discussion1-501001

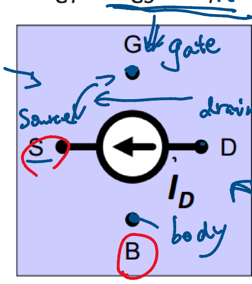
Saturday, July 2, 2022 6:57 PM

CMOS
- complementary
- metal
- oxide
- semi conductor

NMOS / PMOS

MOS I-V Model: Active Region

$V_{GT} = V_{GS} - V_{Th}$



Active region ($V_{GT} \geq 0$) Lin, Sat, V-Sat

$$\boxed{I_D = k' \cdot \frac{W}{L} \cdot \left(V_{GT} \cdot V_{min} - \frac{V_{min}^2}{2}\right) \cdot (1 + \lambda \cdot V_{DS})}$$

Channel length modulation

constant

$$V_{min} = \min(V_{DS}, V_{GT}, V_{DSAT})$$

Lin Sat V-Sat

linear Saturation velocity - saturation

Neglect CLM in linear region

The body effect can be seen as a change in threshold voltage and it is modeled as just that:

NMOS:

$$V_{TH} = V_{T0_n} + \gamma\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right) > 0$$

constant

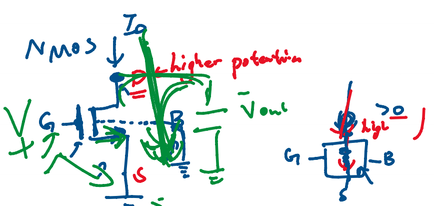
where V_{T0_n} is the threshold voltage when $V_{SB} = 0$, ϕ_f is a physical parameter ($2\phi_f \approx 0.6V$ for NMOS and $0.75V$ for PMOS) and γ is a process parameter called **body-effect parameter** ($\gamma \approx 0.4V^{1/2}$ for NMOS and $-0.5V^{1/2}$ for PMOS). For PMOS, the bulk voltage should always be higher than the source because the pn junction is in the opposite direction (source p^+ and bulk n^-). Then, the threshold voltage should be rewritten as:

$$V_{TH} = V_{T0_p} + \gamma\left(\sqrt{2\phi_f + V_{BS}} - \sqrt{2\phi_f}\right)$$

fix

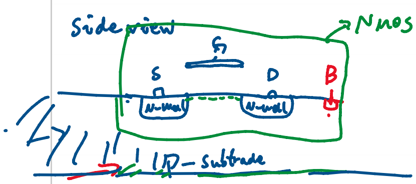
If you want to see what is the influence of the body-effect in the small signal model, you should check the small signal model topic.

NMOS

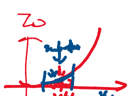


$I_D > 0$

Side view → NMOS



operation region

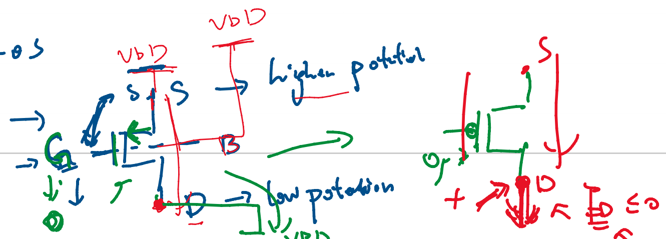


$I_D \to 0$

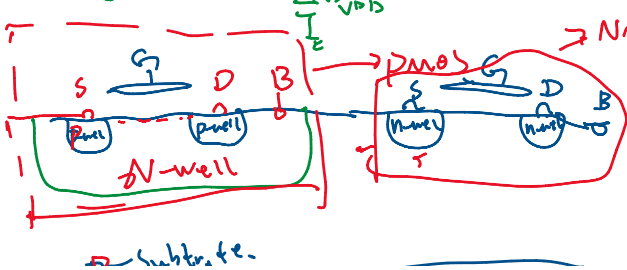
- $V_{GT} \leq 0$: $V_{GS} - V_{th} \leq 0$ ⇒ Cut off → open
- $V_{GS} > V_{th}$:
  - linear: $V_{DS} < V_{GT}$ & $V_{DS} < V_{DSAT}$
  - Sat: $V_{GT} < V_{DS}$, $V_{GT} < V_{DSAT}$
  - V-Sat (V_{VSAT}): $V_{DSAT} < V_{GT}$, $V_{DSAT} < V_{DS}$

voltage

PMOS



→ NMOS



operation region

- $|V_{GS}| \leq |V_{th}|$ ⇒ cutoff
- $|V_{GT}| \leq 0$ ⇒ cut off.
- $|V_{GT}| > 0$ ⇒ $|V_{GS}| > |V_{th}|$ ⇒ on
  - linear: $|V_{DS}| < |V_{GT}|$, $|V_{DS}| < |V_{DSAT}|$
  - sat: $|V_{GT}| < |V_{DS}|$, $|V_{GT}| < |V_{DSAT}|$
  - v-sat: $|V_{DSAT}| < |V_{GT}|$, $|V_{DSAT}| < |V_{DS}|$

p-Subtrate.

Sat: $|V_{GT}| < |V_{DS}|$, $|V_{GT}| < |V_{DSAT}|$

V-sat: $|V_{DSAT}| < |V_{GT}|$, $|V_{DSAT}| < |V_{DS}|$

Problem 1 -- MOS Transistor – Regions of Operation / Device Parameters

Below is a table of measurements performed on a newly fabricated MOS transistor. We would like to extract information about MOS parameters from these measurements.

$|V_{GT}|, |V_{DS}|, |V_{DSAT}| = 0.4$

Measurement Number	V_{GS}	V_{DS}	V_{SB}	I_D	Operation Region
1	–0.3 V	–0.7 V	0	–12.05 μA	Sat
2	0.3 V	–0.7 V	0	0.0	Cut-off
3	–0.7 V	–0.7 V	0	–88.98 μA	V-Sat
4	–0.4 V	–0.6 V	0	–26.42 μA	Sat
5	–0.3 V	–0.6 V	–0.5V	–7.17 μA	Sat
6	–0.7 V	–0.5 V	0	–76.45 μA	V-Sat
7	–0.7 V	–0.2 V	0	–53.21 μA	linear

$|V_{GT}| = |V_{GS}| - |V_{th}|$

$|V_{th_0}| = 0.1$

You may assume that $|V_{DSAT}| = 0.4V$ and $2\Phi_F = -0.6V$.

2A Is the measured transistor a PMOS or an NMOS device? Explain your answer.

– PMOS

2B From measurements above, determine the following parameters: V_{T0}, γ, λ.

2C Complete the missing column in the table above using the values you obtained in 2B. Fill in either "LINEAR", "CUTOFF", "SATURATION", or "VEL. SATURATION."

$$I_D = k'\frac{W}{L}\left(V_{GT}\cdot V_{min} - \frac{V_{min}^2}{2}\right)(1+\lambda V_{DS})$$

if Sat: $V_{min} = V_{GT}$

$$I_D = \beta\cdot\left(V_{GT}^2 - \frac{V_{GT}^2}{2}\right)(1+\lambda V_{DS})$$

$$= \beta\cdot\frac{(V_{GS}-V_{th})^2}{2}(1+\lambda V_{DS})$$

$$I_{D_1} = \beta\cdot\frac{(V_{GS_1}-V_{th_1})^2}{2}(1+\lambda V_{DS_1}) \quad —① $$

$$I_{D_2} = \beta\cdot\frac{(V_{GS_2}-V_{th_2})^2}{2}(1+\lambda V_{DS_2}) \quad —② $$

$$\frac{①}{②} = \frac{I_{D_1}}{I_{D_2}} = \frac{(V_{GS_1}-V_{th_1})^2}{(V_{GS_2}-V_{th_2})^2}\cdot\frac{(1+\lambda V_{DS_1})}{(1+\lambda V_{DS_2})} \quad —③$$

$\leftarrow V_{SB}=0 \Rightarrow V_{th_1} = V_{th_2}$

if $V_{GS_1} = V_{GS_2}$, $V_{th_1} = V_{th_2}$ ($V_{SB}=0$) $= V_{th_0}$

② if $V_{GS1} = V_{GS2}$, $V_{th1} = V_{th2}$ ($V_{SB} = 0$) $= V_{th0}$

$$\Rightarrow \frac{I_{D1}}{I_{D2}} = \frac{1+\lambda V_{DS1}}{1+\lambda V_{DS2}} \quad — ④$$

$\Rightarrow \lambda$

if v-sat $V_{min} = V_{DSAT}$

$$I_D = \beta\left[(V_{GS} - V_{th}) \cdot V_{DSAT} - \frac{V_{DSAT}^2}{2}\right](1+\lambda V_{DS})$$

$$I_{D1} = \beta\left[(V_{GS1} - V_{th1}) V_{DSAT} - \frac{V_{DSAT}^2}{2}\right](1+\lambda V_{DS1}) \quad — ⑤$$

$$I_{D2} = \beta\left[(V_{GS2} - V_{th2}) V_{DSAT} - \frac{V_{DSAT}^2}{2}\right](1+\lambda V_{DS2}) \quad — ⑥$$

if $V_{GS1} = V_{GS2}$ & $V_{th1} = V_{th2}$ $V_{SB} = 0$

$$\frac{⑤}{⑥} \Rightarrow \frac{I_{D1}}{I_{D2}} = \frac{(1+\lambda V_{DS1})}{(1+\lambda V_{DS2})} \quad — ④$$

plug 3, 6 into ④

$$\frac{I_{D3}}{I_{D6}} = \frac{1+\lambda V_{DS3}}{1+\lambda V_{DS6}} \Rightarrow I_{D3} + \lambda I_{D3} V_{DS6} = I_{D6} + \lambda I_{D6} V_{DS3}$$

$$\Rightarrow \lambda = \frac{I_{D3} - I_{D6}}{-I_{D3} V_{DS6} + I_{D6} V_{DS3}}$$

To solve V_{t0}

$V_{SB} = 0 \Rightarrow V_{th1} = V_{th2}$

$$③ \Rightarrow \frac{I_{d1}}{I_{d2}} = \frac{(V_{GS1} - V_{th0})^2}{(V_{GS2} - V_{th0})^2} \frac{(1+\lambda V_{DS1})}{(1+\lambda V_{DS2})} \quad — ⑦$$

plug 1 & 4 into ⑦

$\Rightarrow V_{th0} \rightarrow -0.1V$

$$r = \frac{V_{th} - V_{t0}}{\sqrt{|2\varphi_F| + V_{BS}} - \sqrt{|2\varphi_F|}}$$

$\sqrt{2\phi_F + V_{BS}} - \sqrt{2\phi_F}$

V_{th5}

4 and 5 into (3) $\Rightarrow$ V_{th5}

$$\frac{I_{d3}}{I_{d4}} = \frac{(V_{GS4} - V_{t0})^2}{(V_{GS5} - V_{th5})^2} \cdot \frac{\cancel{(1+\lambda V_{DS4})}}{\cancel{(1+\lambda V_{DS5})}}$$