P Channel MOSFET level 3 **mosp3**

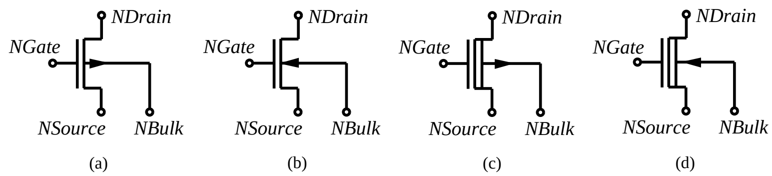

Figure 1: MOSFET Types

Form: `mosp3:`⟨`instance name`⟩ n_1 n_2 n_3 n_4 ⟨`parameter list`⟩

n_1 is the drain node,
n_2 is the gate node,
n_3 is the source node,
n_4 is the bulk node.

Parameters:

Parameter	Type	Default value	Required?
gamma: Bulk threshold parameter ($V^{0.5}$)	DOUBLE	0	no
kp: Transconductance parameter (A/V^2)	DOUBLE	0.000021	no
l: Device length (m)	DOUBLE	0.000002	no
w: Device width (m)	DOUBLE	0.00005	no
ld: Lateral diffusion length (m)	DOUBLE	0	no
wd: Lateral diffusion width (m)	DOUBLE	0	no
nsub:Substrate doping (cm^{-3})	DOUBLE	0	no
phi: Surface inversion potential (V)	DOUBLE	0.6	no
tox: Oxide thickness (m)	DOUBLE	1×10^{-7}	no
u0: Surface mobility (cm^2/V-s)	DOUBLE	600	no
vt0: Zero bias threshold voltage (V)	DOUBLE	0	no
kappa: Saturation field factor (m)	DOUBLE	0.2	no
t: Device temperature (degrees)	DOUBLE	300.15	no
tnom: Nominal temperature (degrees)	DOUBLE	300.15	no
nfs: Fast surface state density (cm^{-2})	DOUBLE	0	no
eta: Static feedback on threshold voltage	DOUBLE	0	no
theta: Mobility modulation (1/V)	DOUBLE	0	no
tpg: Gate material type	DOUBLE	0	no
nss: Surface state density (cm^{-2})	DOUBLE	0	no
vmax: Maximum carrier drift velocity (m/sec)	DOUBLE	0	no
xj: Metallurgical junction depth	DOUBLE	0	no
delta: Width effect on threshold voltage	DOUBLE	0	no

Example:

```
mosp3:m1 2 3 0 0 l=1.2u w=20u
```

Description:

fREEDA™has the PMOS level 3 model based on the MOS level 3 model in SPICE. It uses the charge conservative Yang-Chatterjee model for modeling charge and capacitance.

DC Calculations:
Constants used are:

$$
\begin{aligned}
q &= 1.6021918 \times 10^{-19} (As) && (1)\\
k &= 1.3806226 \times 10^{-23} (J/K) && (2)\\
\epsilon_0 &= 8.85421487 \times 10^{-12} (F/m) && (3)\\
\epsilon_s &= 11.7\, \epsilon_0 && (4)\\
E_g &= 1.16 - \frac{7.02 \times 10^{-4}\, \mathtt{T}^2}{\mathtt{T} + 1108} (V) && (5)\\
C_{ox} &= \frac{\epsilon_0\, 3.9}{\mathtt{TOX}} (F) && (6)
\end{aligned}
$$

All parameters used are indicated in `this` font.
The equations for the PMOS level 3 are identical to the NMOS level 3 except that the directions of the terminal voltages, threshold voltage and the output currents are reversed.
Effective channel length and width:

$$
\begin{aligned}
L_{eff} &= \mathtt{L} - 2\,\mathtt{LD} && (7)\\
W_{eff} &= \mathtt{W} - 2\,\mathtt{WD} && (8)
\end{aligned}
$$

Depletion layer width coefficient

$$X_d = \sqrt{\frac{2\,\epsilon_s}{q\,\mathtt{NSUB}\,10^6}} \qquad (9)$$

Built in voltage:

$$V_{bi} = \mathtt{VTO} - \mathtt{GAMMA}\,\sqrt{\mathtt{PHI}} \qquad (10)$$

Square root of substrate voltage:

$$
\begin{aligned}
V_{BS} \leq 0 &\implies SqV_{BS} = \sqrt{\mathtt{PHI} - V_{BS}}\\
V_{BS} > 0 &\implies SqV_{BS} = \frac{\sqrt{\mathtt{PHI}}}{1 + \frac{0.5}{\mathtt{PHI}}\, V_{BS}(1 + \frac{0.75}{\mathtt{PHI}} V_{BS})} && (11)
\end{aligned}
$$

Short-channel effect correction factor:
In a short channel device, device threshold voltage tends to lower since part of the depletion charge in the bulk terminates the electric fields at the source and drain. The value of this correction factor is determined by the metallurgical depth `XJ`.

$$
\begin{aligned}
c_0 &= 0.0631353 && (12)\\
c_1 &= 0.8013292 && (13)\\
c_2 &= -0.01110777 && (14)\\
T_1 &= \mathtt{XJ}\,(c_0 + c_1\, X_d\, SqV_{BS} + c_2\, (X_d\, SqV_{BS})^2) && (15)\\
F_s &= 1 - \frac{\mathtt{LD} + T_1}{L_{eff}} \sqrt{1 - (\frac{X_d\, SqV_{BS}}{\mathtt{XJ} + X_d\, SqV_{BS}})^2} && (16)
\end{aligned}
$$

Narrow channel effect correlation factor:
The edge effects in a narrow channel cause the depletion charge to extend beyond the width of the channel. This has an effect of increasing the threshold voltage.

$$F_n = \frac{\pi\, \epsilon_s\, \mathtt{DELTA}}{2\, C_{ox}\, W_{eff}} \qquad (17)$$

Static feedback coefficient:
The threshold voltage lowers because the charge under the gate terminal depleted by the drain junction field increases with V_{DS}. This effect is Drain Induced Barrier Lowering (DIBL).

$$\sigma = \frac{8.14 \times 10^{-22}\,\texttt{ETA}}{{L_{eff}}^3\,C_{ox}} \tag{18}$$

Threshold voltage:

$$V_{th} = -V_{bi} - \sigma\,V_{DS} + \texttt{GAMMA}\,SqV_{BS}\,F_s\, + F_n\,SqV_{BS}{}^2 \tag{19}$$

Subthreshold operation:
This variable is invoked depending on the value of the parameter `NFS` and is used only during subthreshold mode.

$$X_n = 1 + \frac{q\,\texttt{NFS}\,10^4}{C_{ox}} + \frac{F_n}{2} + \frac{\texttt{GAMMA}}{2}\,\frac{F_s}{SqV_{BS}} \tag{20}$$

Modified threshold voltage:
This variable defines the limit between weak and strong inversion.

$$\texttt{NFS} > 0 \quad\Longrightarrow\quad V_{on} = V_{th} + \frac{k\,T}{q}\,X_n \tag{21}$$

$$\texttt{NFS} \leq 0 \quad\Longrightarrow\quad V_{on} = V_{th} \tag{22}$$

Subthreshold gate voltage:

$$V_{gsx} = \mathrm{MAX}(V_{GS}, V_{on}) \tag{23}$$

Surface mobility:

$$\mu_s = \frac{\texttt{UO}\,10^{-4}}{1 + \texttt{THETA}\,(V_{gsx} - V_{th})} \tag{24}$$

Saturation voltage:
Calculation of this voltage requires many steps. The effective mobility is calculated as

$$\mu_{eff} = \mu_s\,F_{drain} \tag{25}$$

where

$$F_{drain} = \frac{1.0}{1 + \frac{\mu_s\,V_{DS}}{\texttt{VMAX}\,L_{eff}}} \tag{26}$$

$$\beta = \frac{W_{eff}}{L_{eff}}\,\mu_{eff}\,C_{ox} \tag{27}$$

The Taylor expansion of coefficient of bulk charge is

$$F_B = \frac{\texttt{GAMMA}}{4}\,\frac{F_s}{SqV_{BS}}\, + 2\,F_n \tag{28}$$

The standard value of saturation voltage is calculated as

$$V_{sat} = \frac{V_{gsx} - V_{th}}{1 + F_B} \tag{29}$$

The final value of the saturation voltage depends on the parameter `VMAX`

$$\texttt{VMAX} = 0 \quad\Longrightarrow\quad V_{dsat} = V_{sat} \tag{30}$$

$$\texttt{VMAX} > 0 \quad\Longrightarrow\quad V_c = \frac{\texttt{VMAX}\,L_{eff}}{\mu_s} \tag{31}$$

$$V_{dsat} = V_{sat} + V_c - \sqrt{V_{sat}^2 + V_c^2} \tag{32}$$

Velocity saturation drain voltage:
This ensures that the drain voltage does not exceed the saturation voltage.

$$V_{dsx} = \mathrm{MIN}(V_{DS}, V_{dsat}) \tag{33}$$

Drain Current:
Linear Region:

$$I_{DS} = \beta \frac{\mu_s}{\mathtt{UO}\, 10^{-4}} F_{drain} \, (V_{gsx} - V_{th} - \frac{1 + F_b}{2} V_{dsx}) \, V_{dsx} \tag{34}$$

Saturation region:

$$I_{DS} = \beta \, (V_{GS} - V_{th} - \frac{1 + F_b}{2} V_{dsat}) \, V_{dsat} \tag{35}$$

Cutoff Region:

$$I_{DS} = 0 \tag{36}$$

Channel length modulation:
As V_{DS} increases beyond V_{dsat}, the point where the carrier velocity begins to saturate moves towards the source. This is modeled by the term $\triangle_l$.

$$\triangle_l = X_d \sqrt{\frac{X_d^2 \, E_p^2}{4} + \mathtt{KAPPA} \, (V_{DS} - V_{dsat})} - \frac{E_p \, X_d^2}{2} \tag{37}$$

where E_p is the lateral field at pinch-off and is given by

$$E_p = \frac{\mathtt{VMAX}}{\mu_s \, (1 - F_{drain})} \tag{38}$$

The drain current is multiplied by a correction factor l_{fact}. This factor prevents the denominator $L_{eff} - \triangle_l$ from going to zero.

$$\triangle_l \leq 0.5 \, L_{eff} \quad \Longrightarrow \quad l_{fact} = \frac{L_{eff}}{L_{eff} - \triangle_l} \tag{39}$$

$$\triangle_l > 0.5 \, L_{eff} \quad \Longrightarrow \quad l_{fact} = \frac{4 \, \triangle_l}{L_{eff}} \tag{40}$$

The corrected value of drain-source current is

$$I_{DSnew} = I_{DS} \, l_{fact} \tag{41}$$

Subthreshold operation:
For subthreshold operation, if the fast surface density parameter `NFS` is specified and $V_{GS} \leq V_{on}$, then the final value of drain-source current is given by

$$I_{DSfinal} = I_{DSnew} \, e^{\frac{kt}{q} \, \frac{V_{GS} - V_{on}}{X_n}} \tag{42}$$

Yang-Chatterjee charge model
This model ensures continuity of the charges and capacitances throughout different regions of operation. The intermediate quantities are:

$$V_{FB} = V_{to} - \mathtt{GAMMA} \sqrt{\mathtt{PHI}} - \mathtt{PHI} \tag{43}$$

and

$$C_o = C_{ox} \, W_{eff} \, L_{eff} \tag{44}$$

Accumulation region $V_{GS} \leq V_{FB} + V_{BS}$

$$Q_d = 0 \tag{45}$$

$$Q_s = 0 \tag{46}$$

$$Q_b = -C_o \, (V_{GS} - V_{FB} - V_{BS}) \tag{47}$$

Cut-off region $V_{FB} + V_{BS} < V_{GS} \leq V_{th}$

$$Q_d = 0 \tag{48}$$
$$Q_s = 0 \tag{49}$$
$$Q_b = -C_o \frac{\texttt{GAMMA}^2}{2} \{-1 + \sqrt{1 + \frac{4\,(V_{GS} - V_{FB} - V_{BS})}{\texttt{GAMMA}^2}}\} \tag{50}$$

Saturation region $V_{th} < V_{GS} \leq V_{DS} + V_{th}$

$$Q_d = 0 \tag{51}$$
$$Q_s = -\frac{2}{3}\,C_o\,(V_{GS} - V_{th}) \tag{52}$$
$$Q_b = C_o\,(V_{FB}\,\texttt{PHI} - V_{th}) \tag{53}$$

Linear region $V_{GS} > V_{DS} + V_{th}$

$$Q_d = -C_o\,[\frac{V_{DS}^2}{8\,(V_{GS} - V_{th} - \frac{V_{DS}}{2})} + \frac{V_{GS} - V_{th}}{2} - \frac{3}{4}\,V_{DS}] \tag{54}$$
$$Q_s = -C_o\,[\frac{V_{DS}^2}{24\,(V_{GS} - V_{th} - \frac{V_{DS}}{2})} + \frac{V_{GS} - V_{th}}{2} + \frac{1}{4}\,V_{DS}] \tag{55}$$
$$Q_b = C_o\,(V_{FB}\,\texttt{PHI} - V_{th}) \tag{56}$$

The final currents at the transistor nodes are given by

$$I_d = I_{DSfinal} + \frac{dQ_d}{dt} \tag{57}$$
$$I_g = \frac{dQ_g}{dt} \tag{58}$$
$$I_s = -I_{DSfinal} - \frac{dQ_s}{dt} \tag{59}$$

Notes:
This is the `M` element in the SPICE compatible netlist.

Version:
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Credits:

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