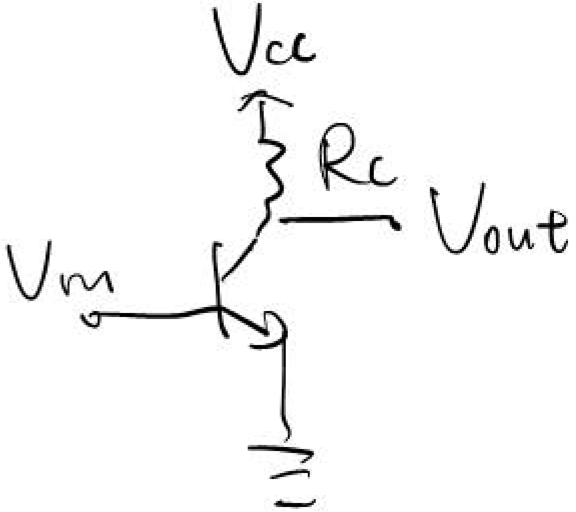
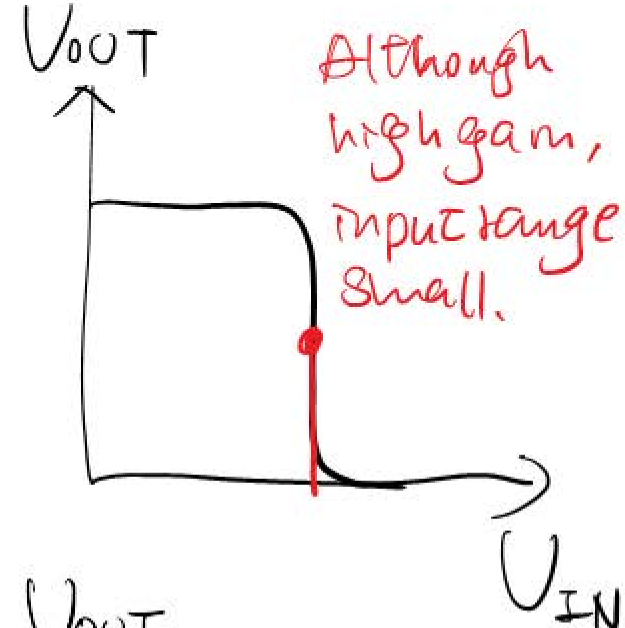
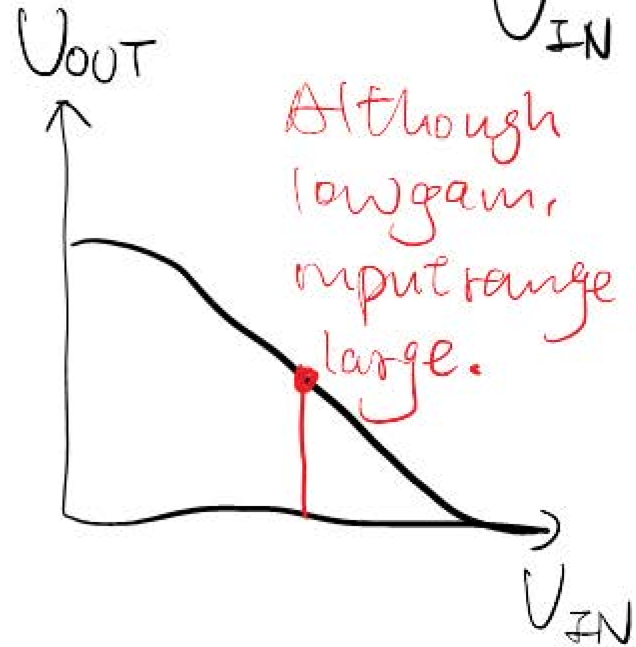


If Rc large

trade-off

If Rc small





JOINT INSTITUTE

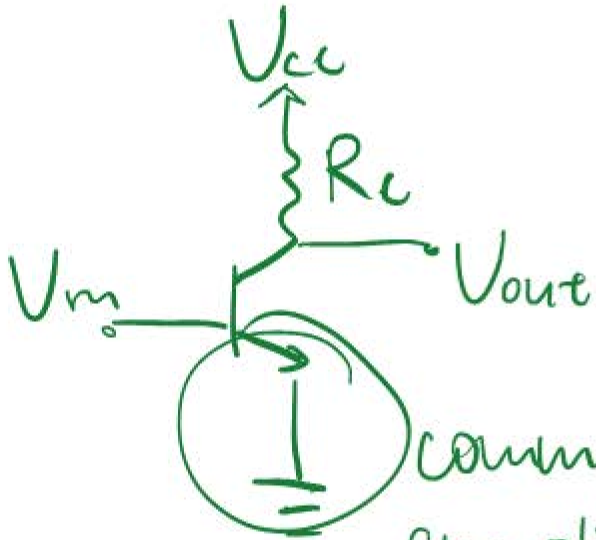
交大密西根学院

FET Single Stage Amplifier

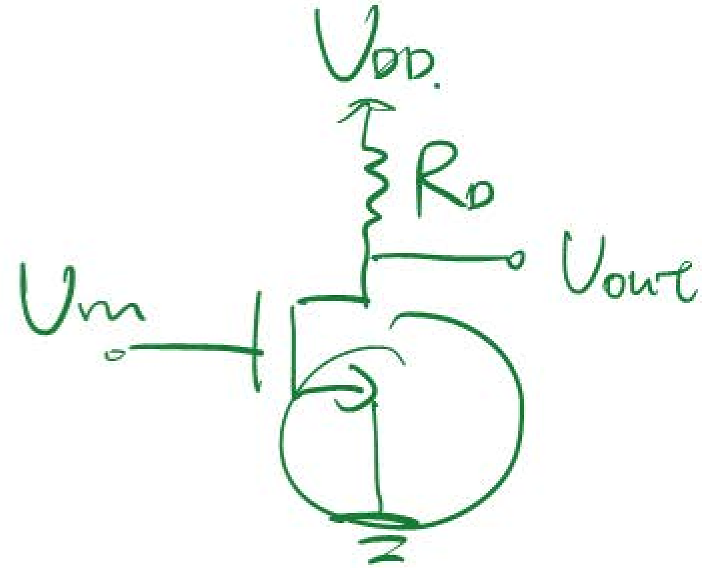
Ve311 Electronic Circuits (Fall 2020)

Dr. Chang-Ching Tu

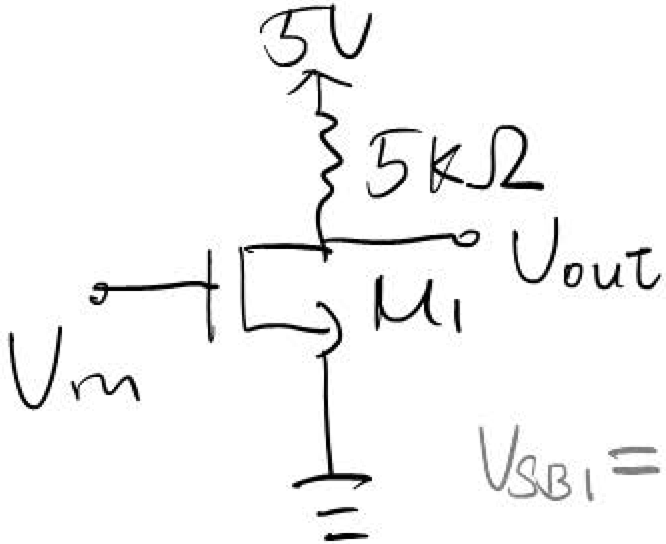
Last Updated on **October 21, 2020**



common-emitter amplifier



Common-Source with Resistive Load



$V_{SB1} = 0$

M_1 has size $\frac{10um}{2um} = \frac{W_{drawn}}{L_{drawn}}$

$\lambda \neq 0,\ \gamma \neq 0$

$V_{in} = 0.8 + 0.001 \sin(2\pi 100 t)$

$V_{out} = V_{OUT} + v_{out} = ?$

1° Find out $V_{OUT} = ?$

then confirm whether

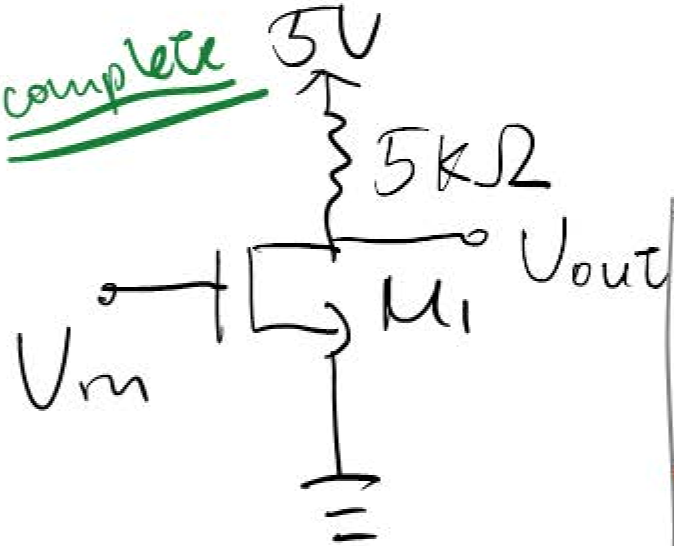
$V_{DS} \geq V_{GS} - V_{TH}$

$V_{OUT} \geq \underbrace{V_{IN}}_{=0.8} - \underbrace{V_{TH}}_{=0.7} = 0.1$

$V_{OUT} = 5 - (5K) \cdot I_{D1}$

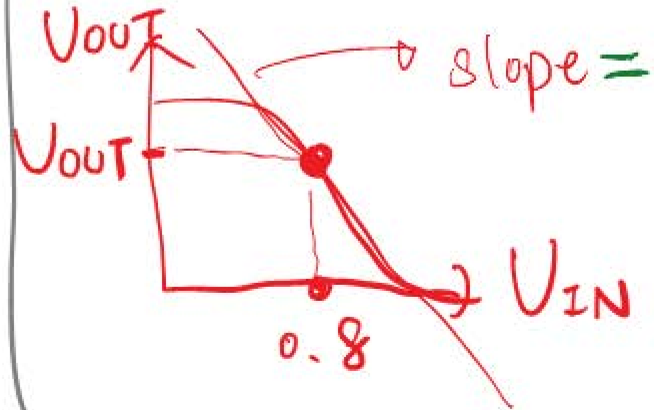
$I_{D1} = \frac{1}{2} \mu_n C_{ox} \left(\frac{10um}{2um - 2L_D}\right) (0.8 - 0.7)^2 (1 + \lambda V_{OUT})$

complete



2° Find out $v_{out} = ?$

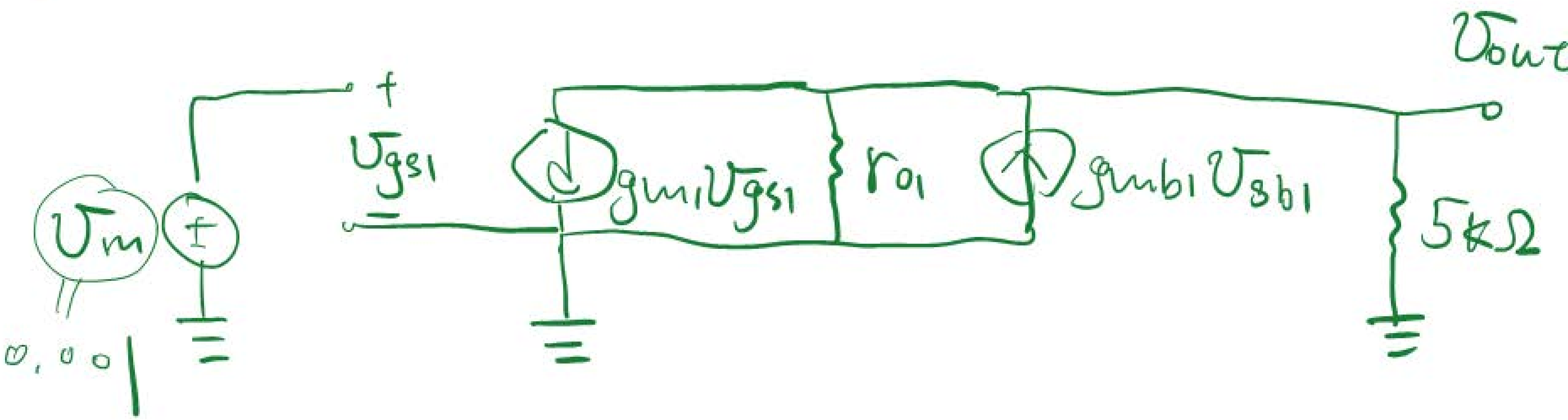
If using Pspice, do DC sweep.



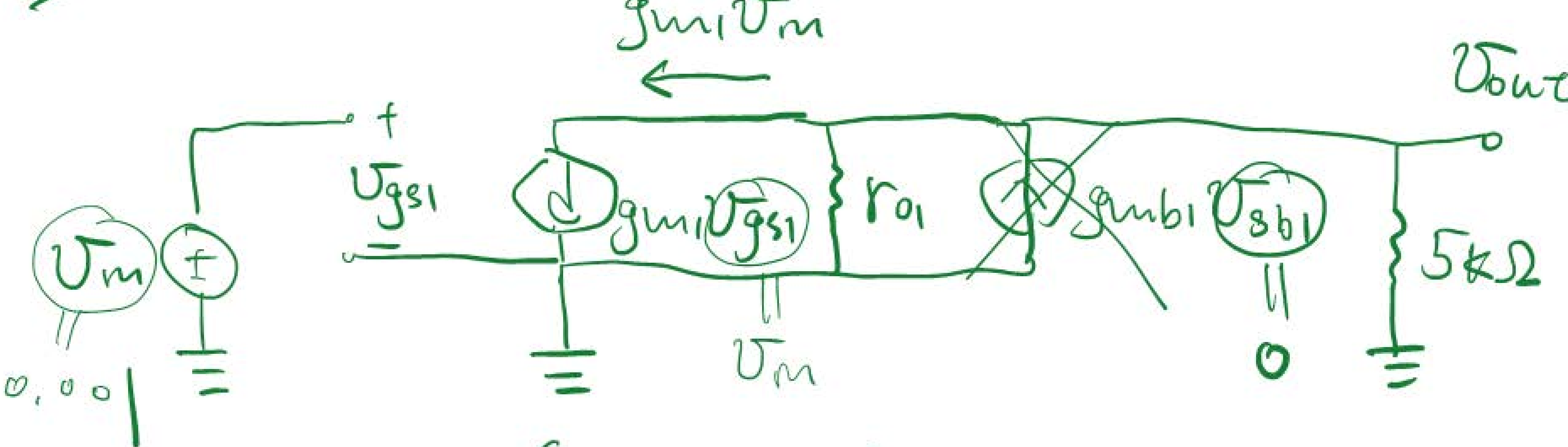
slope = $A_v = \left.\dfrac{dV_{OUT}}{dV_{IN}}\right|_{@V_{IN}=0.8}$

$v_{out} = 0.001 A_v \sin(\omega t)$

small-signal



Small-signal



$$v_{out} = -(g_{m1}v_{in})(r_{o1} \parallel 5k)$$

$$\begin{cases} g_{m1} = \mu_n C_{ox}\left(\frac{W}{L_{eff}}\right)(0.1)^2(1+\lambda V_{OUT}) \\ r_{o1} \cong \frac{1}{I_{D1}\lambda} \end{cases}$$

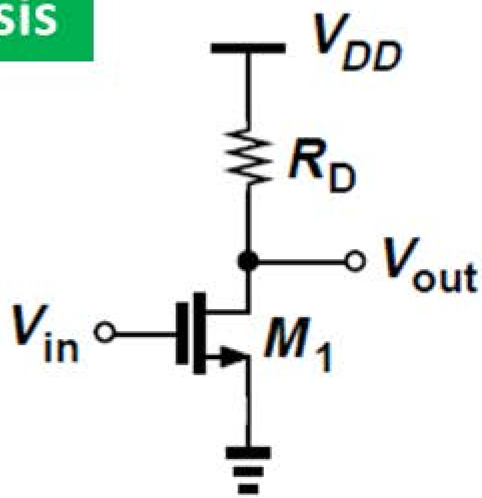
$$\boxed{A_v = \frac{v_{out}}{v_{in}}} = -g_{m1}(r_{o1} \parallel 5k)$$

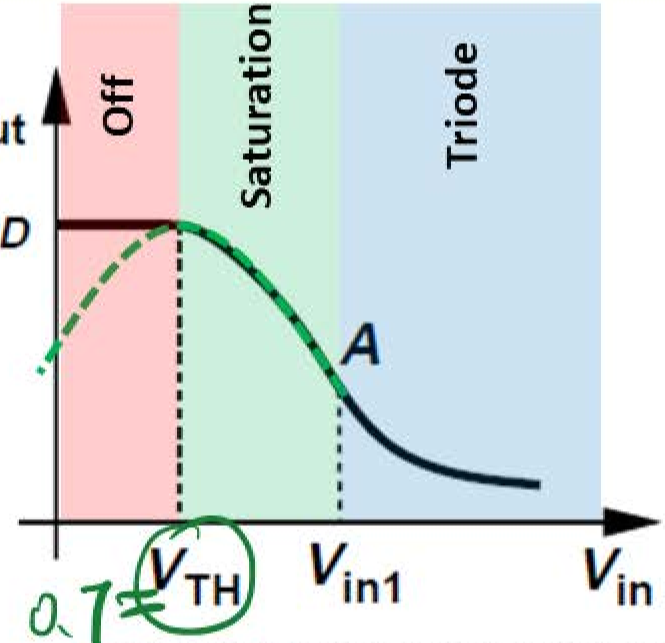
Common-Source with Resistive Load

DC Analysis

$\lambda = 0$

$\gamma = 0$





$$V_{out} = V_{in1} - V_{TH}$$
$$= V_{DD} - R_D \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{TH})^2$$

- $V_{in} < V_{TH} \rightarrow M_1$ **Off**

  $$V_{out} = V_{DD}$$

- $V_{in1} > V_{in} > V_{TH} \rightarrow M_1$ **in Saturation**

  $$V_{out} = V_{DD} - R_D \boxed{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in} - V_{TH})^2} = I_{D1}$$

- $V_{in} > V_{in1} \rightarrow M_1$ **in Triode**

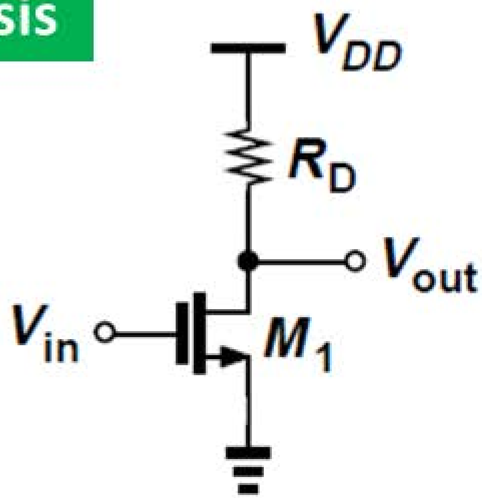
  $$V_{out} = V_{DD} - R_D \boxed{\mu_n C_{ox}\frac{W}{L}\left[(V_{in} - V_{TH})V_{out} - \frac{1}{2}V_{out}^2\right]} = I_{D1}$$

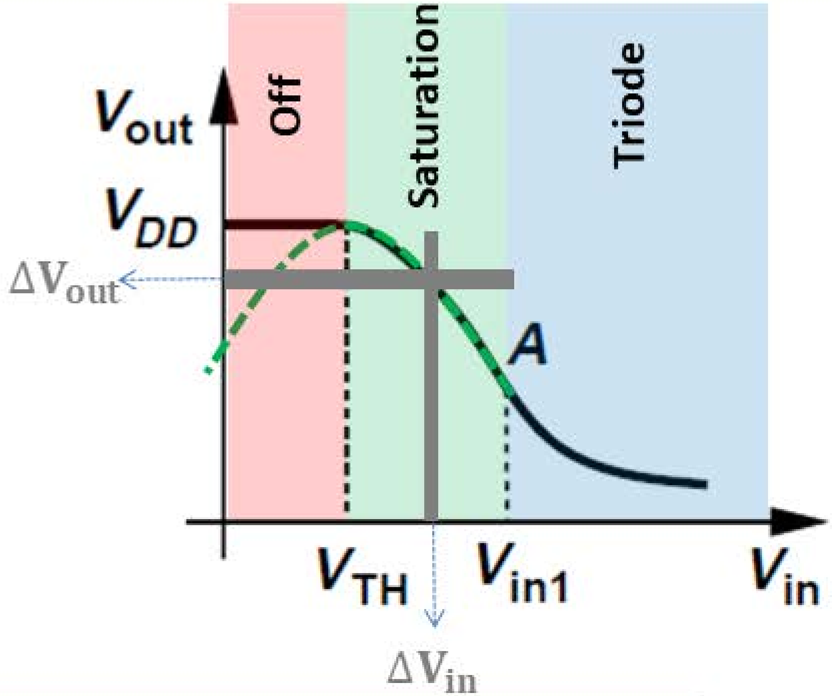
Common-Source with Resistive Load

DC Analysis

$\lambda = 0$

$\gamma = 0$





$$A_v = \frac{\partial V_{out}}{\partial V_{in}} = -R_D \mu_n C_{ox} \frac{W}{L}(V_{in} - V_{TH})$$
$$= -gm \cdot R_D$$

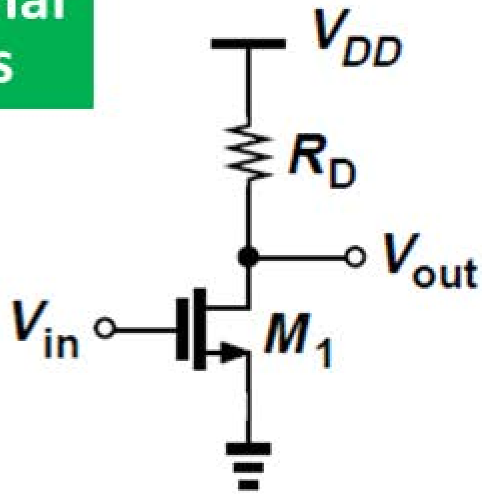
- V_{gs} increases by ΔV_{in} → I_d increases by $\Delta V_{in} \cdot gm$ → V_{out} decreases by $\Delta V_{in} \cdot (gm \cdot R_D)$

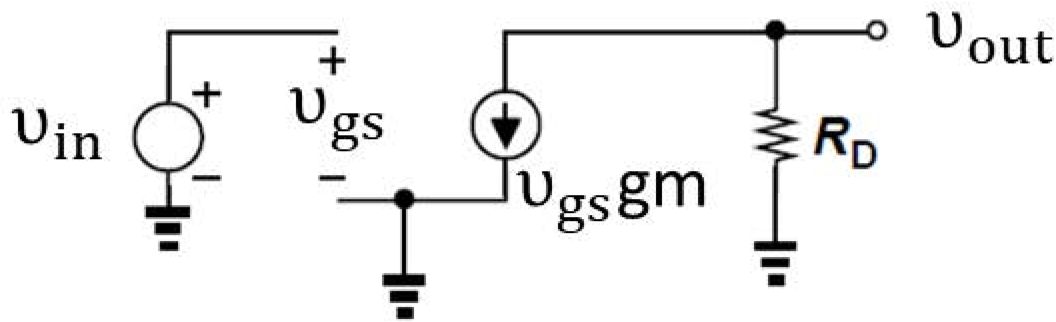
Common-Source with Resistive Load

Small-signal Analysis

$\lambda = 0$

$\gamma = 0$





$$A_v = \frac{\upsilon_{out}}{\upsilon_{in}} = -gm \cdot R_D$$

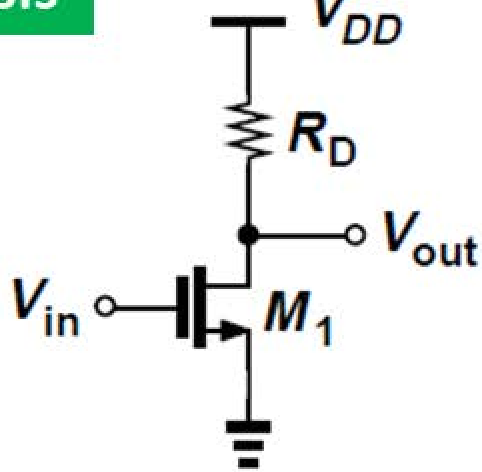
- Small-signal analysis leads to the same result as DC analysis.

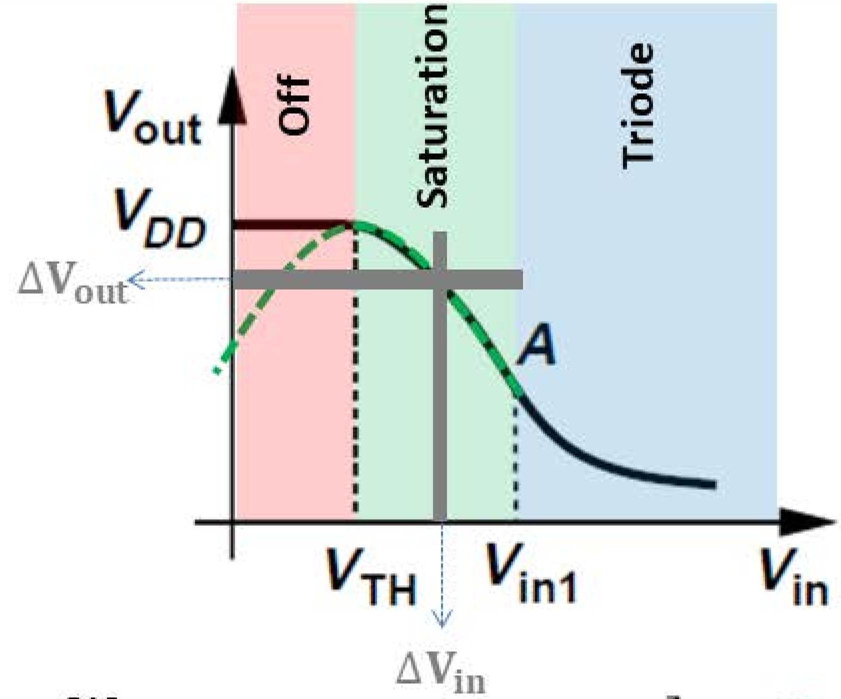
Common-Source with Resistive Load

DC Analysis

$\lambda \neq 0$

$\gamma \neq 0$





$$A_v = \frac{\partial V_{out}}{\partial V_{in}} = \frac{\partial\left[V_{DD} - R_D \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in}-V_{TH})^2(1+\lambda V_{out})\right]}{\partial V_{in}}$$ ID1

$$= -R_D \underbrace{\boxed{\mu_n C_{ox}\frac{W}{L}(V_{in}-V_{TH})(1+\lambda V_{out})}}_{= gm} - R_D \underbrace{\boxed{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in}-V_{TH})^2}}_{\approx I_D} \lambda \underbrace{\boxed{\frac{\partial V_{out}}{\partial V_{in}}}}_{= A_v}$$

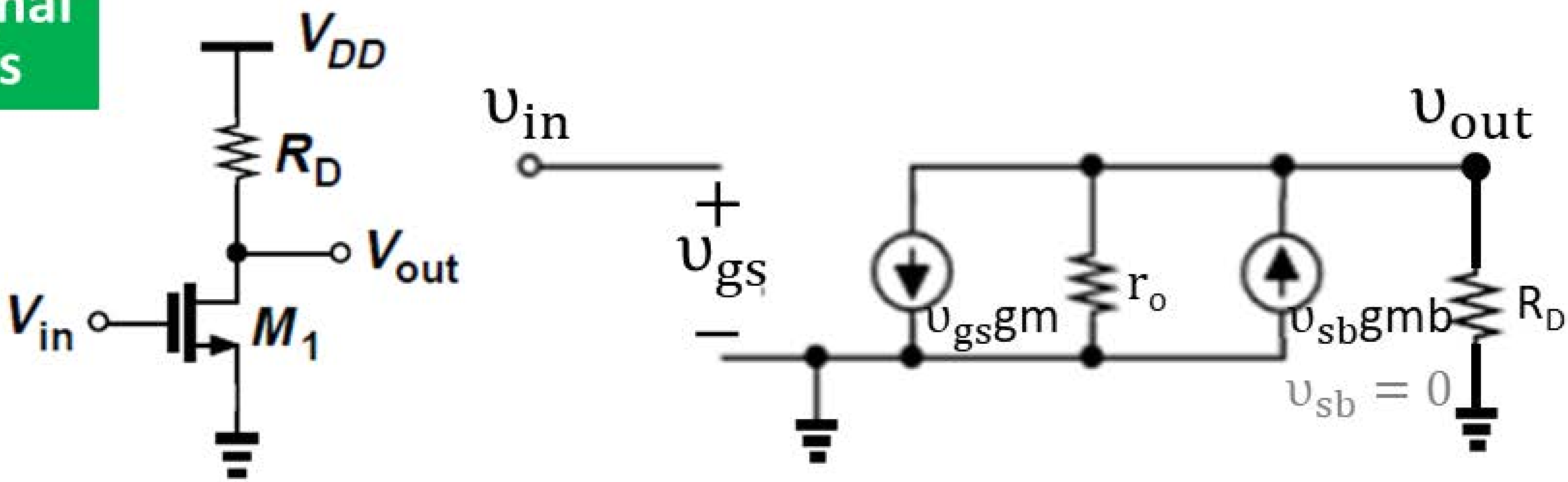
$$A_v = \frac{-gmR_D}{1+R_D\underbrace{\boxed{I_D\lambda}}_{= 1/r_o}} = -gm\frac{1}{\frac{1}{R_D}+\frac{1}{r_o}} = \boxed{-gm(R_D \parallel r_o)}$$

Common-Source with Resistive Load

Small-signal Analysis

$\lambda \neq 0$

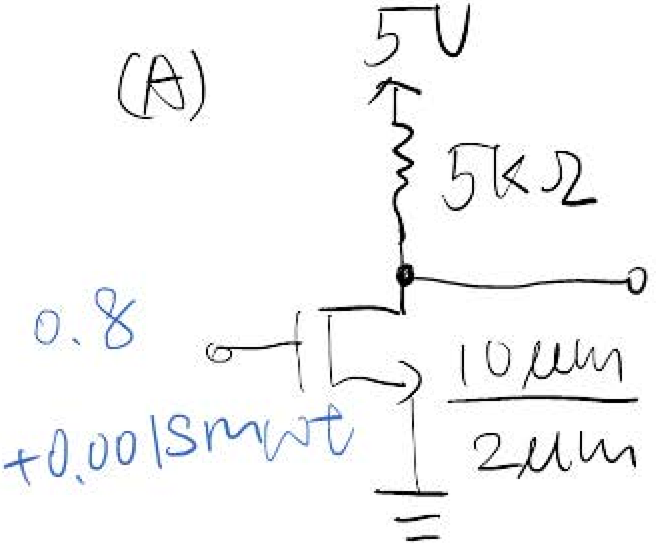
$\gamma \neq 0$

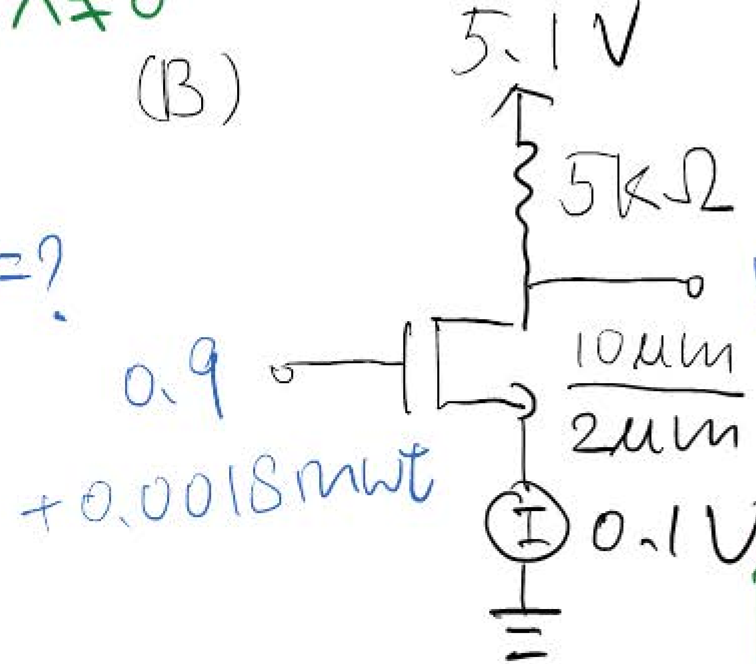


$$A_v = \frac{\upsilon_{out}}{\upsilon_{in}} = -gm \cdot (R_D \parallel r_o)$$

- Small-signal analysis leads to the same result as DC analysis.
- gm is a function of V_{GS} and V_{DS}, while r_o is a function of I_D. → **Nonlinearity**

$r \neq 0,\ \lambda \neq 0$





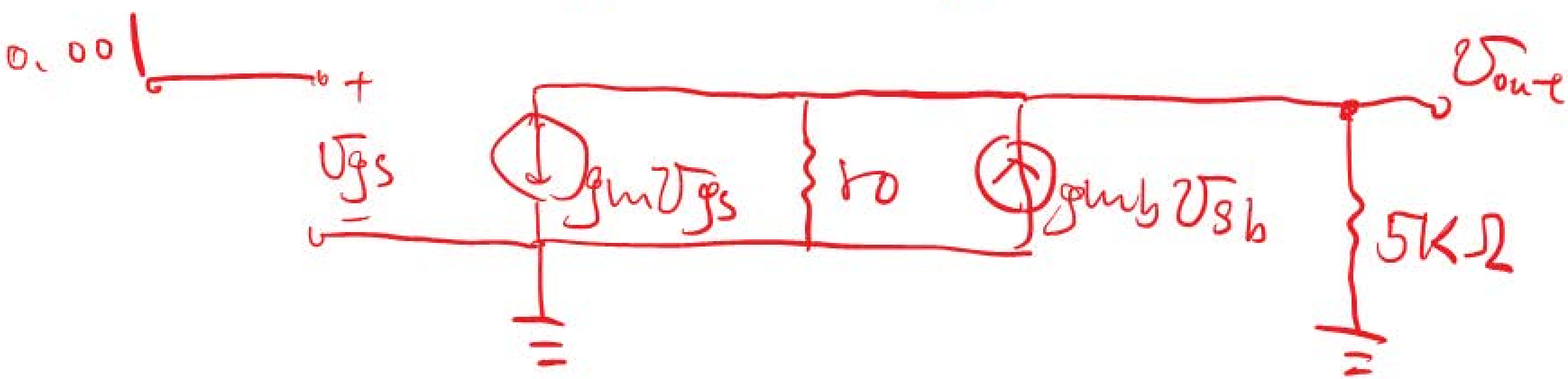
$$\boxed{\begin{aligned} V_{SB} &= 0 \\ v_{sb} &= 0 \end{aligned}}$$

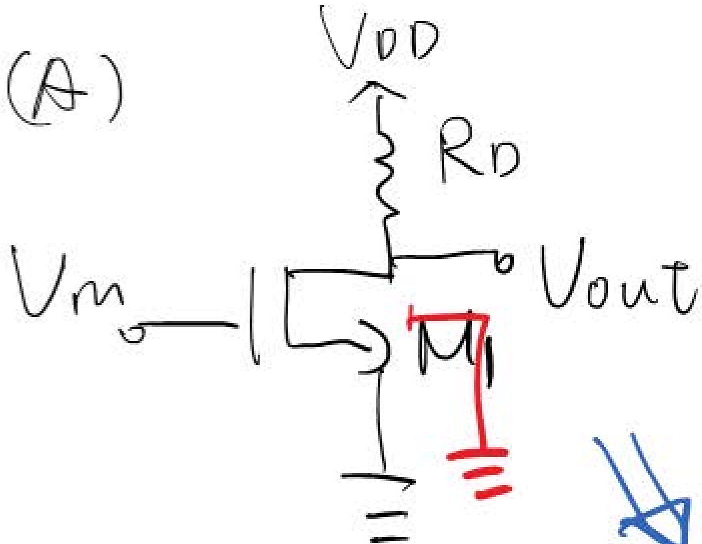
$V_{TH} = V_{TH0} = 0.7$

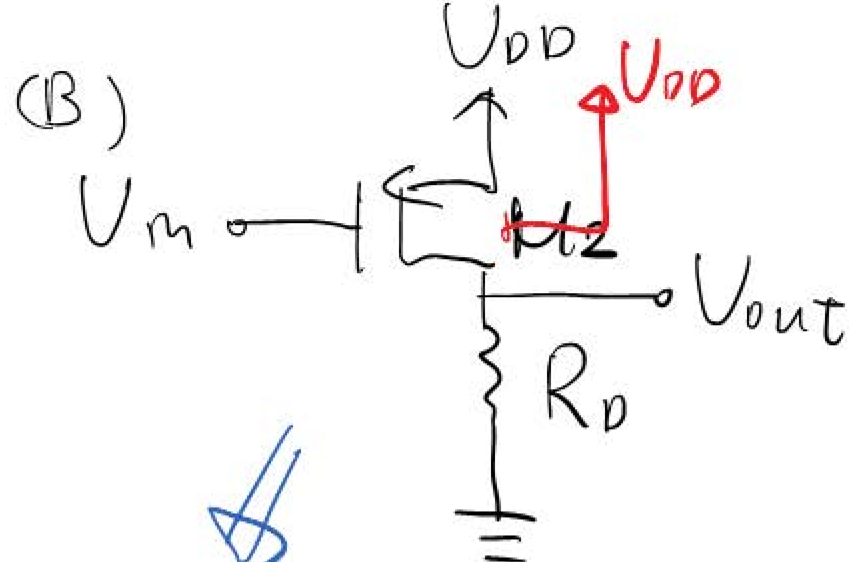
$$\boxed{\begin{aligned} V_{SB} &= 0.1 \\ v_{sb} &= 0 \end{aligned}}$$

$V_{TH} > V_{TH0} = 0.7$

$\Downarrow$ $\Downarrow$

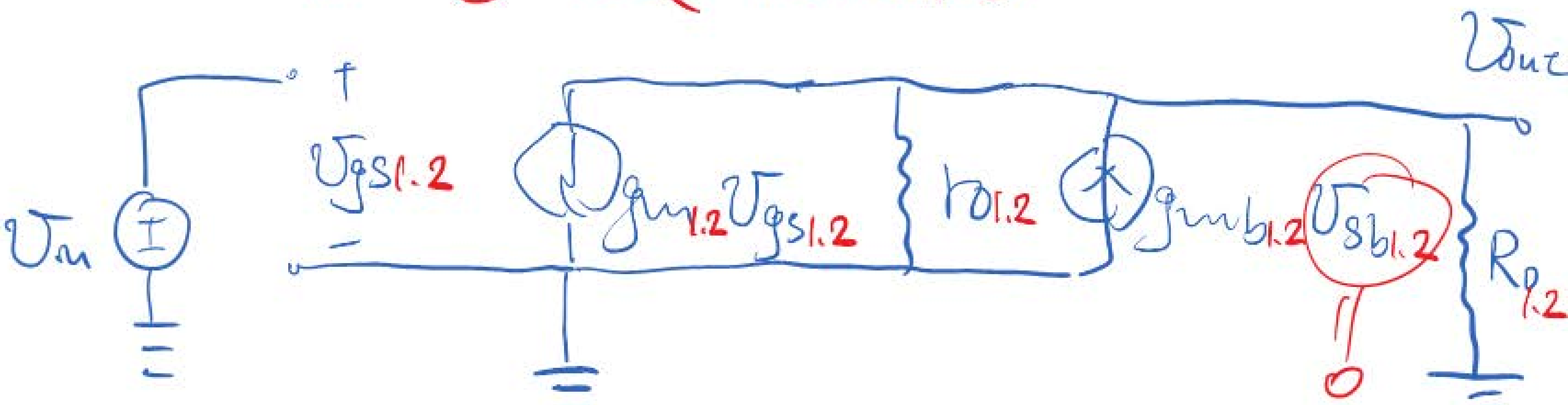






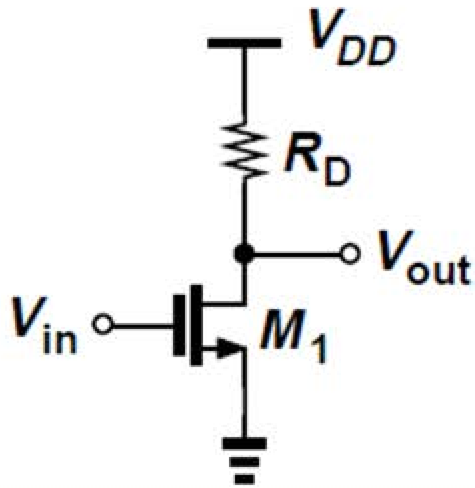
what are the analytical expressions for Av?

$$A_v = -g_{m1.2}(r_{o1.2} // R_{D1.2})$$

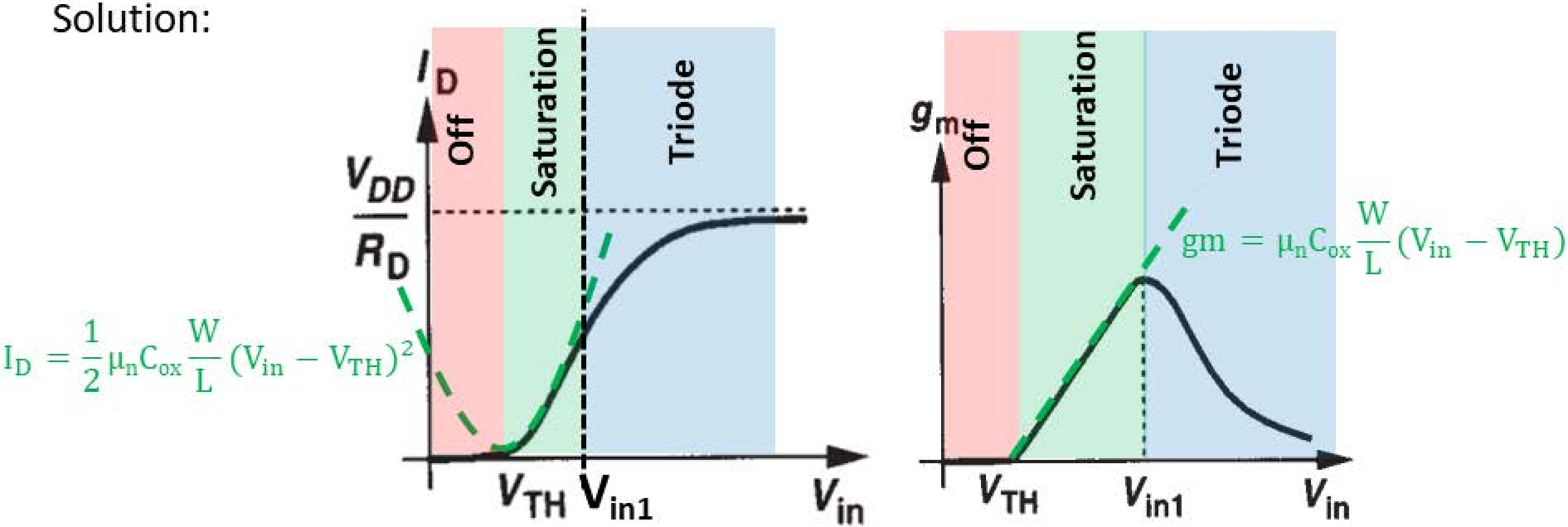


Example

Sketch the drain current and transconductance of M_1 as a function of input voltage. Assume $\lambda = \gamma = 0$.

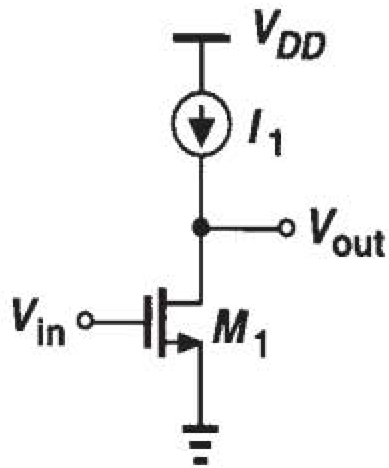


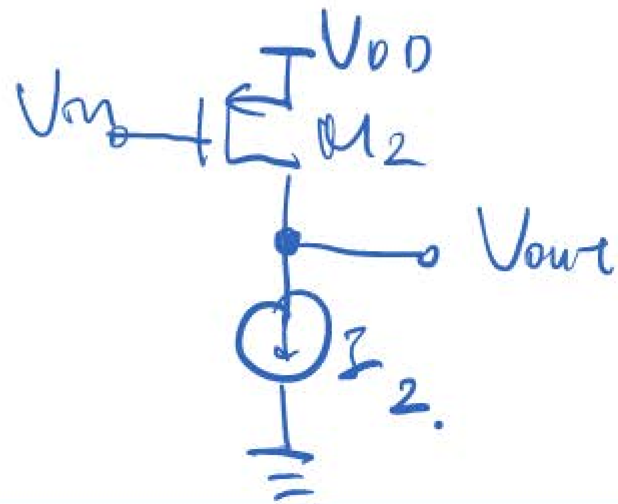
Solution:



Example

Assuming M_1 in saturation, calculate its small-signal gain.





Solution:

- Small-signal Analysis:

$$A_v = \frac{\upsilon_{out}}{\upsilon_{in}} = -gm_1 r_{o1}$$

- DC Analysis:

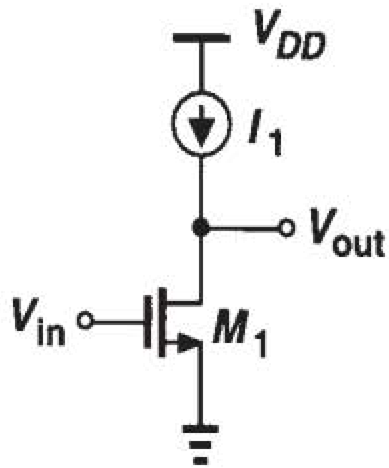
$$I_1 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in} - V_{TH})^2(1 + \lambda V_{DS})$$

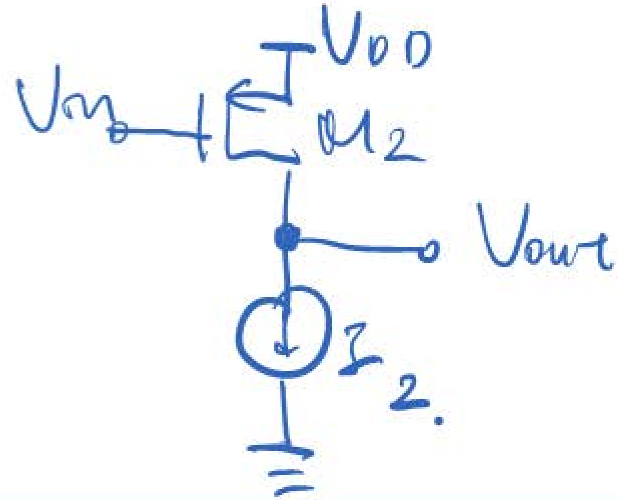
Example

Assuming M_1 in saturation, calculate its small-signal gain.

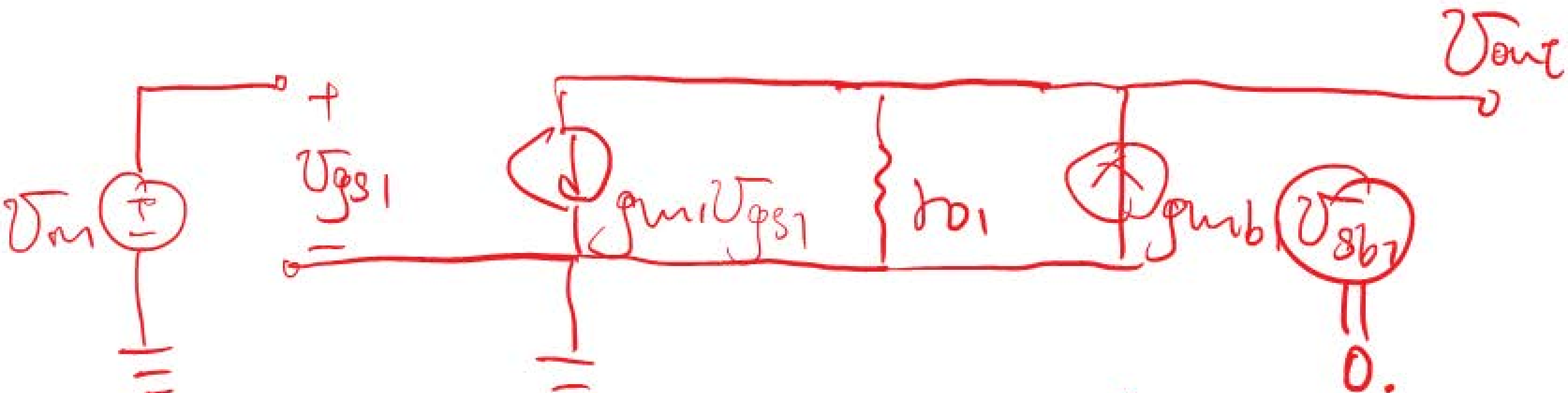
$\lambda \neq 0$

$\gamma \neq 0$





Solution:



$$v_{out} = -(g_{m1} v_{in}) r_{o1}$$