MOSFET Theory (H.4)

20170308

Body Effect
Latchup

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References

Some Figures from the following sites

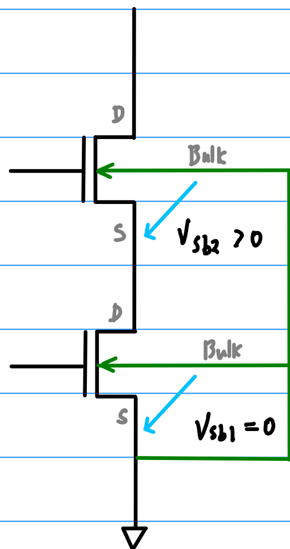
[1] http://pages.hmc.edu/harris/cmosvlsi/4e/index.html
Weste & Harris Book Site

[2] en.wikipedia.org

to implement logic functions

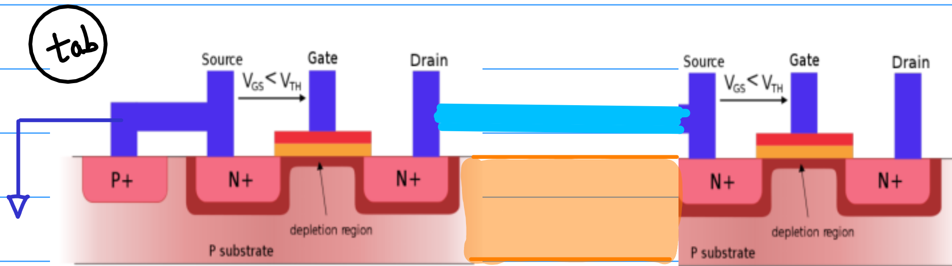
several devices in serial

NAND

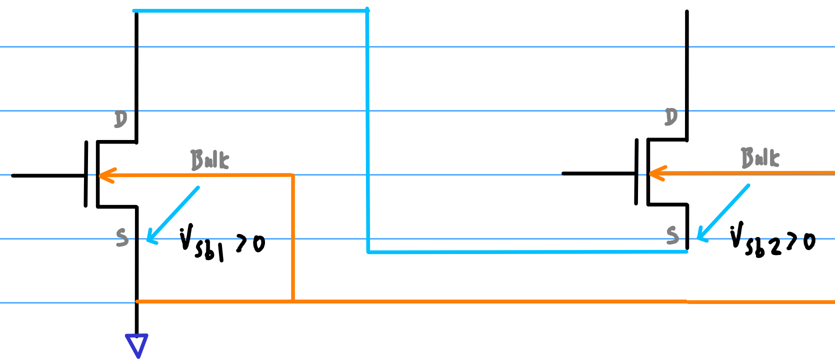


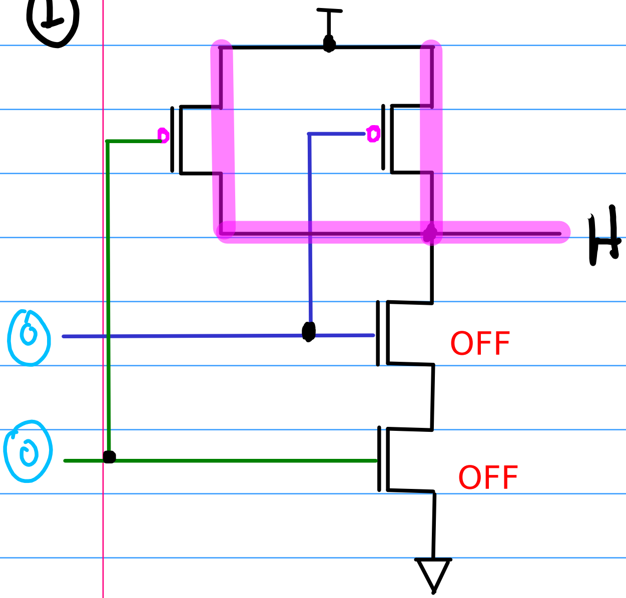
inc ↑ V_{sb} source-substrate voltage
inc ↑ depletion layer width
inc ↑ trapped carriers in the depletion region
dec ↓ the channel charge

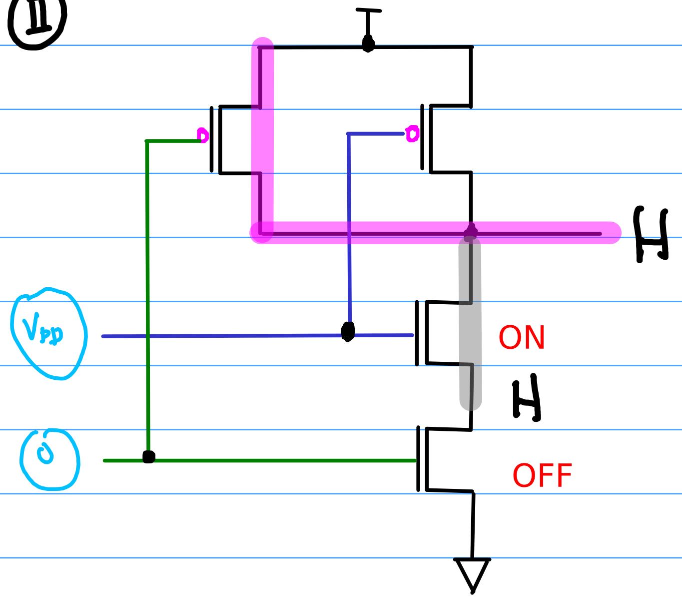
inc ↑ the gate-channel voltage drop

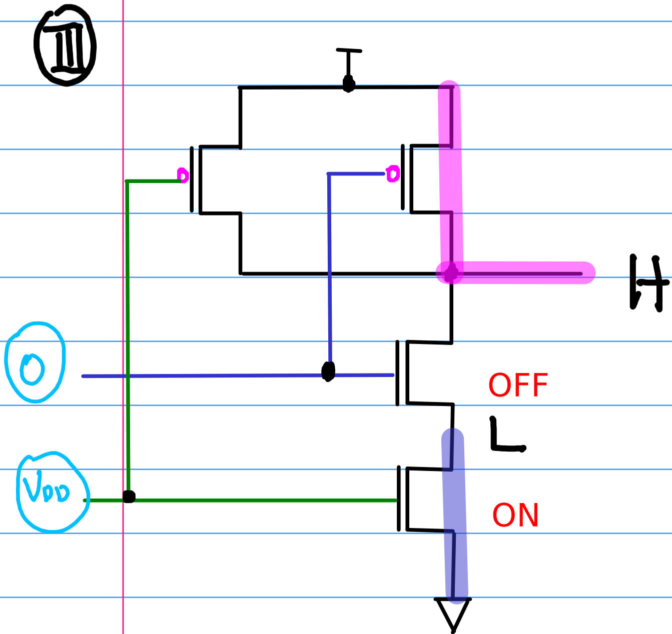


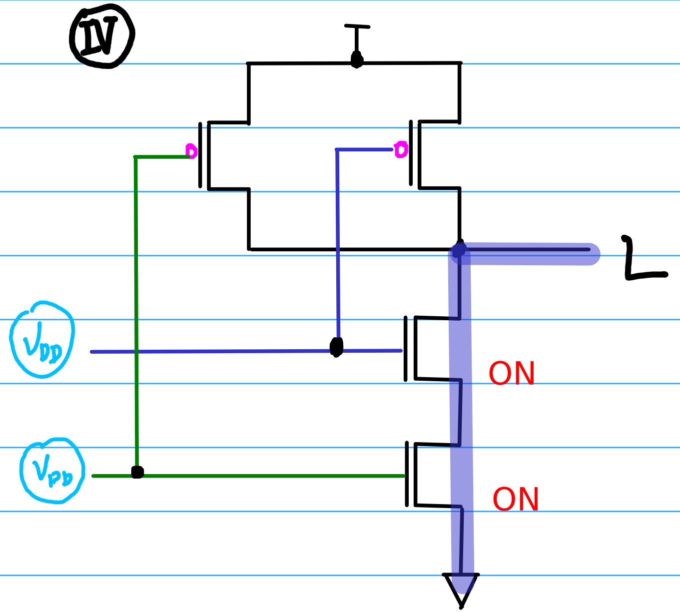
Can not be connected to the GND

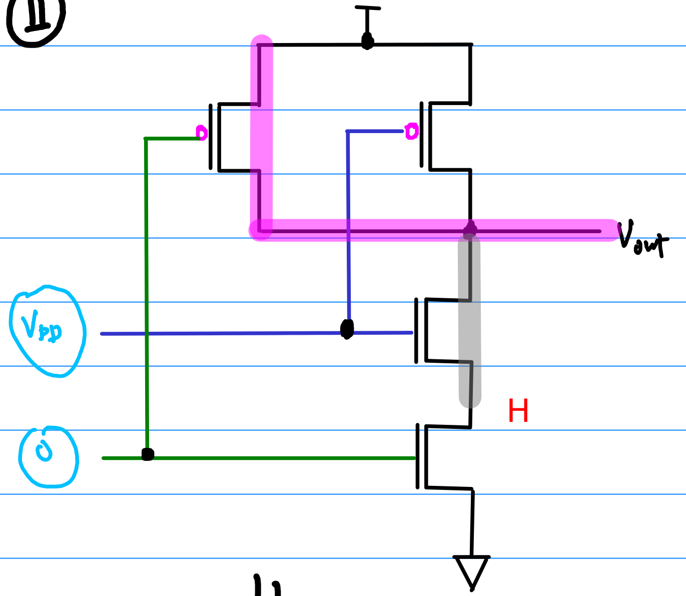



I
0
0
OFF
OFF
H

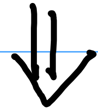

II
VDD
0
ON
OFF
H
H

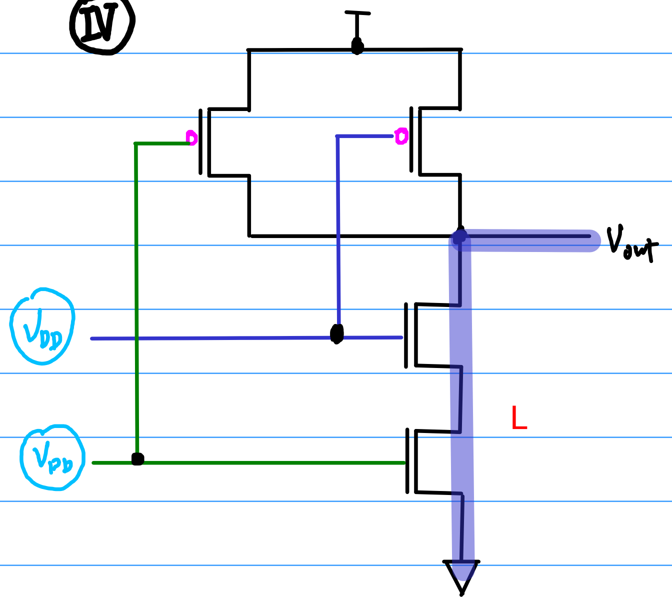

III
0
VDD
OFF
ON
H
L


IV
VDD
VDD
ON
ON
L



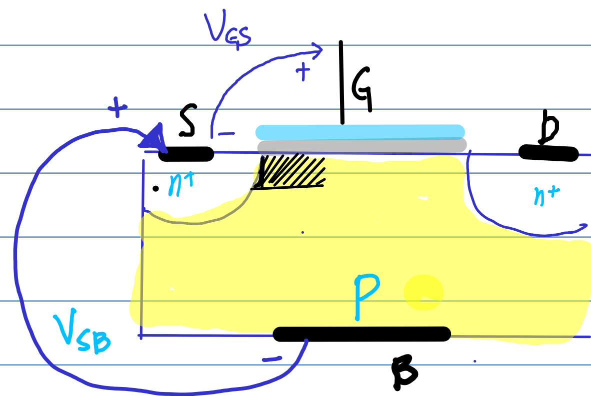
Ⅱ
V_{out}
V_{DD}
0
H





Ⅳ
V_{out}
V_{DD}
V_{DD}
L

Body Effect



$V_{GS} > V_t$

condition for an inverted channel

V_t: gate voltage should be greater than V_t to invert channel

this V_t increases as V_{SB} (source voltage) increases

this is because the source is connected with the inverted channel.

$$V_T = V_{T0} + \gamma \left(\sqrt{|2\phi_F - V_{SB}|} - \sqrt{|2\phi_F|} \right)$$

threshold when $V_{SB} = 0$

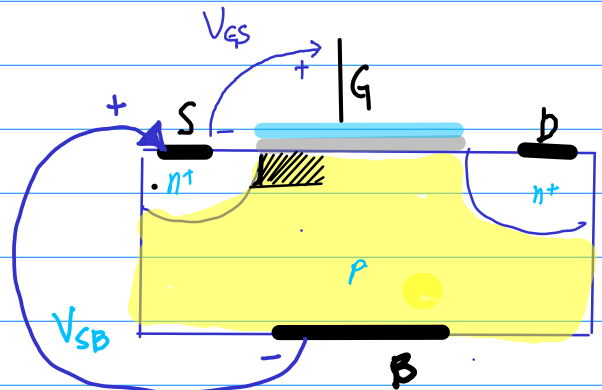
Body Effect Coefficient

Substrate Bulk Potential

$$\phi_F = \frac{E_F - E_i}{q}$$

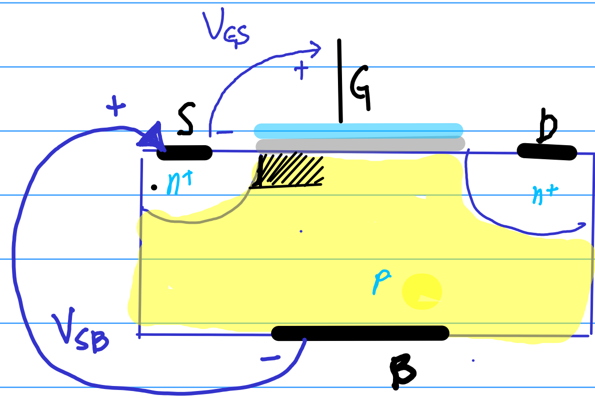
$$\phi_{Fp} \approx \frac{kT}{q} \ln \frac{n_i}{N_A}$$

$$\gamma = \sqrt{\frac{2q \cdot N_A \cdot \varepsilon_{si}}{C_{ox}}}$$

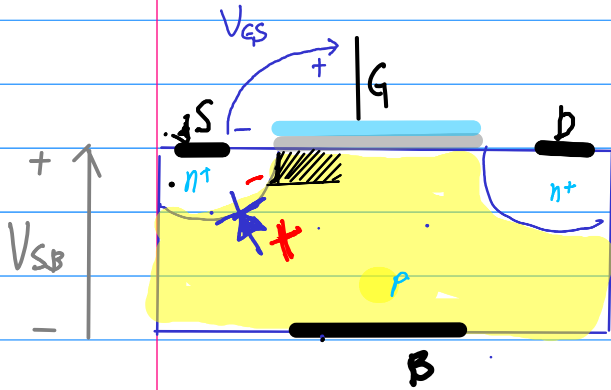


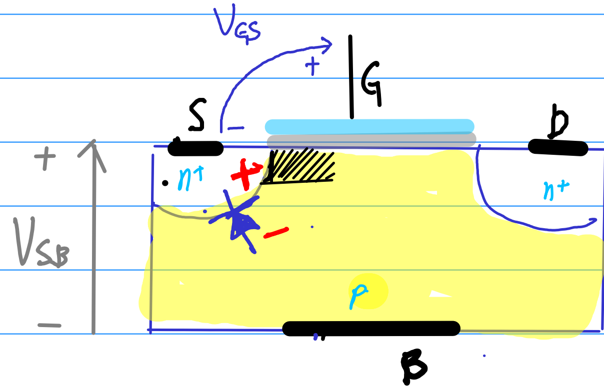
$$V_T = V_{T0} + \gamma \left(\sqrt{|2\phi_{Fp} - V_{SB}|} - \sqrt{|2\phi_F|} \right)$$

$$0.38 + 0.85 \left(\sqrt{|0.7 - V_{SB}|} - \sqrt{0.7} \right)$$



n MOS





$V_{SB} < 0$

ON

forward bias

the pn junction diodes should be turned off

$V_{SB} > 0$

OFF

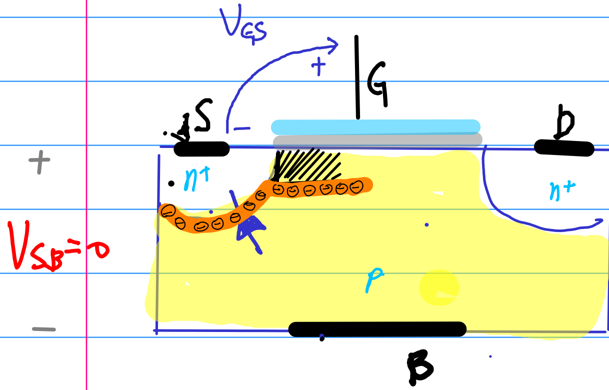
reverse bias

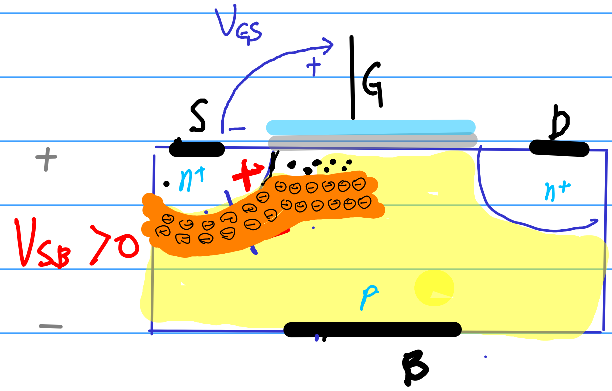
OFF → depletion

$V_{SB} \uparrow$

- space charge ↑
- electrons in the channel ↓

keeps neutral

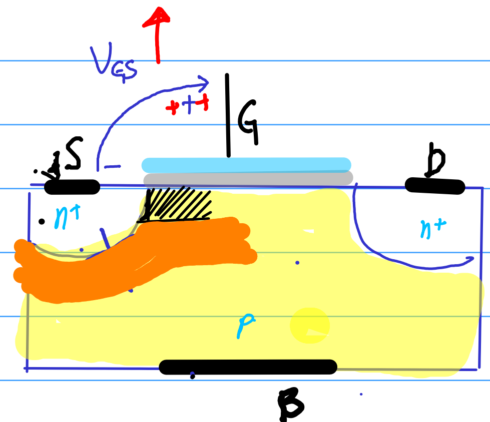




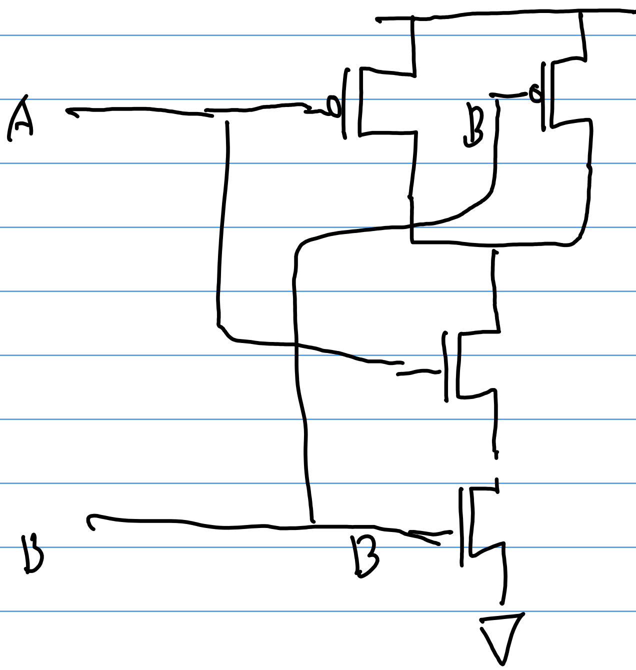
V_{SB} ↑ • Space charge ↑

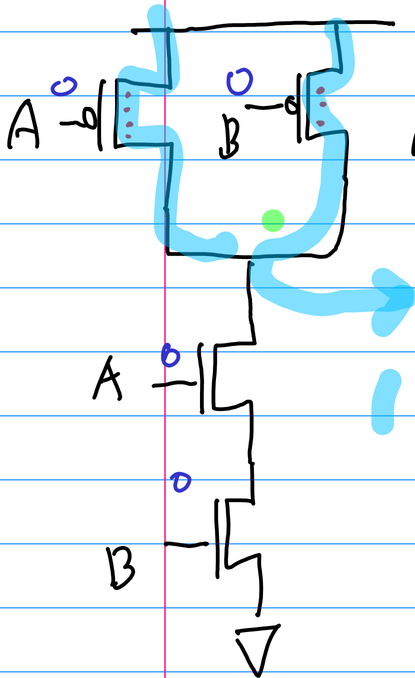
• electrons in the channel ↓

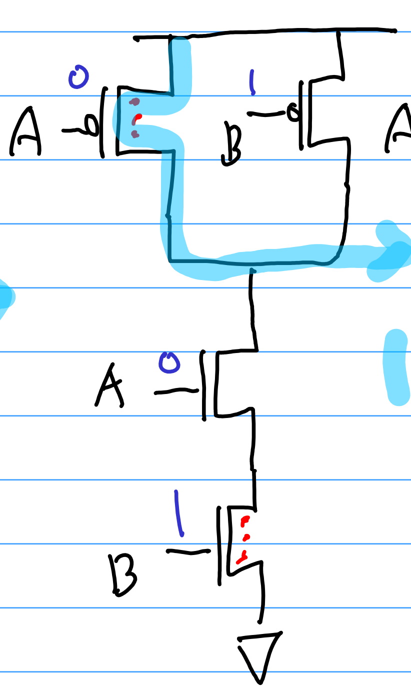
↳ keeps neutral

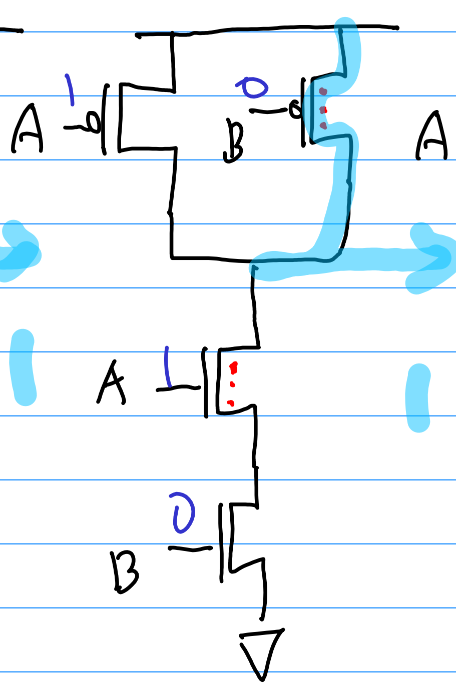


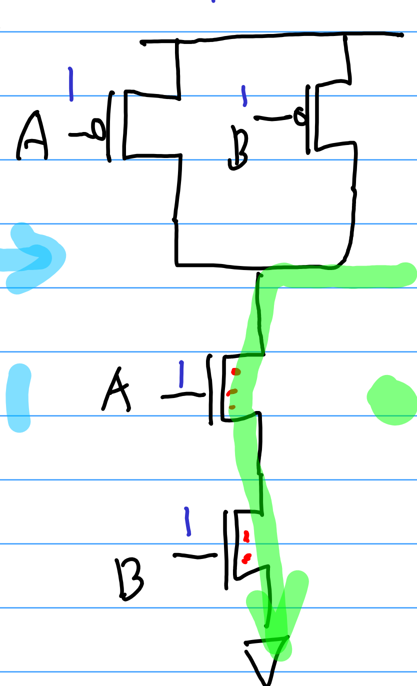
to get the same amount of electrons, V_{GS} has to be increased

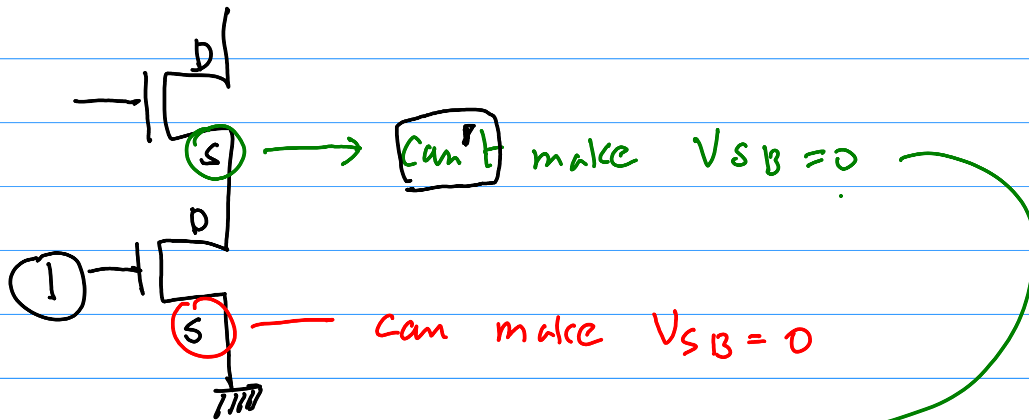

A
B
B
B

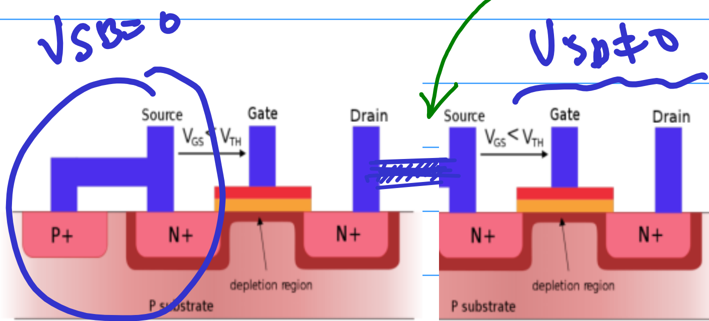

A=0 B=0
A
B
A
B
1


A=0 B=1
A
B
A
B
1


A=1 B=0
A
B
A
B
1


A=1 B=1
A
B
A
B

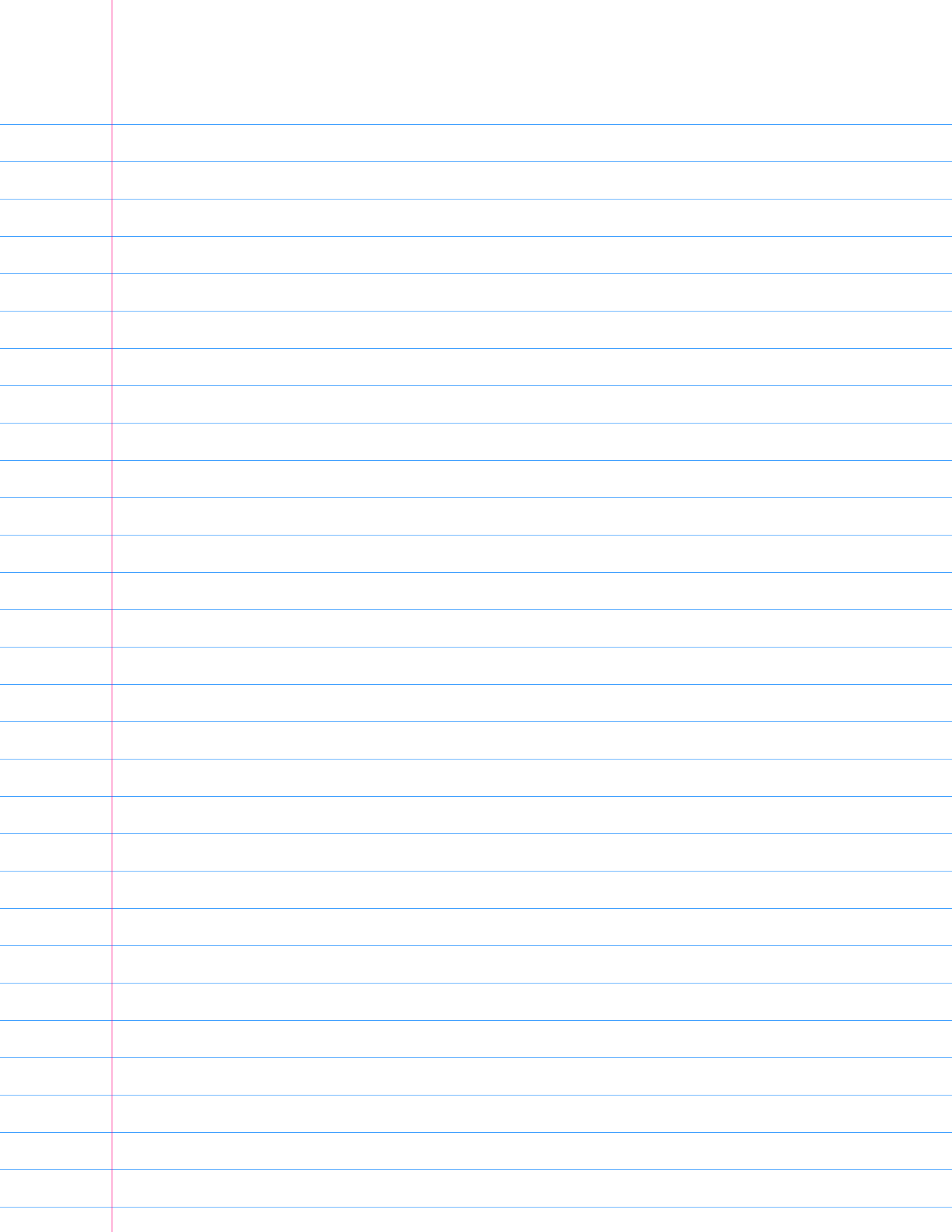


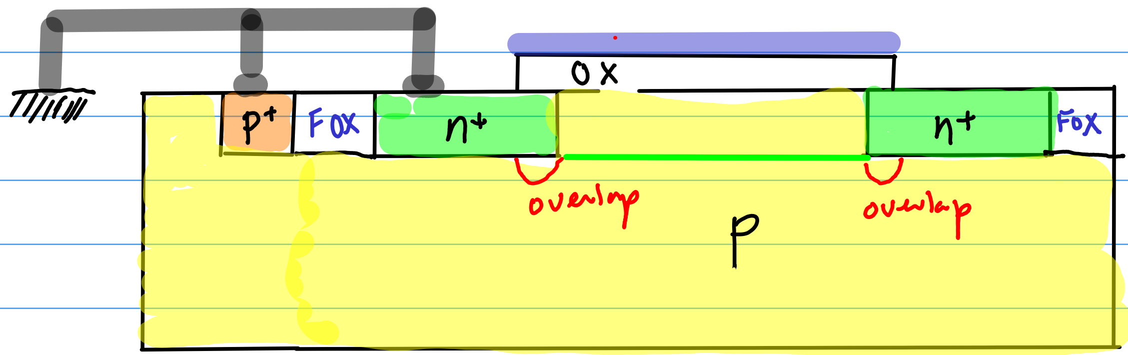


$V_{SB} > 0$ ⋯→ Body effect

→ increase threshold

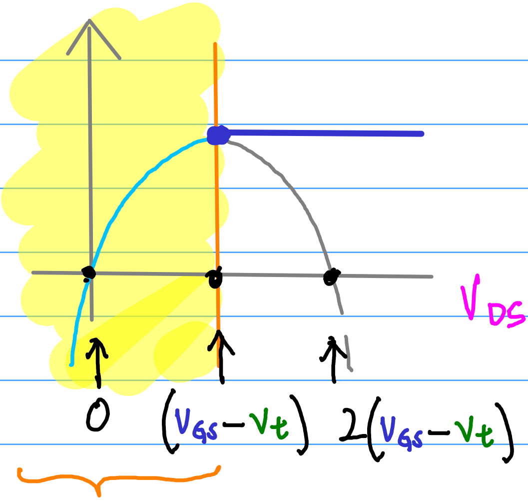
⇒ to turn on nMOS greater V_{GS} required





FOX (Field Oxide)

V_t

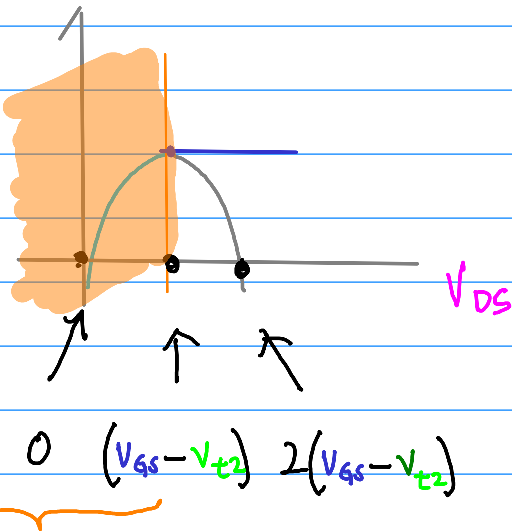


$$\begin{cases} \frac{\beta}{2}\left(2(V_{GS}-V_t)V_{DS}-V_{DS}^2\right) \\ \frac{\beta}{2}(V_{GS}-V_t)^2 \end{cases}$$

$V_t < V_{t2}$

$V_{DS} \leq V_{GS}-V_t$

V_{t2}



$$\begin{cases} \frac{\beta}{2}\left(2(V_{GS}-V_{t2})V_{DS}-V_{DS}^2\right) \\ \frac{\beta}{2}(V_{GS}-V_{t2})^2 \end{cases}$$

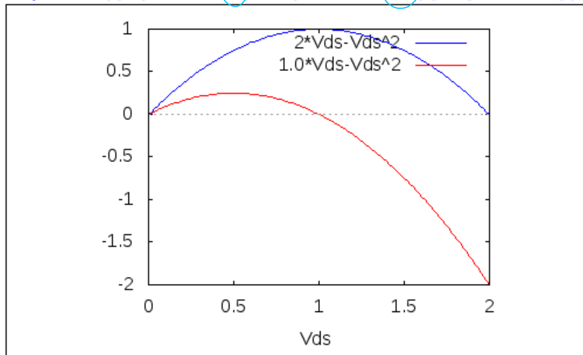
$V_{DS} \leq V_{GS}-V_{t2}$

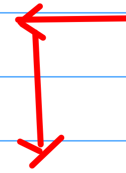
```
(%i7) f(Vds, Vgs, Vt) := (2*(Vgs - Vt)*Vds - Vds^2);
```

(%o7) $f(Vds, Vgs, Vt) := 2\,(Vgs - Vt)\,Vds - Vds^2$

```
(%i14) wxplot2d([f(Vds,2,1), f(Vds,2, 1.5)], [Vds,0,2])$
```

(%t14)



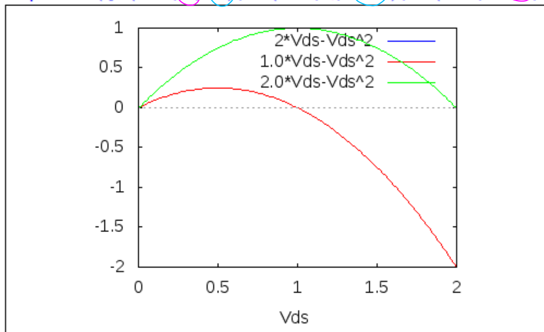


```
(%i7) f(Vds, Vgs, Vt) := (2*(Vgs - Vt)*Vds - Vds^2);
```

(%o7) $f(Vds, Vgs, Vt) := 2\,(Vgs - Vt)\,Vds - Vds^2$

```
(%i13) wxplot2d([f(Vds,2, 1), f(Vds,2, 1.5), f(Vds, 2.5, 1.5)], [Vds,0,2])$
```

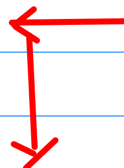
(%t13)



Symmetric axis $V_{gs} - V_t$

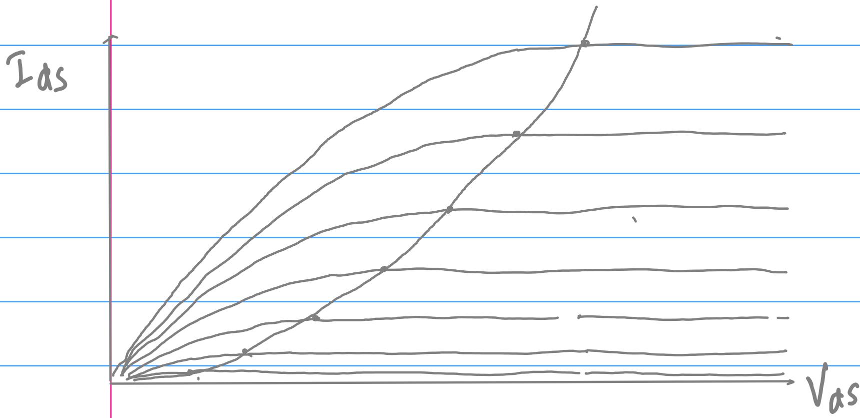
$V_{t2} > V_t$

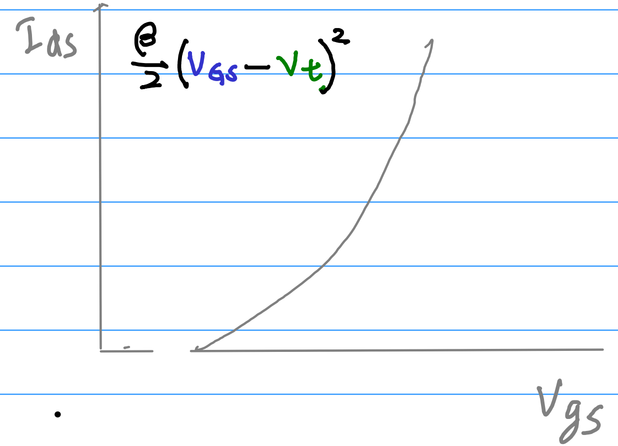
$V_{gs} - V_{t2} < V_{gs} - V_t$



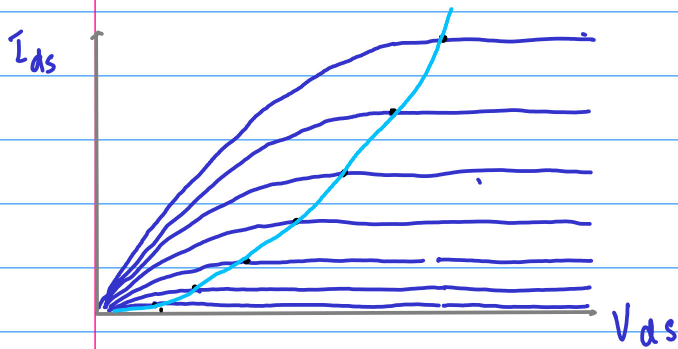
max value becomes smaller

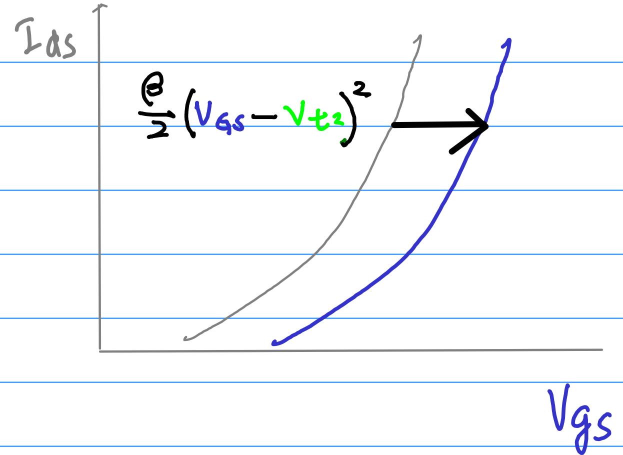
$V_{GS} - V_T = V_{DS}$





$V_{GS} - V_{t2} = V_{DS}$





to get the same Ids
Vds should be increased
by the same amount
threshold voltage increment