# Studying the bulk effect in MOSFET Transistor Amplifiers

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*Abstract* – **In this paper the bulk effect in MOSFET Transistors is investigated. PSPICE results of simulation of the bulk effect in N-channel MOSFET Transistors are given.**

*Keywords* – **Bulk effect, Body effect, Back-gate effect, MOSFET Transistors**

## I. 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 $V_{SB}$.

## II. THEORETICAL BACKGROUND

### *A 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]:

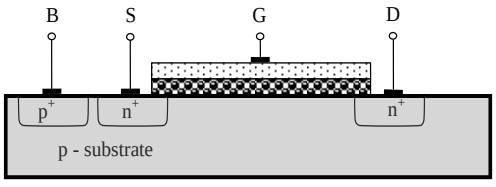


Fig. 1. N – channel MOSFET Transistor (cross section)

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 Fig.2[2].

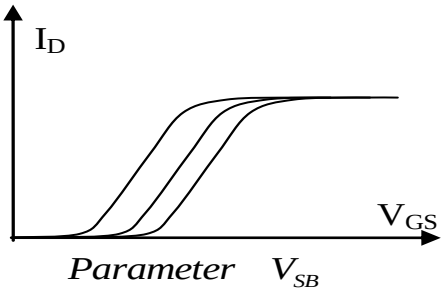


Fig. 2.Characteristic $I_D$ -$V_{GS}$

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]:

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

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

$\varphi_F$ is the substrate Fermi potential

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

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

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

$q$ is the electron charge

$N_A$ is the substrate doping concentration

$\varepsilon_{Si}$ is the dielectric constant of silicon

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

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

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

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

$Q_B$ is the depletion region charge density at surface inversion.

### *B Model of MOSFET Transistor taking into account the Body effect*

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

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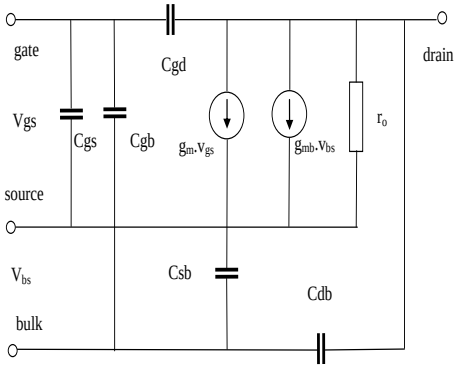


Fig. 3.Model of MOSFET transistor

The equation, describing the processes in this model is[4]:

$$i_{ds} = g_m.v_{gs} + g_{mb}.v_{bs} + \frac{1}{r_o}.v_{ds} \quad (4)$$

Here:

$g_{mb} = \frac{\partial i_D}{\partial v_{bs}}\Big|_{V_{GS},V_{DS},V_{BS}=const} = \frac{\gamma.g_m}{2.\sqrt{-V_{BS}-2.\phi_p}}$ ,where $\phi_p$ is the substrate Fermi potential (by NMOS transistors – p substrate)

The SPICE model of the MOSFET transistor depends on the nature and the complexity of the simulation. Accordingly the appropriate level of the SPICE transistor model should be chosen.

Using SPICE model with level 1 (Shichman - Hodges Model ) devices with gate length greater than 10 um are considered. If the channel length is less than 4 mm this model is inappropriate.

Level 2 SPICE model is based on Myer's model. It is improved compared to the model with level 1[5].

Advantage of this model is the inclusion of the subthreshold conduction [6]. By means of this model the channel length modulation effect can be examined [5].

Level 2 SPICE model has problems mostly concerning the numerical convergence [6].

Level 3 SPICE model is an empirical model. It is more precise and effective in comparison to the SPICE models Level 1 and Level 2. By means of SPICE model level 3 devices with gate length approx. 2µm can be analyzed [5].

This model takes into account as the subthreshold conduction, as well the narrow width and short – channel effects[6].

The PSPICE Model of the MOSFET transistors, used in the presented paper, is as follows[6],[7]:

.model NMOS LEVEL=3; PHI=0.7; TOX=9.5E-09 XJ=0.2U TPG=1; VTO=0.7; DELTA=8.8E-1; LD=5E-8; KP=1.56E-4; UO=420 ;THETA=2.3E-01; RSH=2.0; GAMMA=0.62; NSUB=1.40E+17; NFS=7.2E+11; VMAX=1.8E+5; ETA=2.125E-2; KAPPA=1E-1; CGDO=3E-10; CGSO=3E-10; CGBO=4.5E-10; CJ=5.5E-4; MJ=0.6; CJSW=3E-10; MJSW=0.35; PB=1.1[6]

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 zero-bias 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].

## III. 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.

### *A 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 bellow.

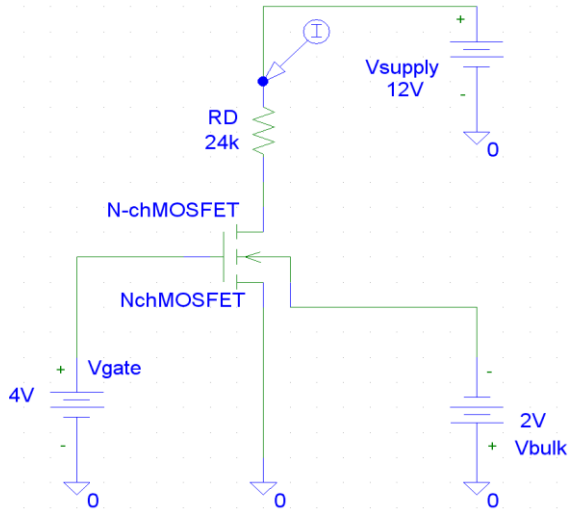


Fig. 4. PSPICE circuit model for study of the relationship between the Bulk effect and the $I_D - V_{GS}$ characteristics

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.

*B 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 Fig.6, is analyzed.

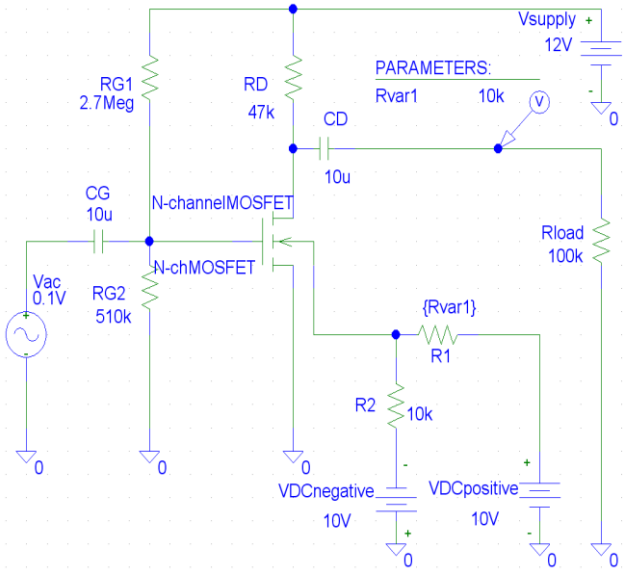


Fig. 5. PSPICE circuit model for AC analysis

The circuit, shown on Fig.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.

## IV. Simulation Results and Analyzes

*A Results, concerning the $I_D - V_{GS}$ characteristics of the MOSFET Transistor in the amplifier*

Results, obtained from PSPICE simulation of the circuit, shown on fig.4, are displayed bellow. 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 Fig.6.

The results are obtained by following conditions:

GAMMA = 0.2,

channel length L = 2µm,

width W = 16µm,

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

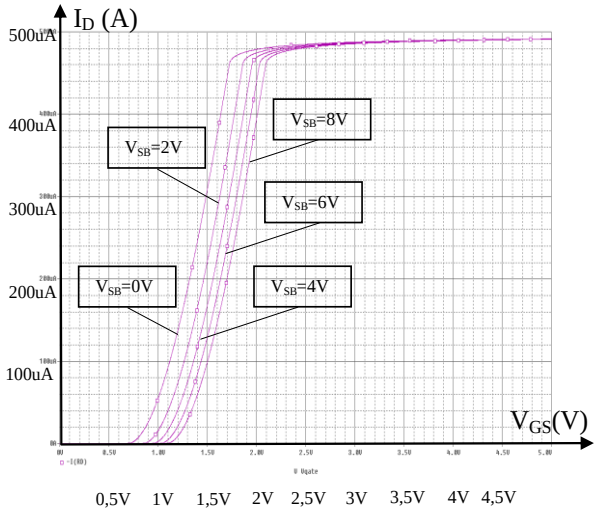


Fig. 6. Characteristics $I_D = f(V_{GS})$ by GAMMA = 0,2 and changing parameter $V_{SB}$

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

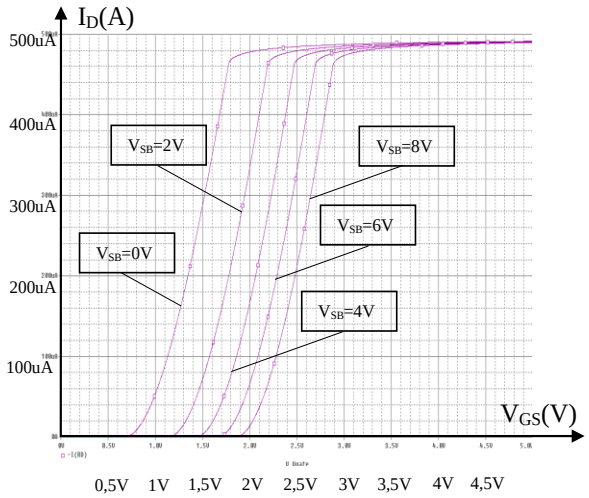


Fig. 7. Characteristics $I_D = f(V_{GS})$ by GAMMA = 0,62 and changing parameter $V_{SB}$

The results from Fig.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 Fig.8.

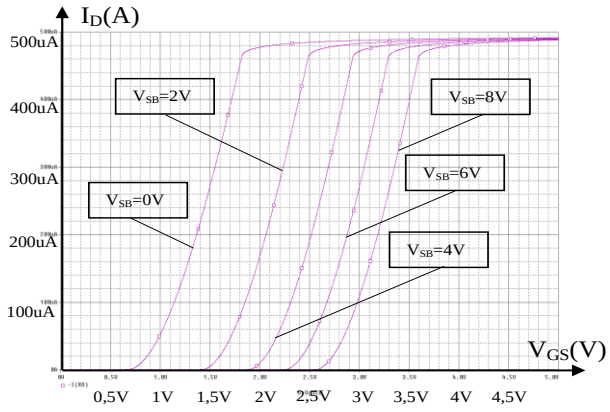


Fig. 8. Characteristics $I_D = f(V_{GS})$ by GAMMA = 1 and changing parameter $V_{SB}$

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

*B Results, concerning the AC analysis of amplifier with MOSFET transistor.*

As shown on Fig. 6, the examined single stage amplifier is common source. In order to obtain the bandwidth of this amplifier by different values of $V_{SB}$ 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.

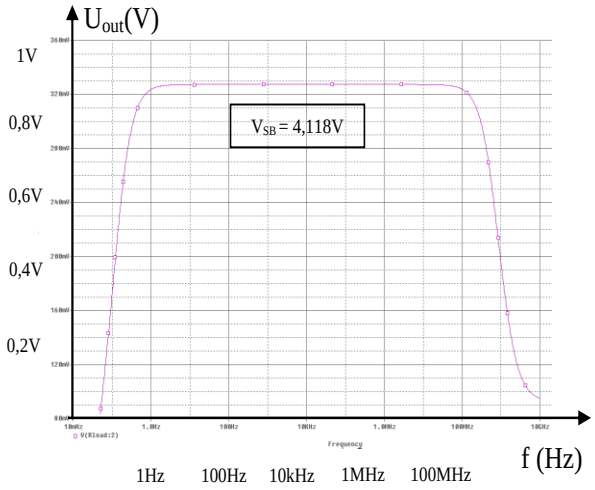


Fig. 9. AC analysis by GAMMA = 0,4 and $V_{SB}$ = 4,118V

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.

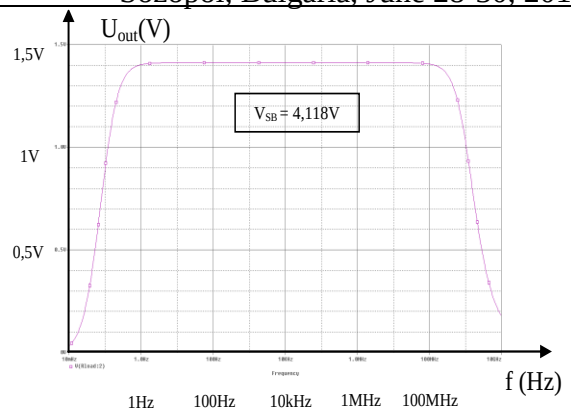


Fig. 10.AC analysis by GAMMA = 0,62 and $V_{SB}$=4,118V

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

## V. 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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