

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 (V_{gs} , V_{ds}).

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 g_m , C_{gs} , C_{gd} , C_{ds} , and R_{ds} . Usually, the extrinsic parameters R_g , R_d , R_s , 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 ($1.2 \text{ V} \leq V_{gs} \leq 2.5 \text{ V}$ and $1 \text{ V} \leq V_{ds} \leq 2.7 \text{ V}$) using on-wafer RF probes from 0.1 to 10 GHz. In our procedure, only extrinsic capacitors $C_{pg} = 80 \text{ fF}$ and C_{pd}

$= 150 \text{ fF}$ 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 $V_{ds} = 0 \text{ V}$ and $V_{gs} < V_p$ (pinch off voltage) [3]. The data set is measured at $V_{gs} = 1.2 \text{ V}$, $V_{ds} = 1.8 \text{ V}$ and $I_{ds} = 16 \text{ mA}$, corresponding to the saturation region of the transistor DC characteristics. The values of the extrinsic components ($R_g = 10.6 \Omega$, $R_d = 11.5 \Omega$, $R_s = 6.1 \Omega$, $L_g = 180 \text{ pH}$, $L_d = 280 \text{ pH}$ and $L_s = 24 \text{ pH}$) 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.

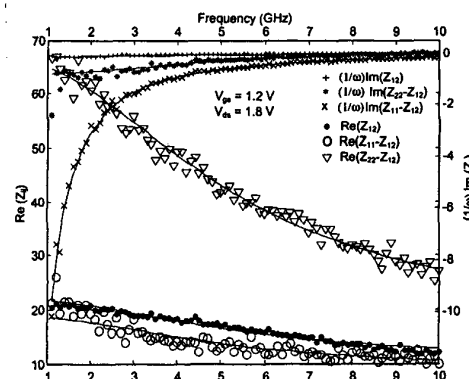


Fig. 1. The measured data and fitting curves of real parts and imaginary parts of Z parameters versus frequency.

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 deembedding 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

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 g_m , capacitors C_{gs} , C_{gd} , C_{ds} , output resistance R_{ds} and extrinsic resistances R_s , R_d , R_g) which depend on bias voltages V_{gs} and V_{ds} .

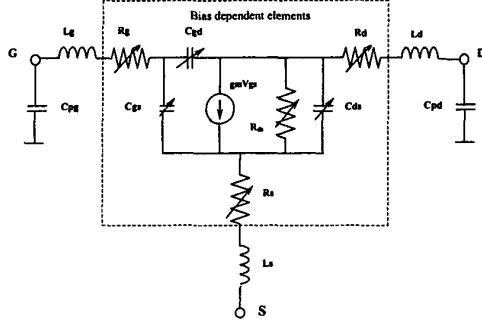


Fig. 2. Equivalent circuit model for n-MOSFET, including bias dependent elements.

The intrinsic non-linear elements of C_{gs} , C_{gd} , C_{ds} , R_{ds} are modelled by the equations (3)-(6) proposed in [2]. In contrast, we considered R_d and R_g as non linear in our model. In our work, we have considered the non linearity of g_m (fig. 3) instead of the drain current source I_{ds} [2].

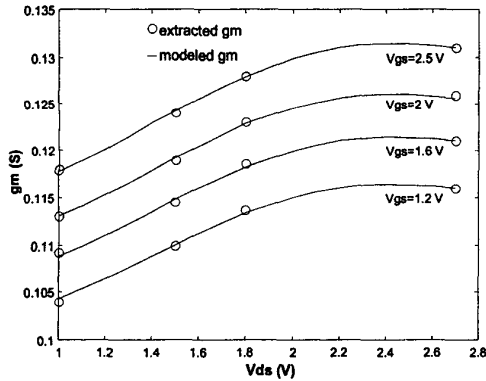


Fig. 3. Extracted and modelled g_m .

This nonlinearity is described by the equation (1).

$$g_m = \sum_{i=0}^5 s_i V_{ds}^i \times \sum_{i=0}^2 t_i V_{gs}^i \quad (1)$$

R_g and R_d are described by polynomial equations.

$$R_g = \sum_{i=0}^4 u_i V_{ds}^i \times \sum_{i=0}^4 v_i V_{gs}^i \quad (2)$$

$$R_d = \sum_{i=0}^4 x_i V_{ds}^i \times \sum_{i=0}^4 y_i V_{gs}^i \quad (3)$$

The unknown coefficients are determined using the least-squares method. Fig. 4 shows the variation of R_g and R_d with V_{gs} and V_{ds} . R_s is estimated by look up tables taking into account its variation with V_{gs} and V_{ds} . The values of L_s , L_d and L_g are fixed as constants for all bias points.

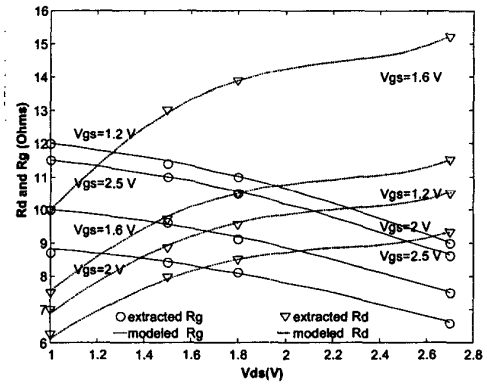


Fig. 4. Extracted and modelled R_d and R_g .

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.

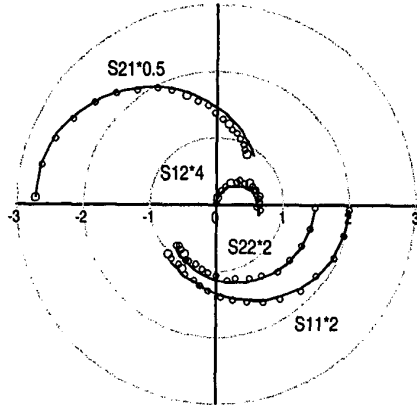


Fig. 5. Polar charts of measured (circles) and modelled (lines) S parameters from 0.1 to 10 GHz for a 0.25 μm n-MOSFET's at $V_{gs} = 1.2$ V and $V_{ds} = 1.8$ V.

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 I_{ds} - V_{ds} 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.

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