OPTIMIZATION AND SIMULATION OF THE EKV MODEL USING MATLAB

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This paper presents a parameter extraction and optimization method of an EKV model implementation in MATLAB. Open source modules provide direct access to model equations and parameters. Thus, parameters can be easily extracted and characteristics optimized for circuit design purposes. Validation against conventional BSIM3v3 model for AMS 0.35 μm CMOS technology is performed and a good agreement is observed.

Keywords: Simulation, Matlab modeling, EKV, open source

1. INTRODUCTION

Electrical simulation is one of the most important phases during the design of integrated circuits. In the case of analog circuits, the resulting analysis must be accurate, and the device models used in the simulators must satisfy several criteria. The availability of a good MOS transistor model has thus become an important issue for the efficient design and simulation of high performance analog and mixed-signal integrated circuits. The EKV Model has recently gained larger availability as a public-domain model and a growing number of analog designers are using it in the academic research as well as in the industrial environments. The quality of the parameters extraction method is fundamental for the usefulness of the simulation model [1-2]. The objective of parameter extraction is to obtain a single parameter set which covers all the geometries and device operating regions.

The high speed of simulation within MATLAB is essential to the optimization process. It is clear that the combined circuit and device optimization is capable of leading to real benefits in both device design and circuit use. Furthermore, the model codes are open-source, providing direct access to model equations and parameters. Hence, parameters can be easily extracted and characteristics optimized for circuit design purposes.

The proposed modifications are: a new interpolation function for the normalized inverted charge, the channel vertical field calculation, change in the mobility model, considerations of the velocity saturation, the channel length modulation, the series resistance, DIBL, etc.

In this context EKV MOSFET model is particularly suitable for open-source implementation in MATLAB as it provides accurate modeling with a small set of parameters [4].

2. MODEL

The EKV model is based on the charge-sheet linearization approach with the with the following essential characteristics: (1) Symmetric handling of source/drain effects combined with substrate reference, (2) Coherent charge-based modeling of static large-signal and dynamic small signal aspects including non-quasistatic aspects, as well as noise, (3) Analytical, continuous, physically correct description of weak, moderate and strong inversion and linear/saturation operation.

The foundations of this model approach are summarized in [5], [6], [7]. The model remains closely related to the surface potential model and preserves its essential features. Beyond this, it provides a versatile analytical description of the ideal physics of long-channel devices, including static to non-quasi-static effects, with a favorable trade-off among accuracy and efficiency.

2.1. Formulation of the Optimized Model

Below we briefly give the main equations and normalization factors of the model:

$$q_{IF(R)} = \sqrt{\frac{1}{4} + I_{F(R)}} - \frac{1}{2} \tag{1}$$

is the interpolation function for the inversion charge linearization [1]:

For computational purposes the weak and strong inversion currents' equations

$$I_{F(R)} = \exp\left(\frac{V_G - \text{VTO} - nV_{S(D)}}{nU_T}\right) \quad \text{and} \quad I_{F(R)} = \left(\frac{V_G - \text{VTO} - nV_{S(D)}}{2nU_T}\right)^2 \quad \text{are combined}$$

into a single expression

$$I_{F(R)} = I_S\left(q_{IF(R)}^2 + q_{IF(R)}\right)$$

$$I_{F(R)} = I_S \cdot \left\{\ln\left[1 + \exp\left(\frac{V_G - \text{VTO} - nV_{S(D)}}{2nU_T}\right)\right]\right\}^2 \tag{2}$$

The normalization quantities used are the specific current I_S, the thermal voltage U_T, the specific charge Q_0 and the specific transconductance G_0 [2].

$$I_S \equiv 2n\beta U_T^2 - \text{specific current} \tag{3}$$

Where

$$\beta = \mu C'_{ox}\left(W_{eff} / L_{eff}\right) - \text{transfer parameter} \tag{4}$$

$$n = 1 + \frac{\text{GAMMA}}{2\sqrt{V_P + \text{PHI} + 4U_T}} - \text{slope factor} \tag{5}$$

$$\gamma' = \text{GAMMA} - \frac{\varepsilon_0 \varepsilon_{Si}}{\text{COX}}\left[\frac{\text{LETA}}{L + \text{DL}}\sqrt{\text{PHI} + V_D} + \left(\frac{\text{LETA}}{L + \text{DL}} - 3\frac{\text{WETA}}{W + \text{DW}}\right)\sqrt{\text{PHI} + V_S}\right] \tag{6}$$

The modified body effect factor γ' (6) accounts for short- and narrow-channel effects. For large device geometries $\gamma' = $ GAMMA (note that GAMMA is the body effect factor, i.e. GAMMA $\equiv \gamma = \sqrt{2q\varepsilon_{Si}N_{SUB}}/C_{ox}$) and if uniform doping in the channel is assumed then V_P is a function only of the gate voltage and the three parameters VTO, GAMMA and PHI.

The specific charge Q_0 and the specific transconductance G_0 are

$$Q_0 = 2nU_TC_{ox} \tag{7}$$

$$G_0 = \frac{I_S}{U_T} \tag{8}$$

The gate-, source- and drain transconductances are defined as,

$$g_{mg} \equiv \frac{\partial I_D}{\partial V_G} \quad , \quad g_{ms} \equiv -\frac{\partial I_D}{\partial V_S} \quad , \quad g_{md} \equiv \frac{\partial I_D}{\partial V_D} \tag{9}$$

where V_G, V_S, and V_D are voltages referred to the substrate.

2.2. Model Implementation

To obtain a better coincidence between the EKV model realization and the experimental results the model implementation should use efficient numerical differentiation and interpolation functions for a good accuracy in solving equations (2) and (9). This could be achieved with the help of a complex computational package such as Matlab, Mathematica, etc. Besides it is quite useful for a designer to have direct access to the model and computational equations and parameters. The open source code approach meets both above mentioned requirements.

Based on our previous work [4] we further develop the computational techniques by adding additional characteristics. In particular, the rigorous first-order derivative of the EKV model drain current expression usually does not give good accuracy and the computational procedure adjustment in various ranges of the controlling variables is difficult. But using the relations proposed in [2] :

$$g_m = \frac{g_{ms} - g_{md}}{n} \quad , \quad g_{ms} = G_0q_{IF} \quad , \quad g_{md} = G_0q_{IR} \tag{10}$$

we get a better fitting to the experimental curves.

We have extended our "`EKV_MOST`" toolbox by including code for simulation of g_m, g_{ms}, g_{md} at different conditions.

3. RESULTS

The contribution of our work articulates in the precise calculation of the transfer characteristics and transconductances. Extraction of corresponding parameters follows the pattern described in [3].
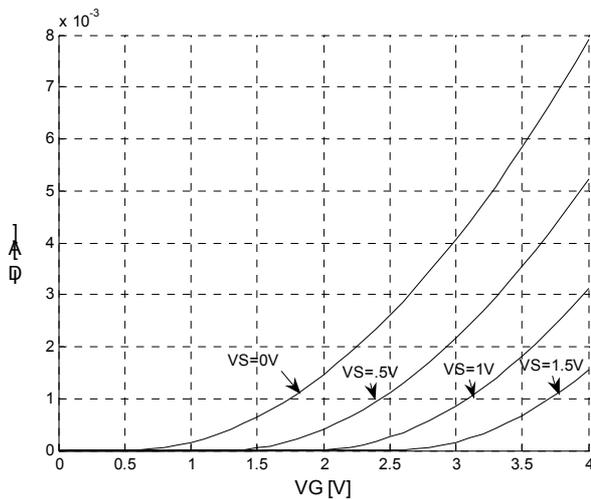
Fig. 1. *ID vs. VG at VD=5V, W=20 um, L=0.7 um.*
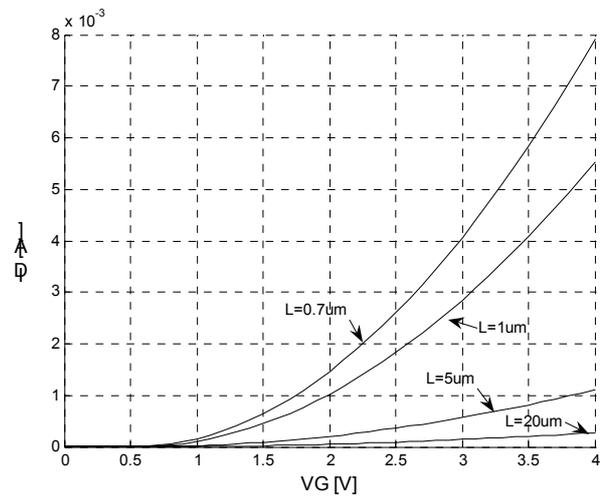
Fig. 2. *ID vs. VG at VD=5V, VS = 0 V, W=20 um.*

Figure 1 shows the transfer characteristics ID vs. VG at different VS and VD = 5 V. The transfer characteristic shown on Figure 2 demonstrate the influence of short channel effects.
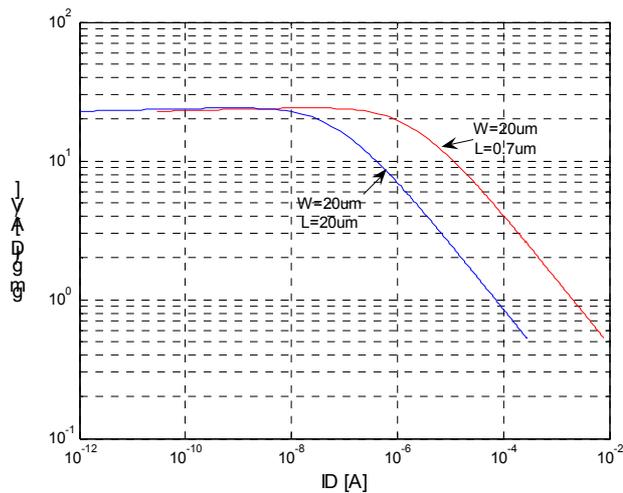
Fig. 3. *gmg /ID vs. ID at VD=5V, VG=0 ÷ 4V, VS=0V.*
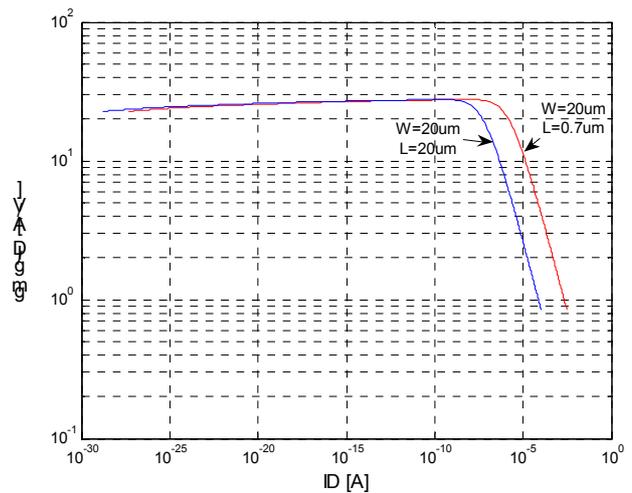
Fig. 4. *gmg /ID vs. ID at VD=5V, VG=0 ÷ 4V, VS=1V*

The transconductance to current ratio at different channel lengths and different VS are shown on Figure 3 and 4. The observed continuity of the transconductance curves is result of the proposed techniques.

4. CONCLUSION

The paper presents the optimized calculation of transistor transfer and transconductance characteristics based on the EKV model using open source Matlab implementation of the program code.

The simulation results of the modeled characteristics show good accuracy in all operational regions and at different transistor sizes. The applicability and usefulness

of the applied approach is clearly demonstrated. Extending our EKV model toolbox reveals greater flexibility for circuit analysis.

5. REFERENCES

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