qquad (2)$$

$$Rd = \sum_{i=0}^{4} x_i Vds^i \times \sum_{i=0}^{4} y_i Vgs^i \qquad (3)$$

The unknown coefficients are determined using the least-squares method. Fig. 4 shows the variation of Rg and Rd with Vgs and Vds. Rs is estimated by look up tables taking into account its variation with Vgs and Vds. The values of Ls, Ld and Lg are fixed as constants for all bias points.

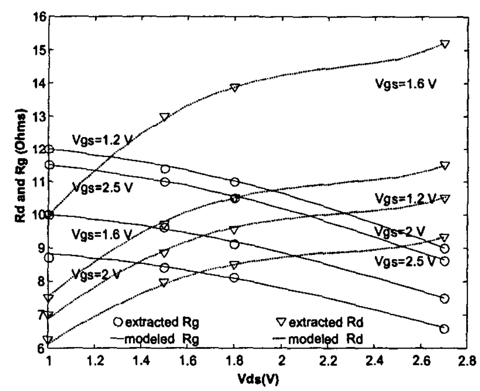

Fig. 4. Extracted and modelled Rd and Rg.

The results of the implemented high-frequency MOSFET model in the circuit simulator ADS have shown very consistent agreement with the measurements over all bias points. By comparing the simulations and the measurements of all S parameters at several bias points it can be verified that the model is valid up to 10 GHz. An example is shown in fig. 5.

The results without bias dependence of resistances which were obtained by the conventional equivalent circuit haven't shown good performance. We'll compare the both during the conference.

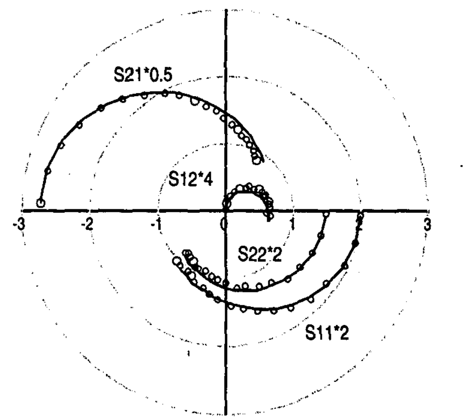

Fig. 5. Polar charts of measured (circles) and modelled (lines) S parameters from 0.1 to 10 GHz for a 0.25 μm n-MOSFET's at Vgs = 1.2 V and Vds =1.8 V.

IV. Conclusion

A new simple non-linear MOSFET model has been developed. The extraction procedure is based on DC and S parameters measurements allowing to determine the bias dependent behaviour of MOSFET in the saturation region of Ids-Vds characteristics. Taking into account the non linear behaviour of resistances permits us to simulate better the transistor characteristics over a wide frequency range. The static case, the small signal case, and the non-linear case have been related to each other with no contradictions. The empirical equations have been extracted and the model has been established for future circuit design.

References

[1] I. Angelo, H. Zirath, and N. ROSMAN, "A new empirical nonlinear model for HEMT and MESFET devices," *IEEE Trans. Microwave Theory and Tech.*, vol. 40, pp. 2258-2266, Dec 1996.

[2] T. J. Chan, C. H. Hung, C. C. Weng and B. K. Lien, "Characteristics of deep-submicrometer MOSFET and its empirical nonlinear RF model," *IEEE Trans. Microwave Theory and Tech.*, vol. 46, pp. 611-615, May 1998.

[3] D. Lovelace, J. Costa, and N. Camilleri, "Extracting small-signal model parameters of silicon MOSFET transistors," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 865-868, 1994.

[4] S. Lee, H. K. Yu, C. G Koo and K.S. Nam, "A novel approach to extracting small-signal model parameters of silicon MOSFETS," *IEEE Microwave Guided Wave Lett., Vol 7,* pp. 75-77, March 1997.