Designing and Modelling of MOSFET Transistors

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ABSTRACT: *We have studied the bulk effect in the MOSFET transistors. To do this work we have initially developed a design and model of the MOSFET transistors which helped us to plan. We have presented the trial results of the effect in N Channel MOSFET transistors.*

Keywords: Bulk Effect, Body Effect, Back-gate Effect, MOSFET Transistors

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1. Introduction

Devices with MOSFET Transistors are widely used in practice. By the design of such type of sets different effects must be taken into account. One of this effects is the Body effect. In a number of cases the source is connected to the bulk. If between the source and the bulk potential difference (V_{SB}) is available, another more complicated way of circuit design must be considered. The body effect is associated with the voltage, applied to the bulk. Due to this fact change in the parameters and the characteristics of the MOSFET transistors can be observed. The aim of the presented paper is to study the relationship between the basic transistor parameters and the value of the voltage V_{SB}.

2. Theoretical Background

2.1. Basic mathematical equations describing the Body effect in MOSFET Transistors

The structure of the *N* channel MOSFET Transistor is shown on the Figure bellow [1]:

By MOSFET Transistors the characteristics $I_D = f\,(U_{GS})$ are from great importance. They are dependent from the voltage difference between bulk and source. The change of this value leads to consequent translation of the analyzed characteristics. This effect is presented on Figure 2[2].

It becomes obvious that the threshold voltage V_t depends on the value of V_{SB}.

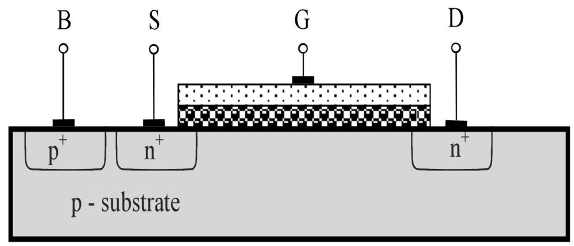

Figure 1. N channel MOSFET Transistor (cross section)

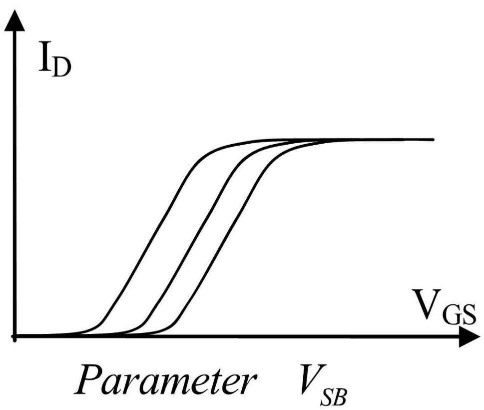

Figure 2.Characteristic I_D -V_{GS}

It becomes obvious that the threshold voltage V_t depends on the value of V_{SB}.

a) Assuming the voltage $V_{SB} = 0$ the following expression is valid [3]:

$$V_{t0}=\Phi_{GC} - 2\varphi - \frac{Q_{B0}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}} \tag{1}$$

Here : $\Phi_{GC} = \varphi_F(substrate) - \varphi_F(gate)$

φ_F is the substrate Fermi potential

$Q_{B0}=\sqrt{-2.q.N_A.\varepsilon_{Si}\left|-2.\varphi_F\right|}$

$C_{ox}=\frac{\varepsilon_{ox}}{t_{ox}}$

C_{ox} is the gate oxide capacitance per unit area

q is the electron charge

N_A is the substrate doping concentration

ε_{Si} is the dielectric constant of silicon

b) If the voltage $V_{SB} > 0$[3] :

$$V_t = \Phi_{GC} - 2\phi - \frac{Q_B}{C_{ox}} - \frac{Q_{ox}}{C_{ox}} \qquad (2)$$

$$V_t = V_{t0} + \gamma.\left(\sqrt{|-2.\phi_F + V_{SB}|} - \sqrt{|-2.\phi_F|}\right), \qquad (3)$$

where: $\gamma = \frac{\sqrt{2.q.N_A.\varepsilon_{Si}}}{C_{ox}}$

Q_B is the depletion region charge density at surface inversion.

2.2. Model of MOSFET Transistor taking into account the Body effect

The model of the analyzed MOSFET transistor is shown on the Figure bellow [4]:

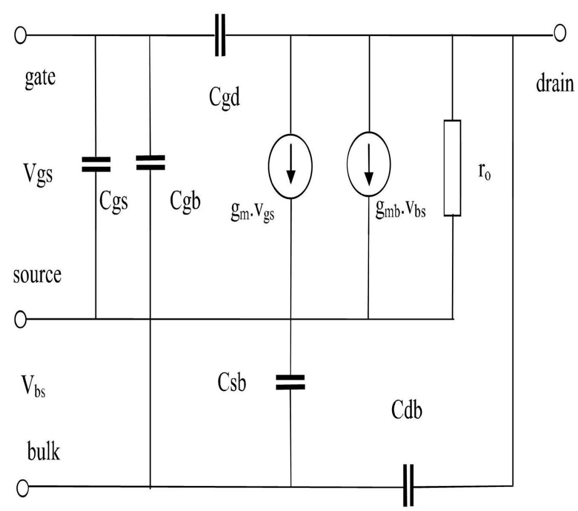

Figure 3.Model of MOSFET transistor

Here PHI is the surface potential; TOX is the oxide thickness; XJ is the Metallurgical junction depth; TPG is the Gate material type (in the case, considered in simulation it is opposite to the substrate); VTO is the zerobias threshold voltage; KP is the transconductance; DELTA designates the width effect on threshold; LD is the lateral diffusion length; RSH is drain source diffusion sheet; GAMMA is bulk threshold parameter; NSUB is the Substrate doping density; NFS is the fast surface-state density; VMAX is the maximum drift velocity; ETA is the static feedback; KAPPA is the saturation field factor; CGDO is the Gate-Drain overlap; CGSO is the Gate - Source overlap; CGBO is the Gate-Bulk overlap; CJ is bulk p-n zero - bias bottom capacitance; MJ is bulk p-n bottom grading coefficient; CJSW is bulk p-n zero-bias perimeter capacitance; MJSW is bulk p-n sidewall grading coefficient; PB is the bilk p-n potential [7].

3. PSPICE Models of the Analyzed Circuits

For educational purposes, aimed toward examination of the Body effect in MOSFET transistor amplifiers in the presented paper several PSPICE circuit models are investigated.

3.1. Body effect and I_D - V_{GS} characteristics of the MOSFET Transistors

The PSPICE MOSFET circuit model for study of the relationship between the Bulk effect and the I_D - V_{GS} characteristics is shown on the Figure below.

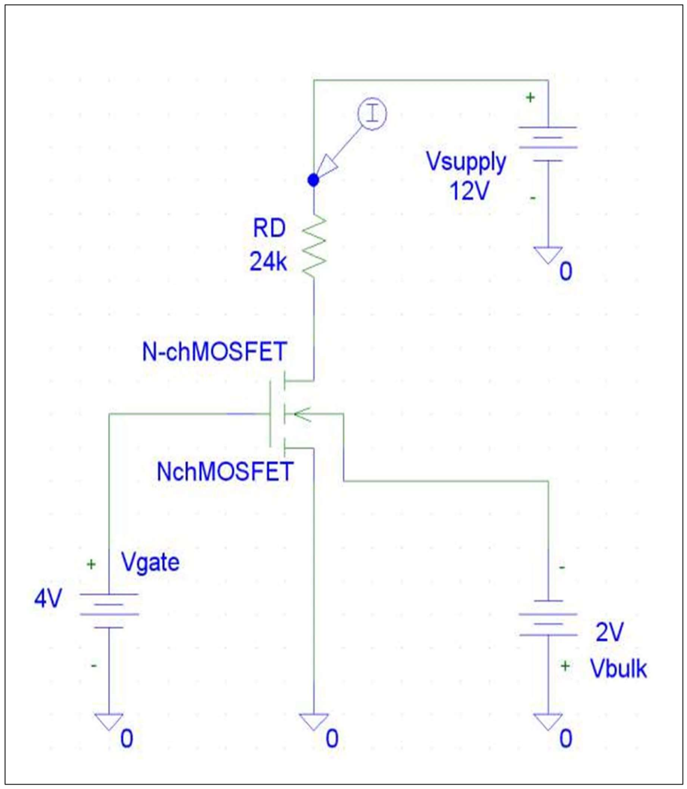

Figure 4. PSPICE circuit model for study of the relationship between the Bulk effect and the I_D - V_{GS} characteristics

DC sweep of the voltage, applied on the gate, is activated. With purpose to change the voltage on the bulk of the MOSFET transistor nested DC analysis is performed.

3.2. Back Gate Effect and Frequency Response

In order to examine the frequency response of the MOSFET amplifier by different (initially set) values of V_{SB}, PSPICE circuit model, presented on Figure 6, is analyzed.

The circuit, shown on Figure 5, is one stage common source MOSFET Transistor Amplifier. In order to perform AC analysis a sweep generator is applied on the input of the circuit.

4. Simulation Results and Analyzes

4.1. Results, concerning the ID VGS characteristics of the MOSFET Transistor in the amplifier

Results, obtained from PSPICE simulation of the circuit, shown on fig.4, are displayed below. A number of different values of the MOSFET Transistor Model parameter GAMMA have been used.

The graphical representation of the relationship: $I_D = f(V_{GS})$ is displayed on Figure 6.

The results are obtained by following conditions:

GAMMA = 0.2,

channel length $L = 2\mu m$,

width $W = 16\ \mu m$,

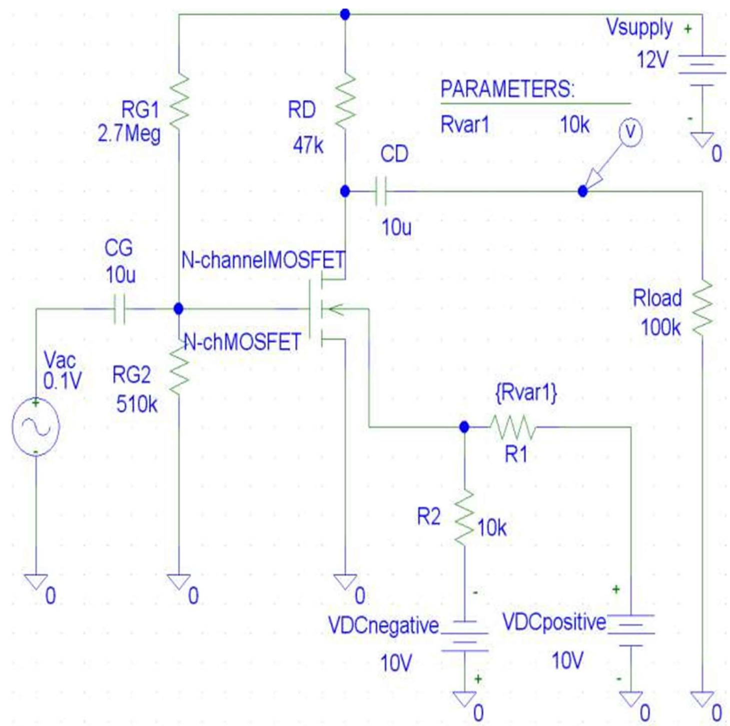

Figure 5. PSPICE circuit model for AC analysis

voltage Vsource-bulk (V_{SB}) changing in the range: $0V \div 8V$ with step = 2V

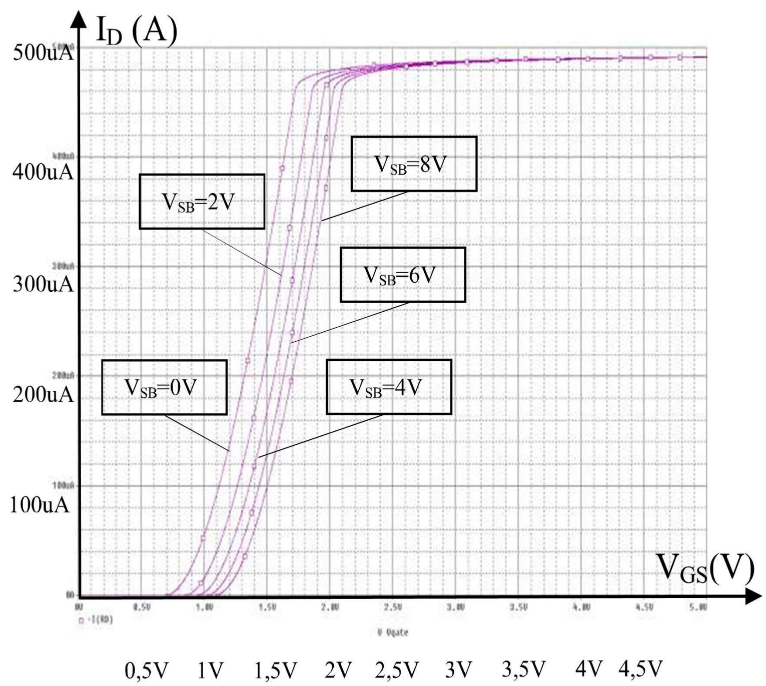

Figure 6. Characteristics ID = $f(V_{GS})$ by GAMMA = 0,2 and changing parameter V_{SB}

The increase of the Value of the parameter GAMMA leads to subsequent change in the characteristics: $I_D = f(V_{GS})$, as shown below.

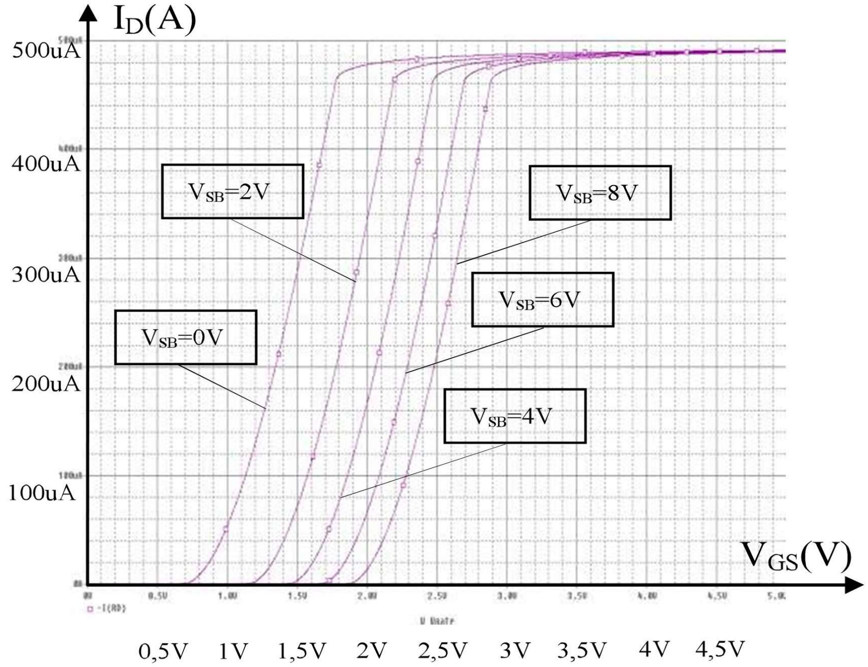

Figure 7. Characteristics $ID = f(V_{GS})$ by GAMMA = 0, 62 and changing parameter V_{SB}

The results from Figure 7 concern GAMMA Value = 0.62, which is typical value for this PSPICE MOSFET Transistor model [6].

The results, obtained after an increase of the value of GAMMA to value = 1, are presented on Figure 8.

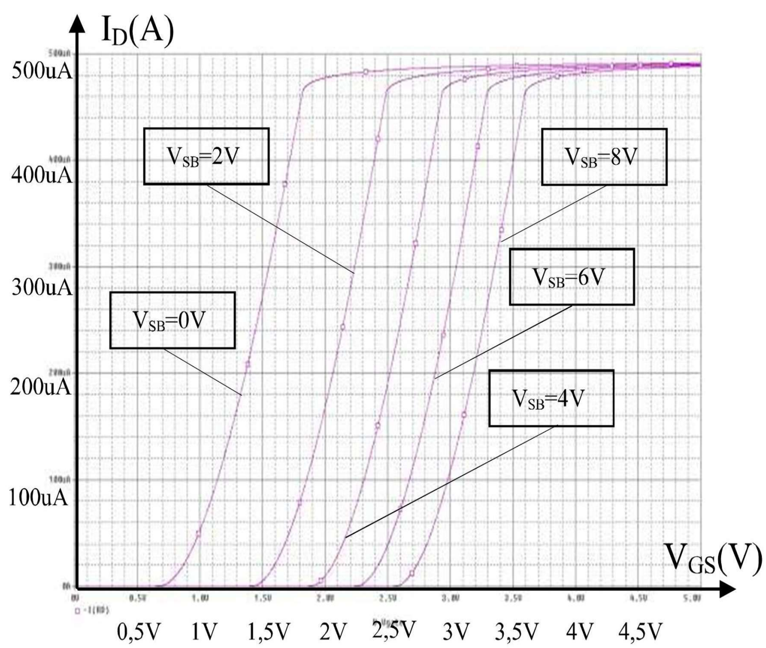

Figure 8. Characteristics $ID = f(V_{GS})$ by $GAMMA$ = 1 and changing parameter V_{SB}

It becomes obvious the increase of the distance between the separate characteristics, obtained by defined value V_{BS}.

4.2. Results, concerning the AC Analysis of Amplifier with MOSFET Transistor

As shown on Figure 6, the examined single stage amplifier is common source. In order to obtain the bandwidth of this amplifier by different values of and fixed value of GAMMA, a number of experiments have been done.

a) The graphic, displayed on Figure 9, concern AC analysis by fixed value of GAMMA = 0.4 and V_{SB} set to 4,118V.

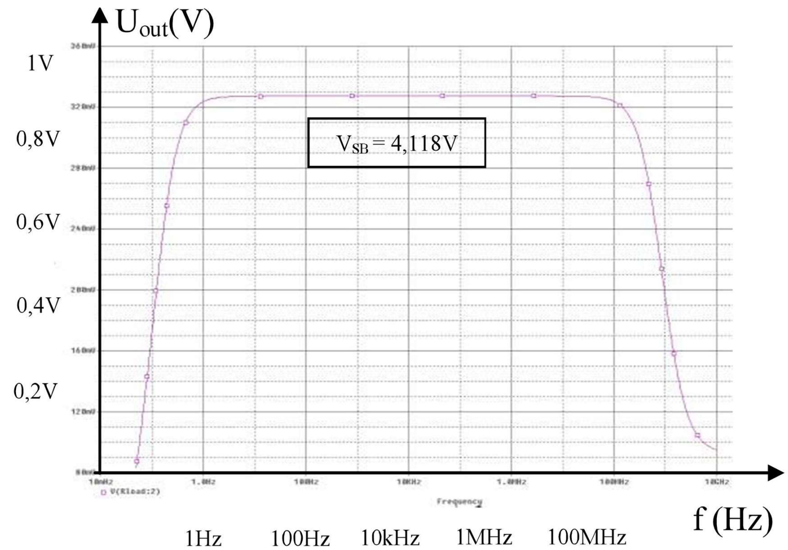

Figure 9. AC analysis by GAMMA = 0,4 and V_{SB} = 4,118V

b) The increase of the value of parameter GAMMA to 0.62, which is typical value for this PSPICE MOSFET Transistor model [6], changes the location of the AC characteristic, as displayed on Figure 10.

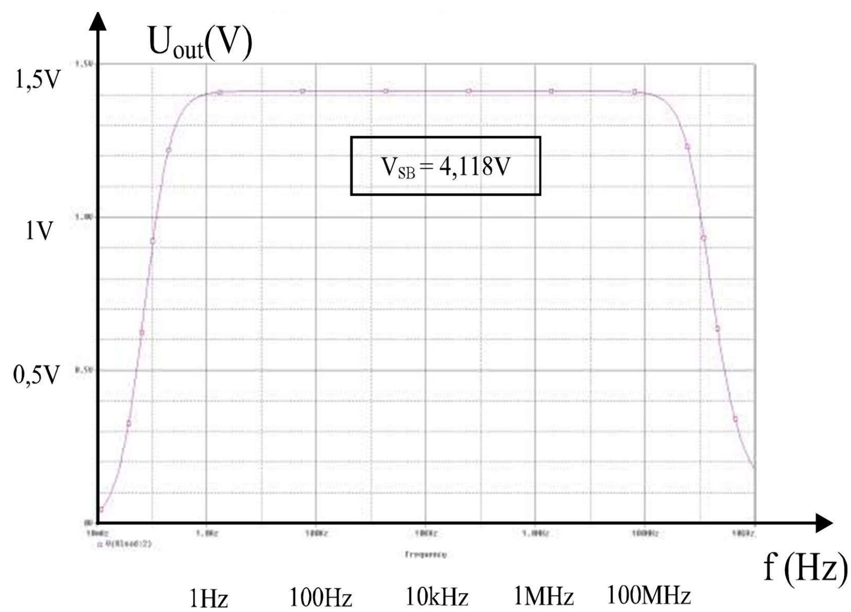

Figure 10. AC analysis by GAMMA = 0,62 and V_{SB}= 4,118V

It is obvious the great difference between the AC characteristics, presented on Fig.9 (where GAMMA = 0,4), and the graphical results, shown on Figure 10.

5. Conclusion

This paper is for educational purposes. It is aimed toward analysis of the Body effect in simple MOSFET circuits (one stage MOSFET transistor amplifiers). Instructions for simulation of the appropriate PSPICE models are given. Results, obtained from simulation are included.

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