Lecture 02: Second-order effects on MOSFET & Biasing

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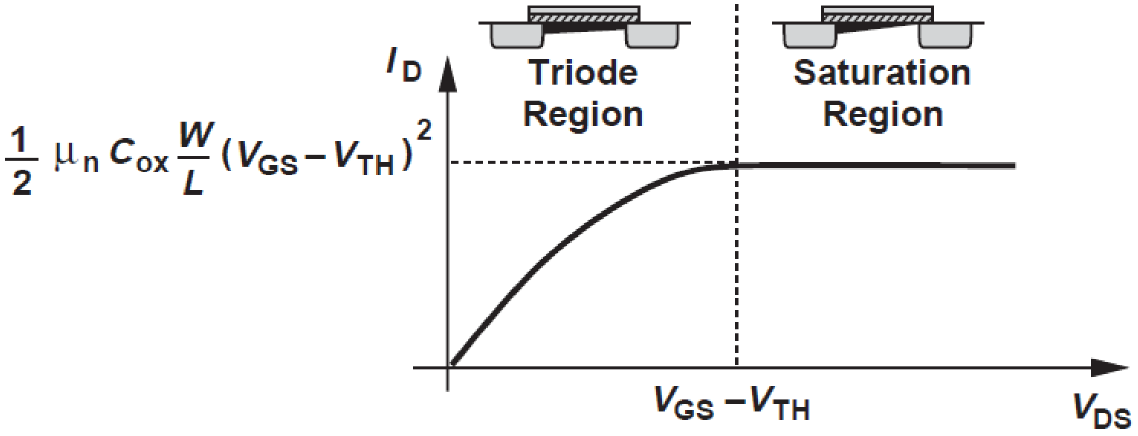
Review



TURN ON the Device

$V_{GS} > V_{TH}$

Triode Region

- $V_{DS} < V_{GS}-V_{TH}$
- I_D depends on V_{GS} and V_{DS}

$$I_D = \mu_n C_{ox}\frac{W}{L}\left[(V_{GS}-V_{TH})V_{DS}-\frac{1}{2}V_{DS}^2\right]$$

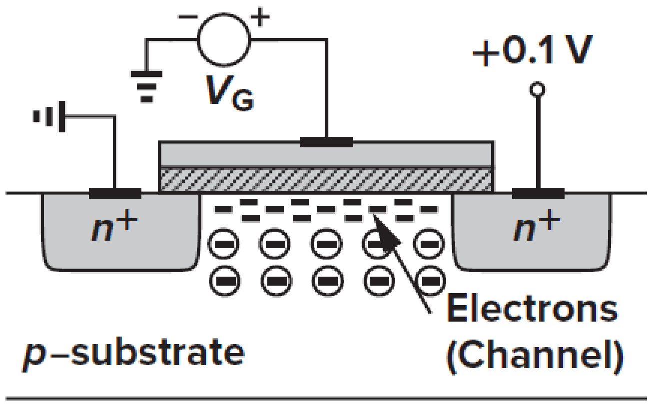
Saturation Region

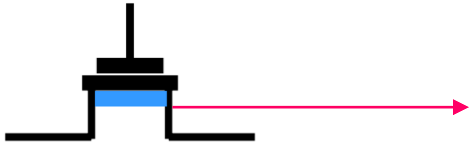
- $V_{DS} \geq V_{GS}-V_{TH}$
- I_D depends on V_{GS} (mostly)

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L_1}(V_{GS}-V_{TH})^2$$

Body Effect

- Remember that a certain value for VGS=VTH is required to create and inversion layer under the oxide.
- VTH can be considered constant for a given NFET* if the source and body experiment the same potential.

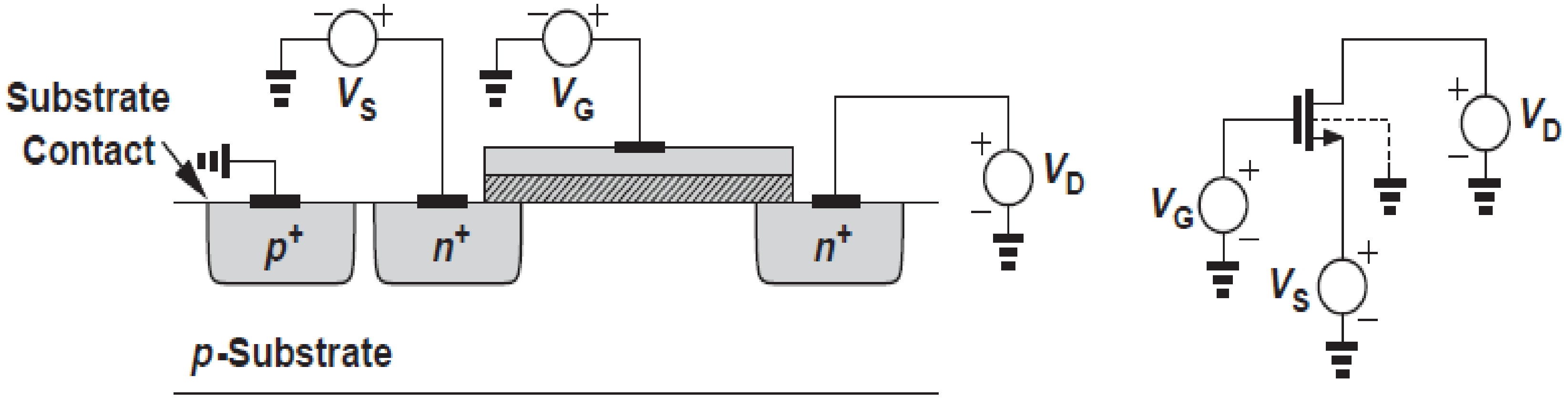




$$V_{TH} = \Phi_{MS} + 2\Phi_F + \frac{Q_{dep}}{C_{ox}}$$

Body Effect

- The body effect appears when source-bulk voltage is different to ZERO (≠0).



- As the source becomes more positive with respect to the bulk, VTH increases.

Body Effect

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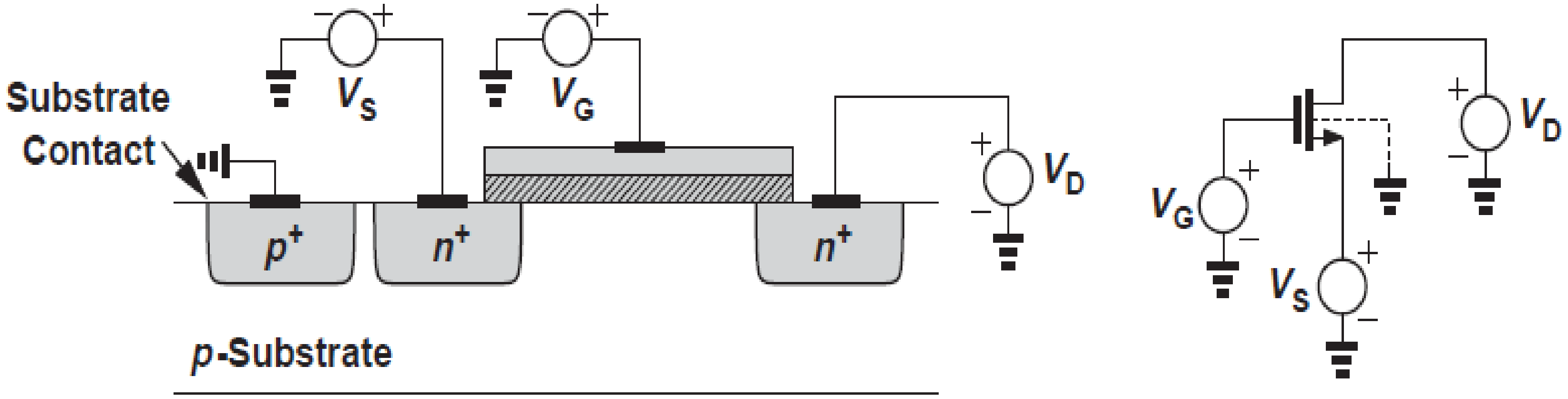

- As the source becomes more positive with respect to the bulk, VTH increases. Why?

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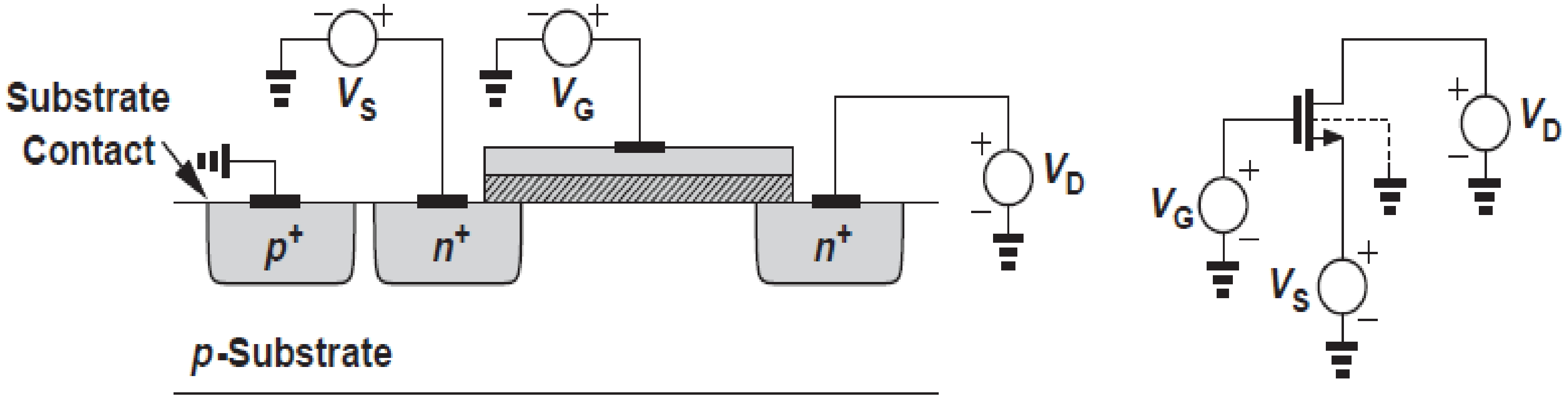

- As the source becomes more positive with respect to the bulk, VTH increases. Why? A: Because the depletion region becomes larger

$$V_{TH} = \Phi_{MS} + 2\Phi_F + \frac{Q_{dep}}{C_{ox}}$$

Body Effect

- This phenomenon is called the “body effect” and it can be proved that:

$$V_{TH} = V_{TH0} + \gamma\left(\sqrt{|2\phi_F + V_{SB}|} - \sqrt{|2\phi_F|}\right)$$

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$$\boxed{V_{TH} = V_{TH0} + \gamma\left(\sqrt{|2\phi_F + V_{SB}|} - \sqrt{|2\phi_F|}\right)}$$

$$\Phi_{MS} + 2\Phi_F + \frac{Q_{dep}}{C_{ox}}$$

$$\gamma = \sqrt{2q\epsilon_{si}N_{sub}}/C_{ox}$$

The “threshold” explained before

body-effect coefficient

(0.3~0.4V^1/2)

Channel Length Modulation

- Remember that:
- If $V_{DS}=V_{GS}-V_{TH}$ then the channel is pinched-off.
- Actually, for greater values of VDS the region under the gate without inversion layer extents towards the source.

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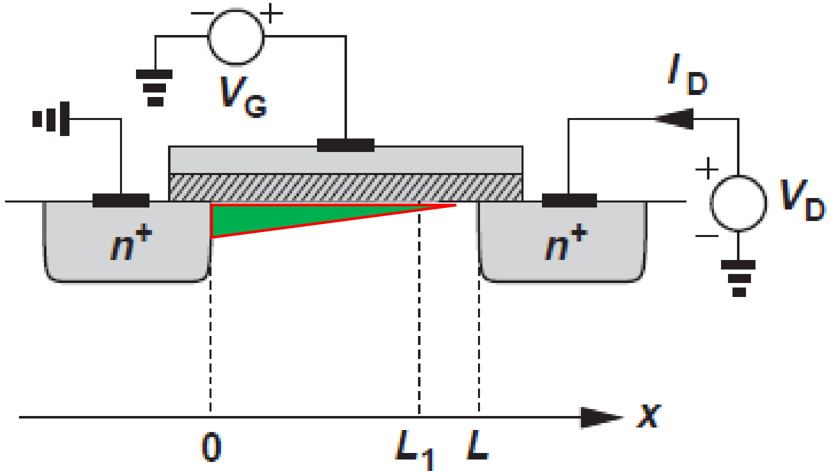
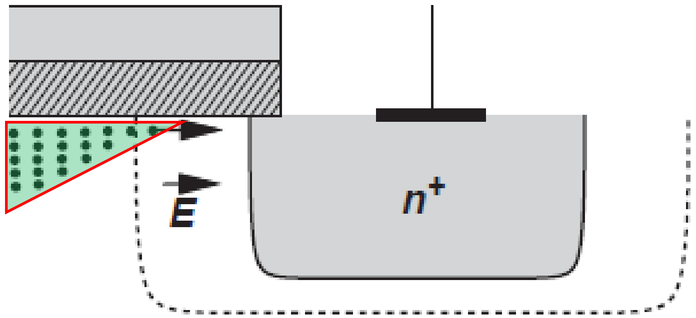




Channel Length Modulation

- Current expression:

$$\boxed{I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L_1}(V_{GS} - V_{TH})^2}$$

- L_1 is a function of V_{DS}. We can write:

$$L_1 = L - \Delta L$$

Assuming that $L \gg \Delta L$, then,

$$1/L_1 \approx (1+\Delta L/L)/L$$

And assuming a first-order relationship between $\Delta L/L$ and V_{DS}, such as $\Delta L/L = \lambda V_{DS}$

Channel Length Modulation

- Current expression is modified to:

$$I_D \approx \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2(1 + \lambda V_{DS})$$

Channel Length Modulation

- Current expression is modified to:

$$I_D \approx \underbrace{\boxed{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2}}_{\textbf{Same as before}}\underbrace{\boxed{(1+\lambda V_{DS})}}_{\textbf{Additional term}}$$

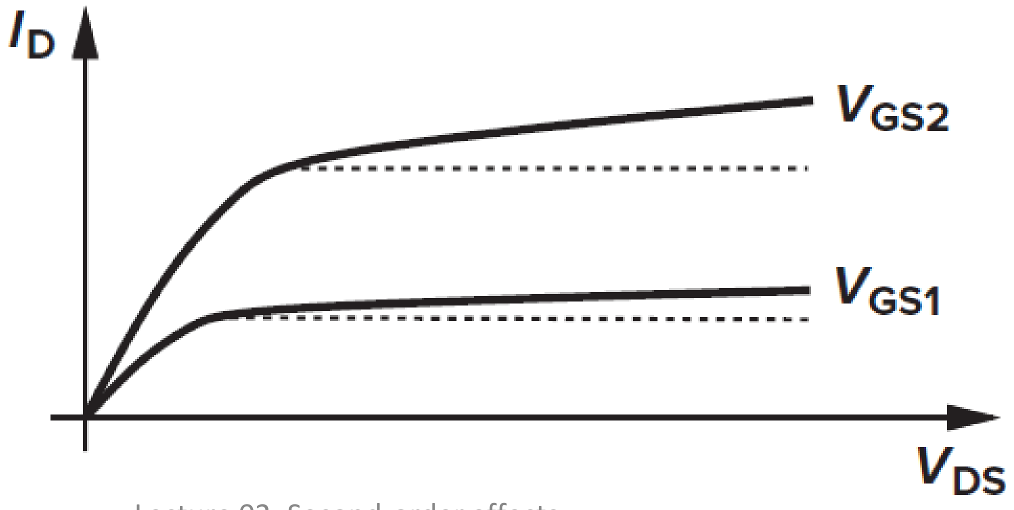
- Now the current has a dependence on VDS and results in a non-ideal current source between source and drain.

Channel Length Modulation

- Current expression is modified to:

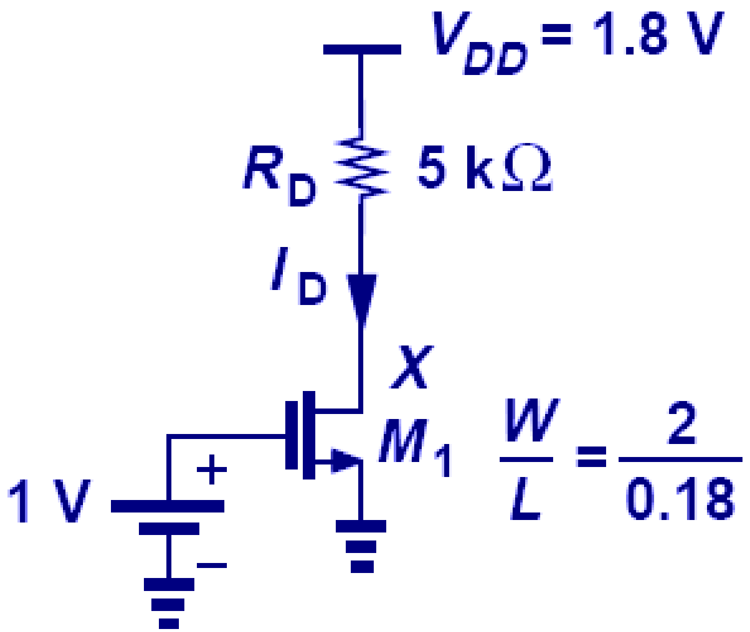
$$\boxed{I_D \approx \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2}\boxed{(1 + \lambda V_{DS})}$$

Same as before **Additional term**



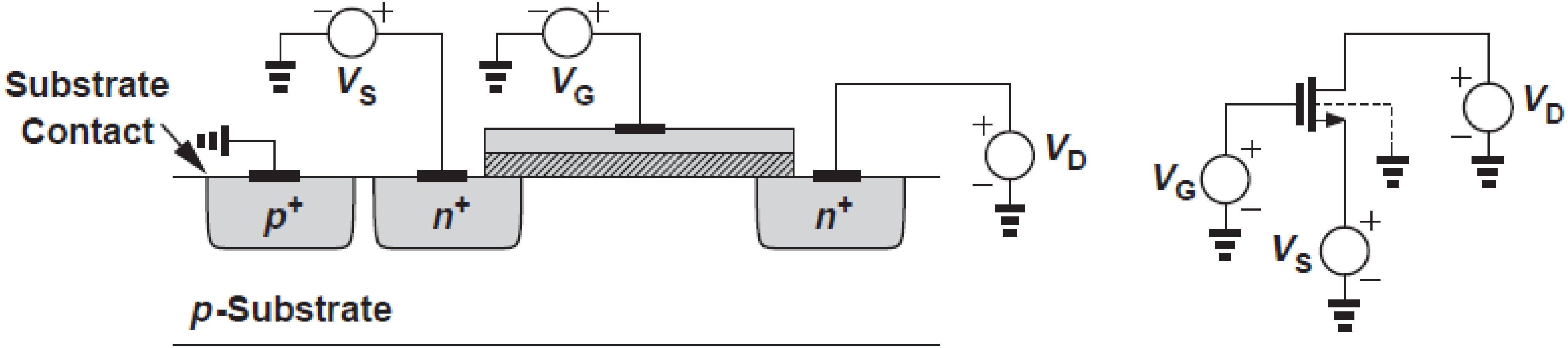
Exercise for class

Calculate the bias current of M1.
Assume:
$\mu_n C_{ox}$ = 100uA/V^2
V_{TH} = 0.4V



- ➢ **When the region of operation is not known, a region is assumed (with an intelligent guess). Then, the final answer is checked against the assumption.**

Circuit for exercise



Additional exercises

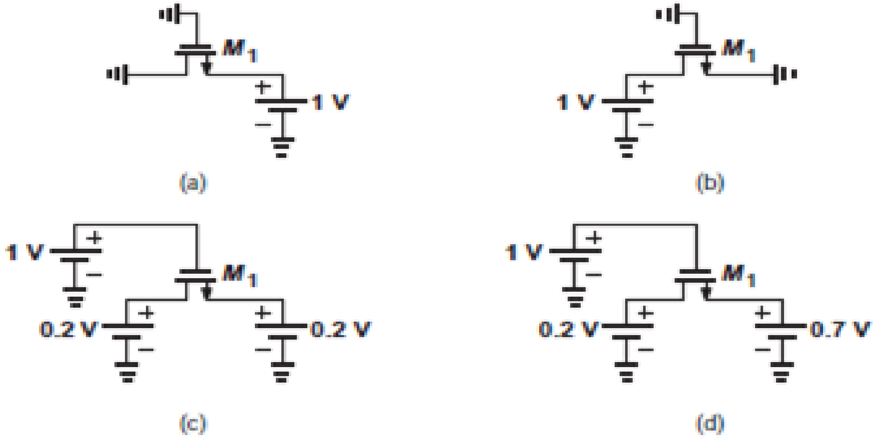


Figure 6.38

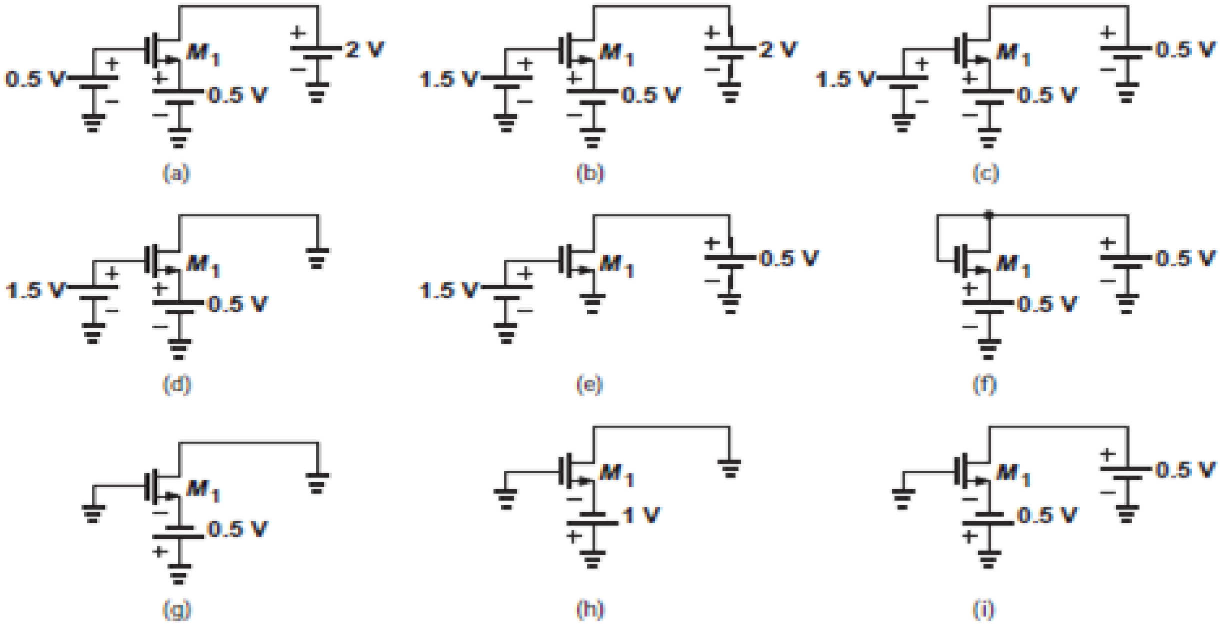
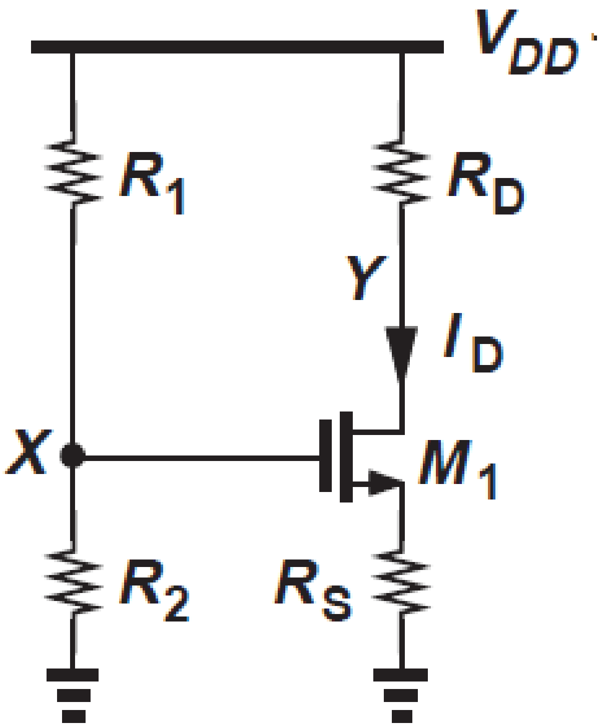


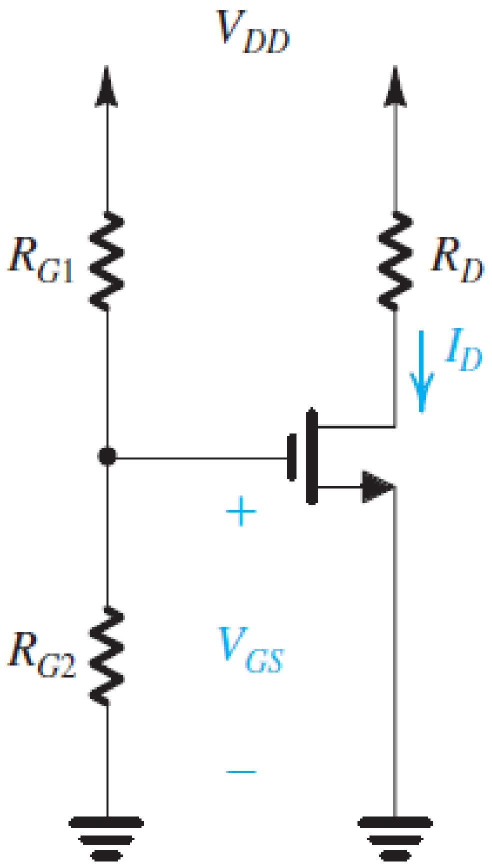
Figure 6.39

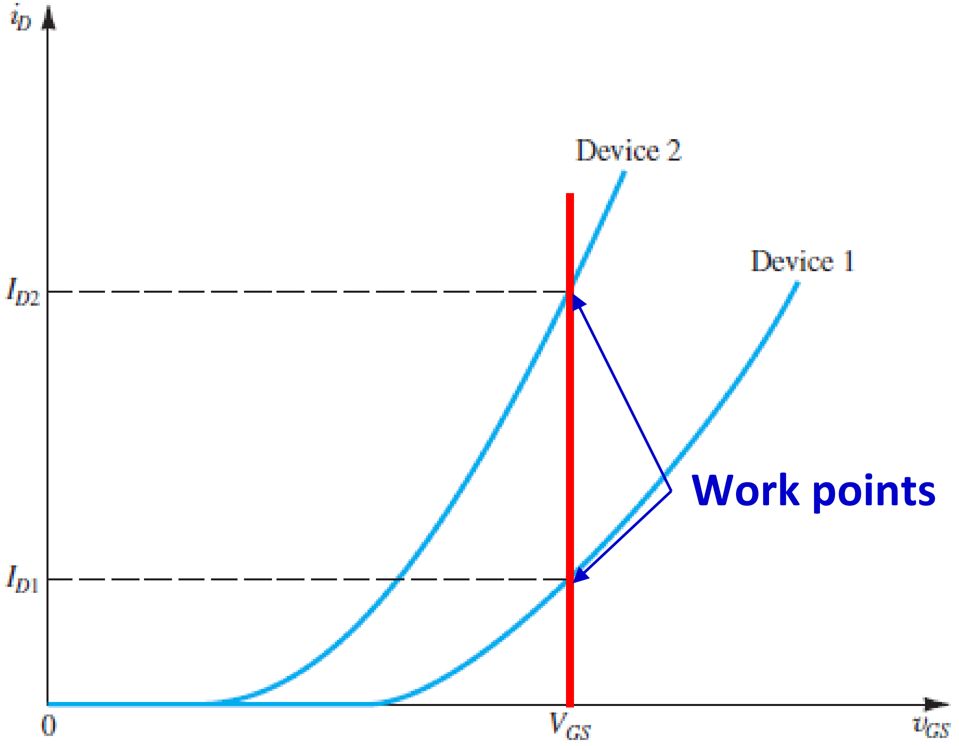
Biasing in MOS transistor



- The main idea is to find the “work point” of the transistor.
- Remember to assume a region, do the calculations and then verify the results.

Biasing by fixing VGS





- This is the easiest way to bias the transistor, but it is not a good way

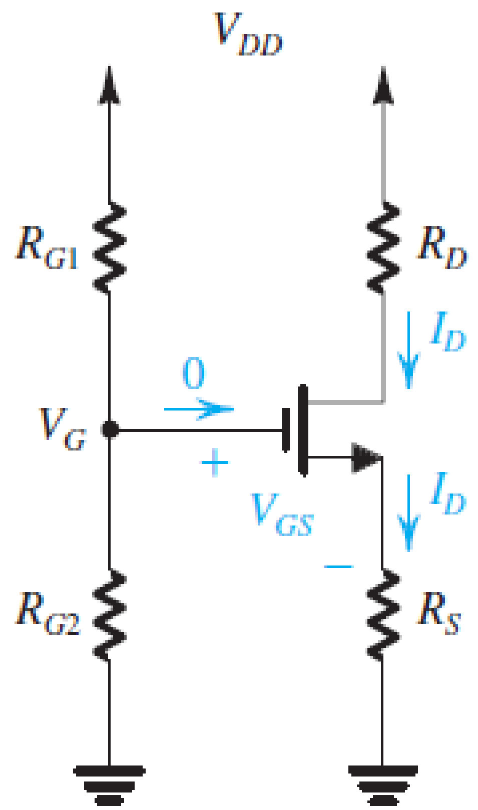
Review

- Recall that:

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2.$$

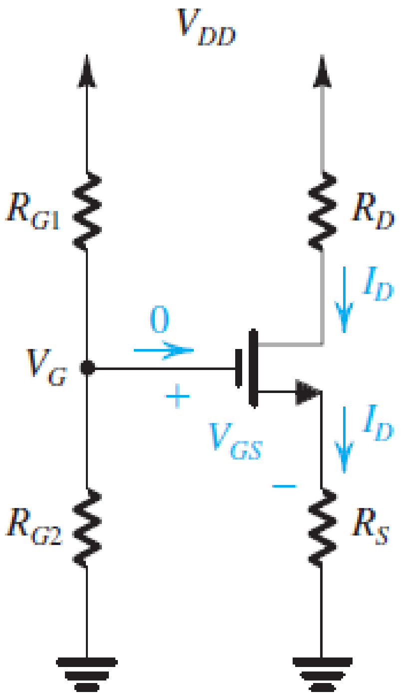
- We fixed the gate-source voltage using a voltage divider. But this has a lot of dependences.
- Check the curves for extreme transistors of the same batch

Biasing by fixing VGS and Rs resistor

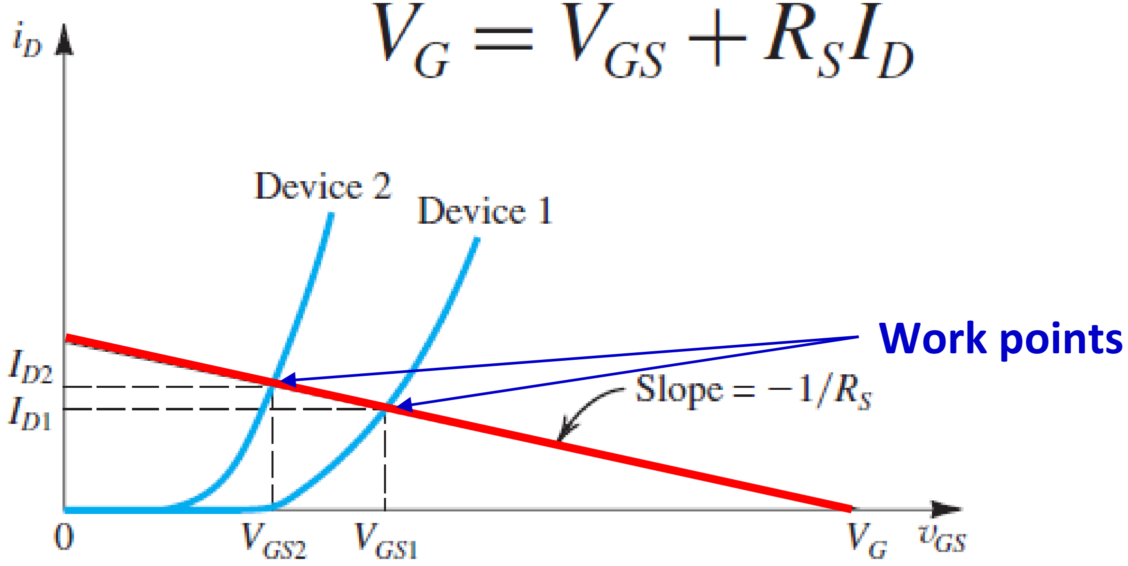


- Connecting an Rs resistor to the source terminal can help to solve the great dependence of ID on MOS parameters.

Biasing by fixing VGS



$$V_G = V_{GS} + R_S I_D$$

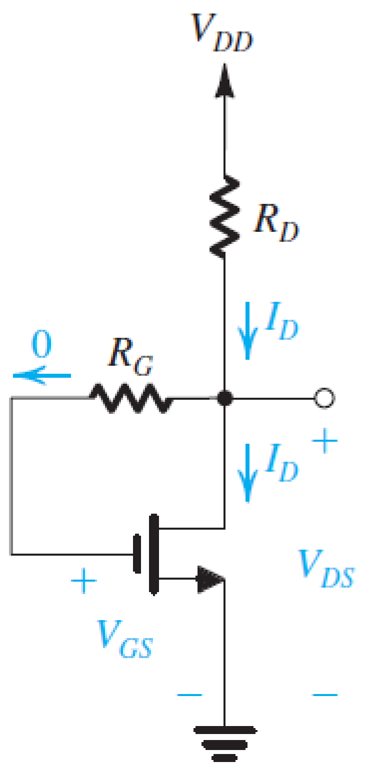


- Here, the variability of I_D is smaller
- Take care of the valid region of red line!

Examples

- Determine the bias current of $M1$ for the two bias schemes explained before, assuming $V_{TH} = 0.5V$, $\mu_n C_{ox} = 100\ \mu A/V^2$, $W/L = 5/0.18$, and $\lambda = 0$. What is the maximum possible value of R_D for $M1$ to remain in saturation?. RG1=4k, RG2=10K, RS=1K.

Self Biasing



$$V_{GS} = V_{DS} = V_{DD} - R_D I_D$$

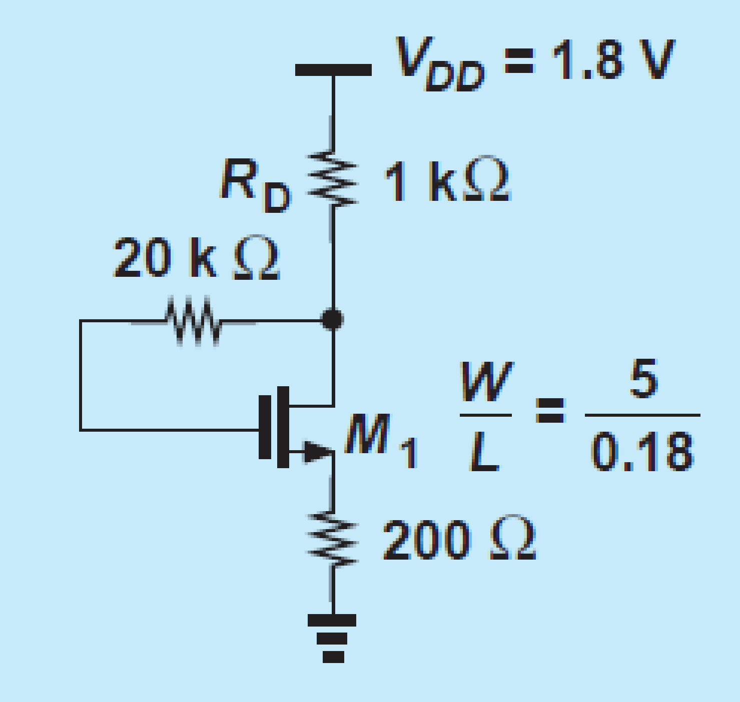
$$V_{DD} = V_{GS} + R_D I_D$$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2.$$

- What is the operation region of the MOSFET?
- Also it is possible to add an Rs resistor!

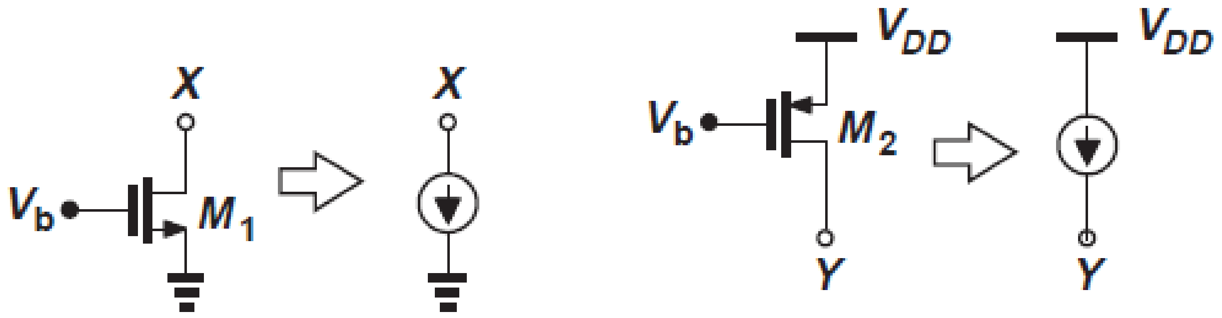
Examples

- Calculate the drain current of $M1$ if $\mu nCox = 100\ \mu A/V^2$, $VTH = 0.5$ V, and $\lambda = 0$. What value of RD is necessary to reduce ID by a factor of two?



Biasing with current source

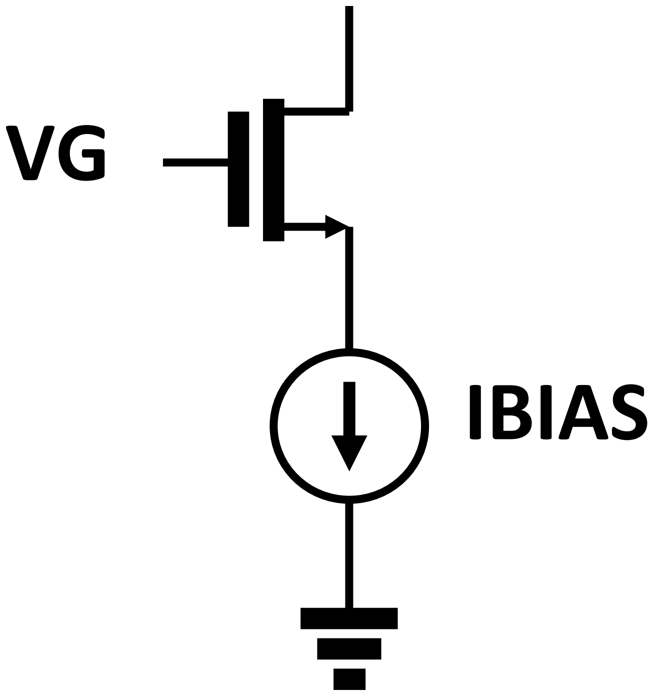
- MOSFETS operating in saturation region may act similar to a current source? Why?
- What are the differences regarding an ideal current source?



(a) (b)

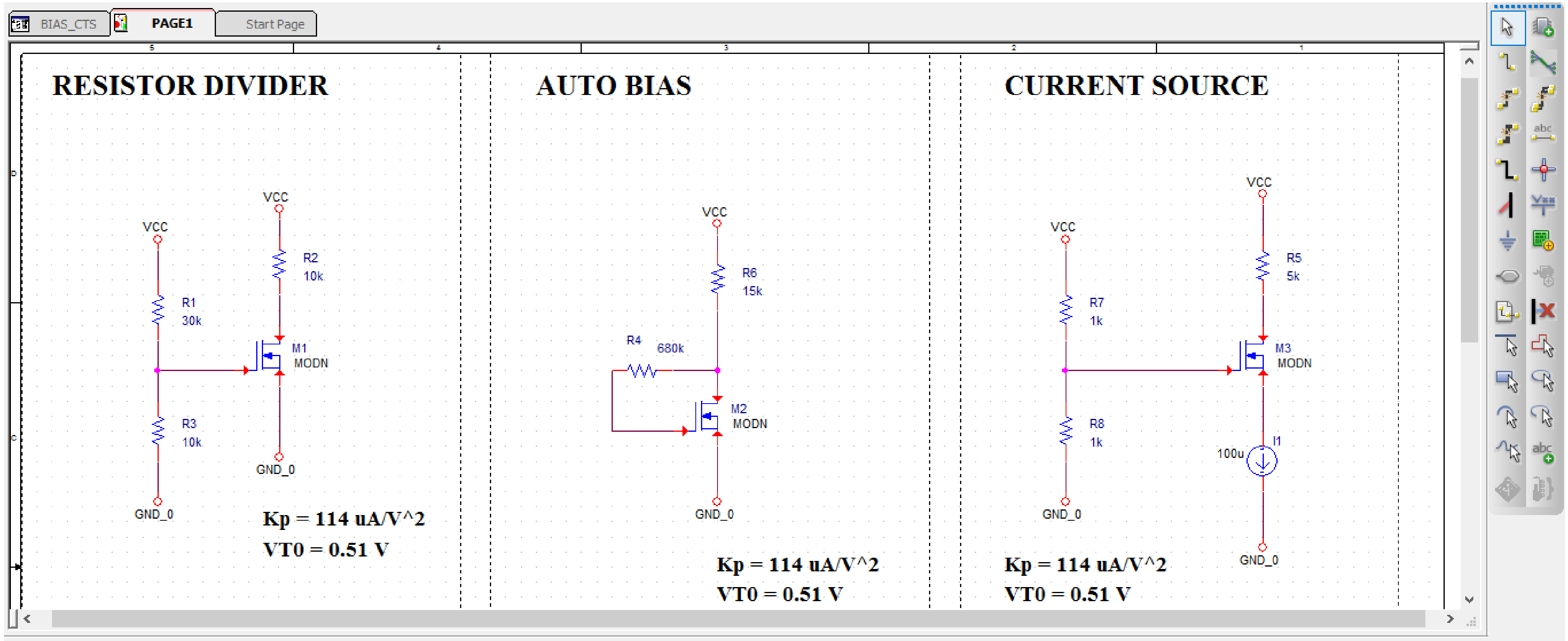
- Actually, current sources are implemented with MOS devices!!!

Biasing with current source



- Fix the bias point by using a current source
- Fixing ID is almost the same as fixing VGS in saturation region.

Additional Examples: OrCAD



Thanks!