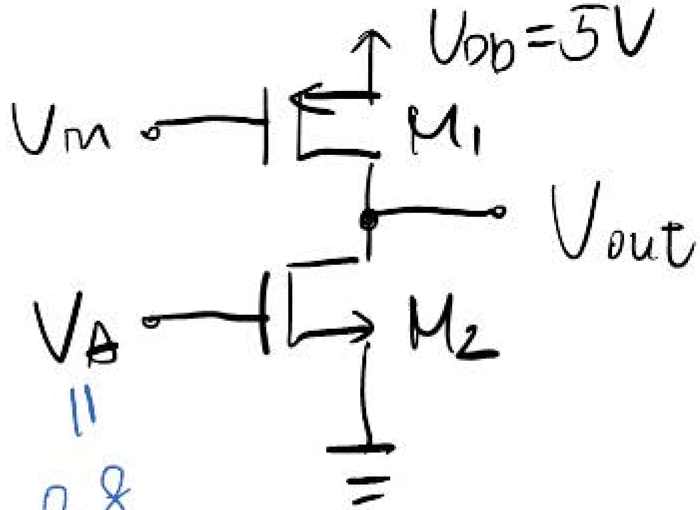
Common-Source with Current-Source Load



$V_B = 0.8$

$V_{BS1} = 0 \Rightarrow |V_{TH1}| = 0.8$

$V_{SB2} = 0 \Rightarrow V_{TH2} = 0.7$

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

$V_{in} = 4.1 + 0.001 \sin(2\pi 100 t)$

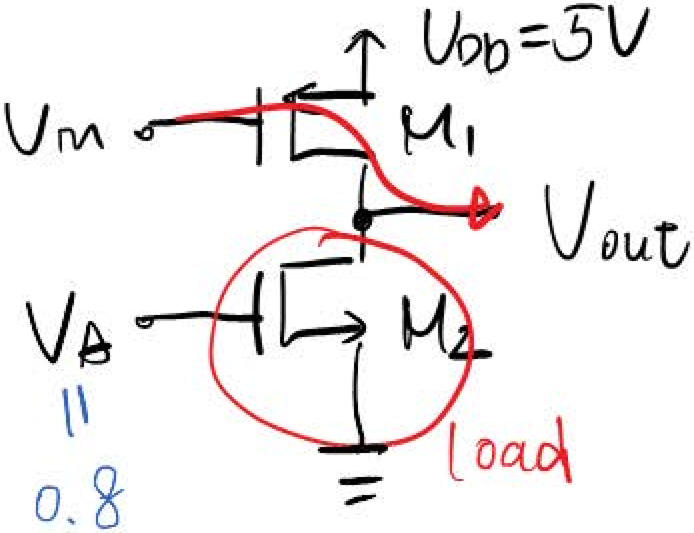
$V_{out} = V_{OUT} + v_{out} = ?$

1° Find out $V_{OUT} = ?$

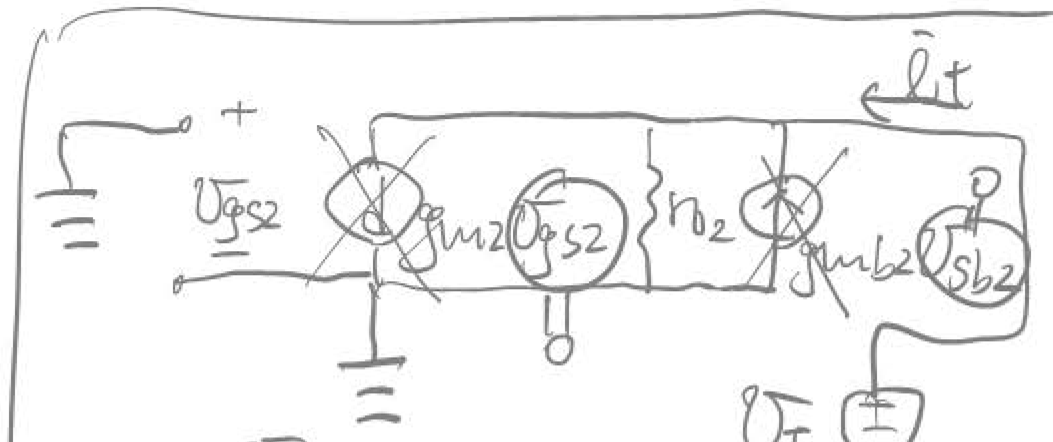
Then we make sure M_1 and M_2 in sat.

$$\frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L_{eff}}\right)_1 (5-4.1-0.8)^2 \cdot [1+\lambda(5-V_{OUT})]$$

$$= \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L_{eff}}\right)_2 (0.8-0.7)^2 [1+\lambda V_{OUT}]$$

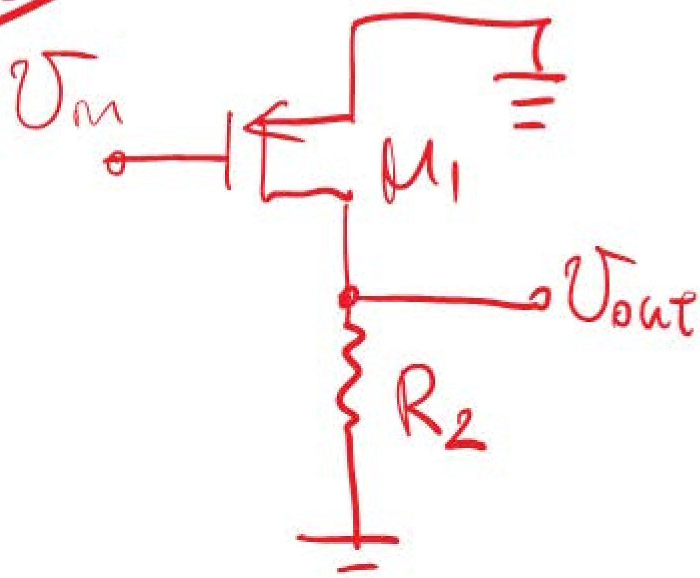


2° Find out $v_{out} = ?$



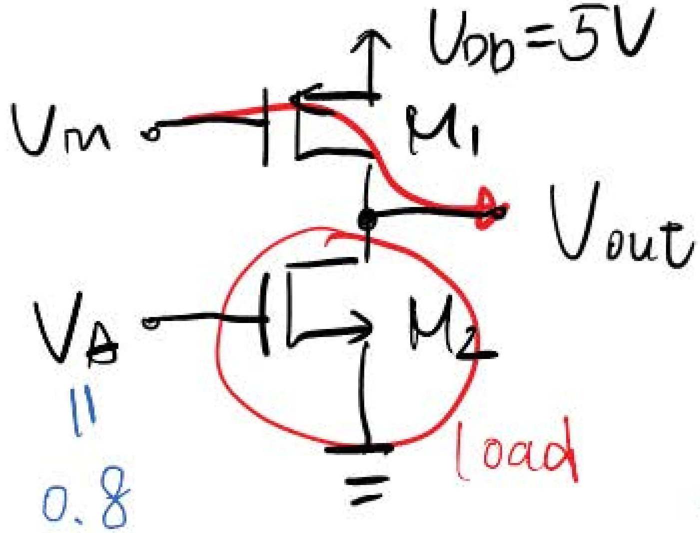
$$R_2 = v_t / i_t = r_{o2}$$

small signal



$$A_v = \frac{v_{out}}{v_{in}} = -g_{m1}(r_{o1} // R_2)$$

$$= -g_{m1}(r_{o1} // r_{o2})$$

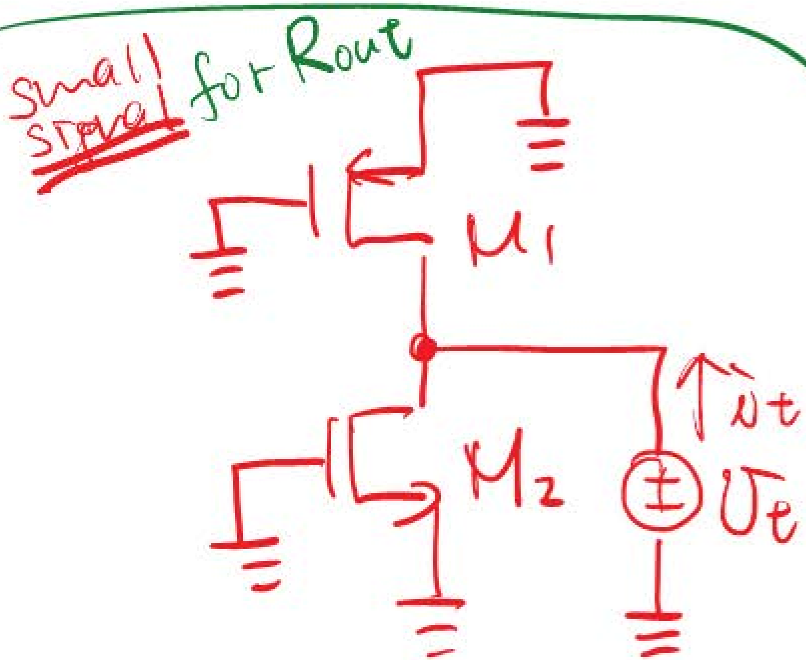


$3°$ Find out $R_{in} = ?$

$R_{in} = \infty$

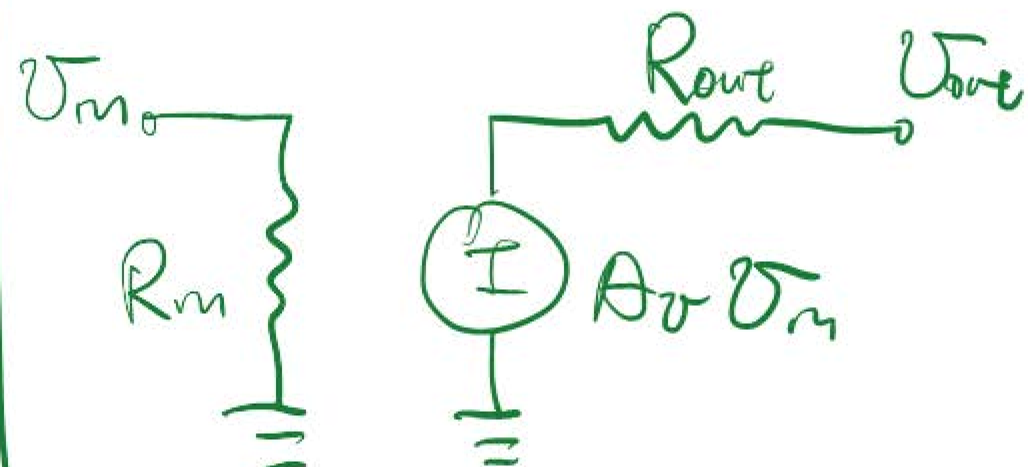
$4°$ Find out $R_{out} = ?$

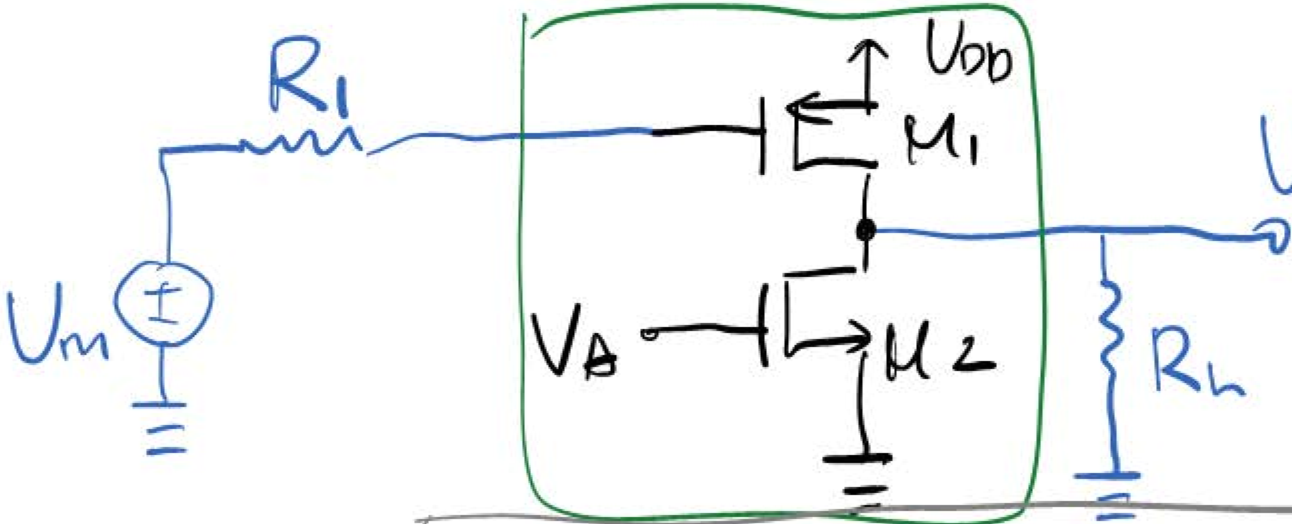
$R_{out} = r_{o1} // r_{o2}$



$R_{out} = v_t / i_t$

Equivalent Small Signal Circuit

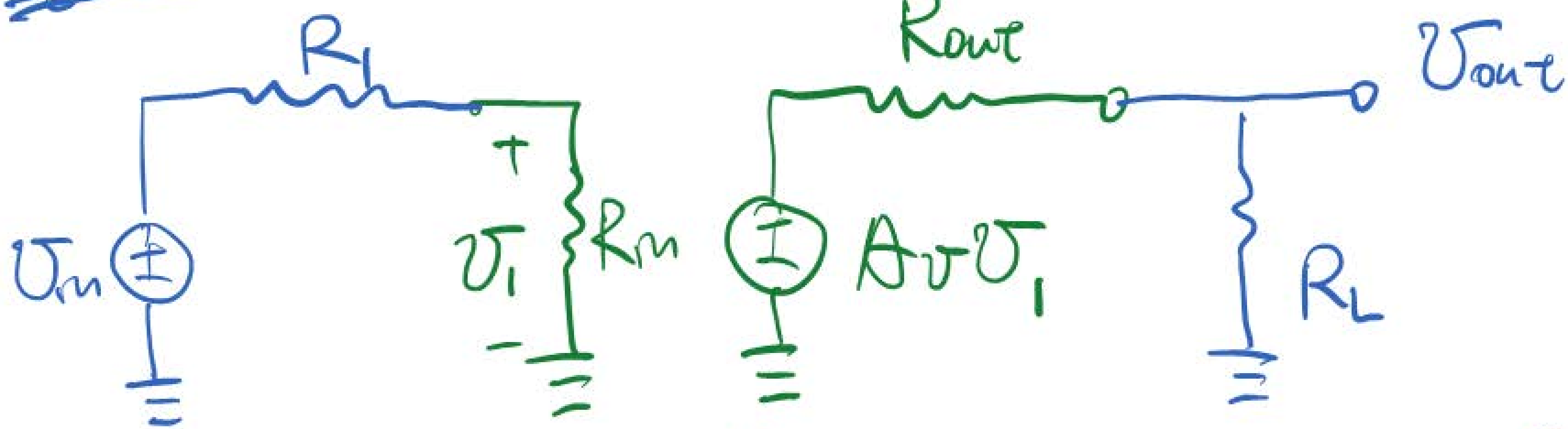




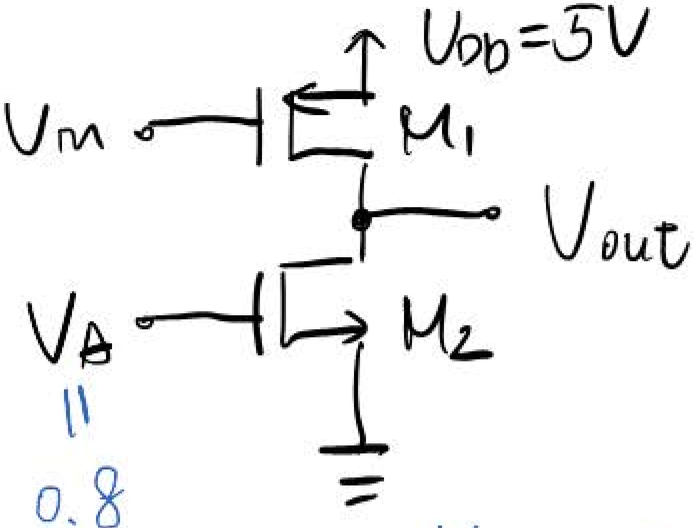
$A_v = ?$

$$\boxed{A_v = -g_{m1}(r_{o1} // r_{o2}) \frac{R_L}{R_{out} + R_L}}$$

small signal



$R_{in} = \infty$, $R_{out} = r_{o1} // r_{o2}$, $A_v = -g_{m1}(r_{o1} // r_{o2})$



$V_{BS1} = 0 \Rightarrow |V_{TH1}| = 0.8$

$V_{SB2} = 0 \Rightarrow V_{TH2} = 0.7$

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

$$V_{in} = 4.1 + 0.001 \sin(2\pi 100 t)$$

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

5° Find out available output swing range.

0.1 ~ 4.9

$$V_{out,max} = 5 - (5 - 4.1 - 0.8)$$

$$= 4.9$$

$$= V_{DD} - \boxed{(V_{SG1} - |V_{TH1}|)}$$

overdrive of M_1

$$V_{out,min} = 0.8 - 0.7$$

$$= \boxed{V_{GS2} - V_{TH2}}$$

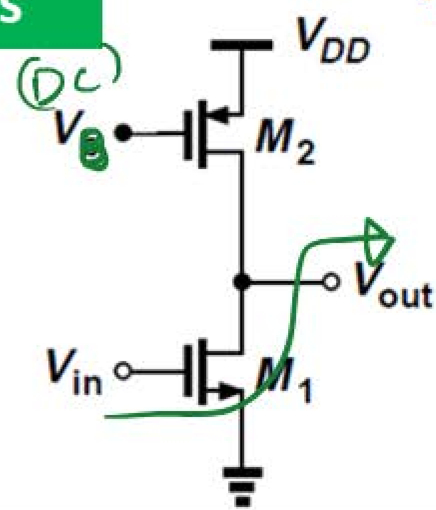
$$= 0.1$$

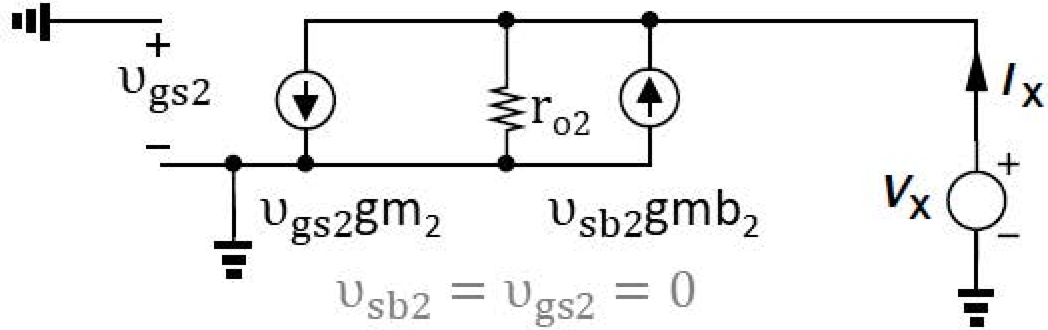
overdrive of M_2.

Common-Source with Current-Source Load

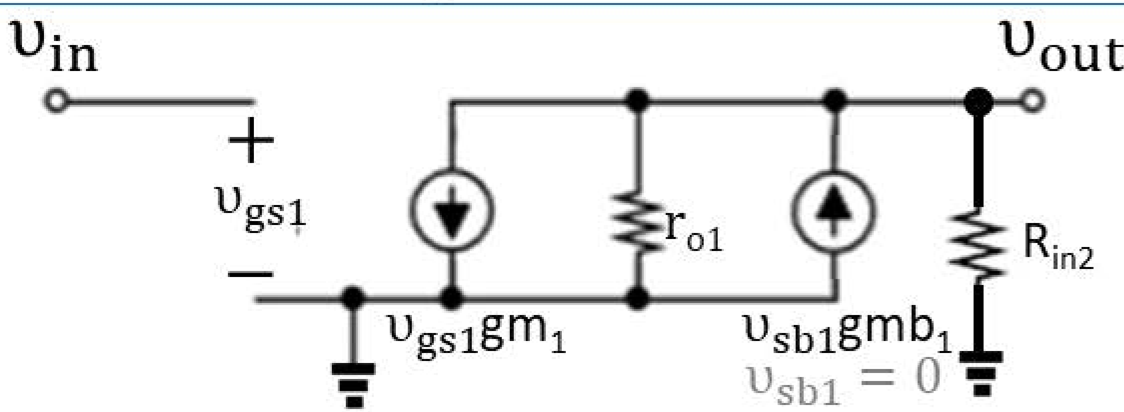
Small-signal Analysis

$\lambda \neq 0 \quad \gamma \neq 0$



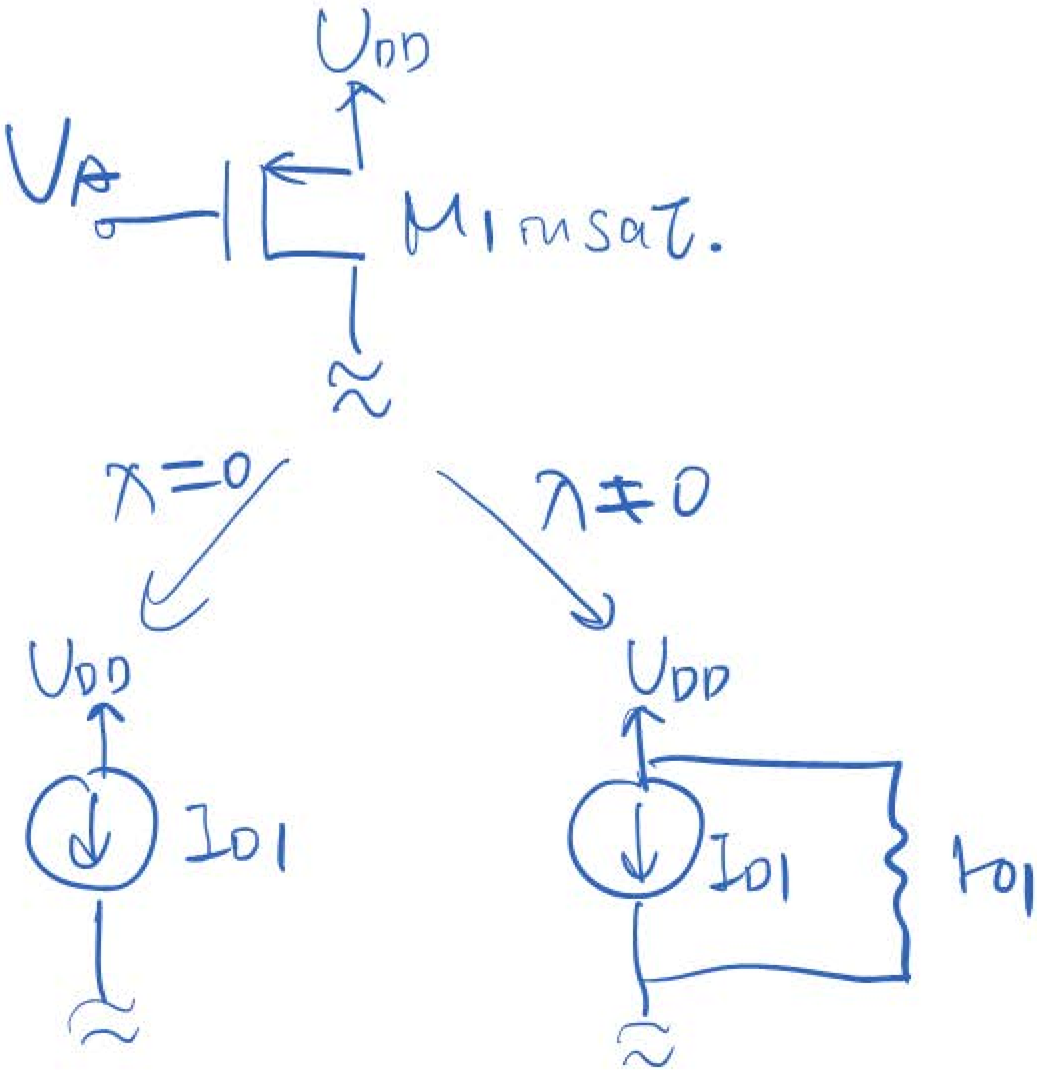


$$R_{in2} = \frac{\upsilon_x}{i_x} = r_{o2}$$



$$A_v = \frac{\upsilon_{out}}{\upsilon_{in}} = -gm_1(r_{o2} \parallel r_{o1})$$

- To achieve high A_v, the output swing is severely limited in the CS stages with resistive load and diode-connected load.
- Here $V_{out,\,max} = V_{DD} - (V_{SG2} - V_{TH2})$, which can be quite close to V_{DD}.

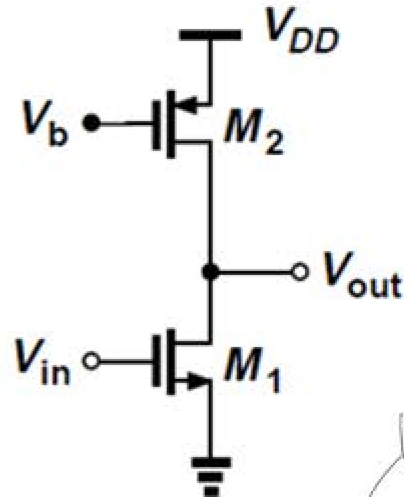


V_{DD}
V_B
M_1 in sat.
$\lambda = 0$
$\lambda \neq 0$
V_{DD}
I_{D1}
V_{DD}
I_{D1}
r_{o1}

Common-Source with Current-Source Load

Small-signal Analysis

$\lambda \neq 0 \quad \gamma \neq 0$



$$A_v = \frac{\upsilon_{out}}{\upsilon_{in}}$$

$$= -gm_1(r_{o2} \parallel r_{o1})$$

$$r_o \approx \frac{1}{\lambda I_D} \quad \lambda \propto \frac{1}{L}$$

high, large, small

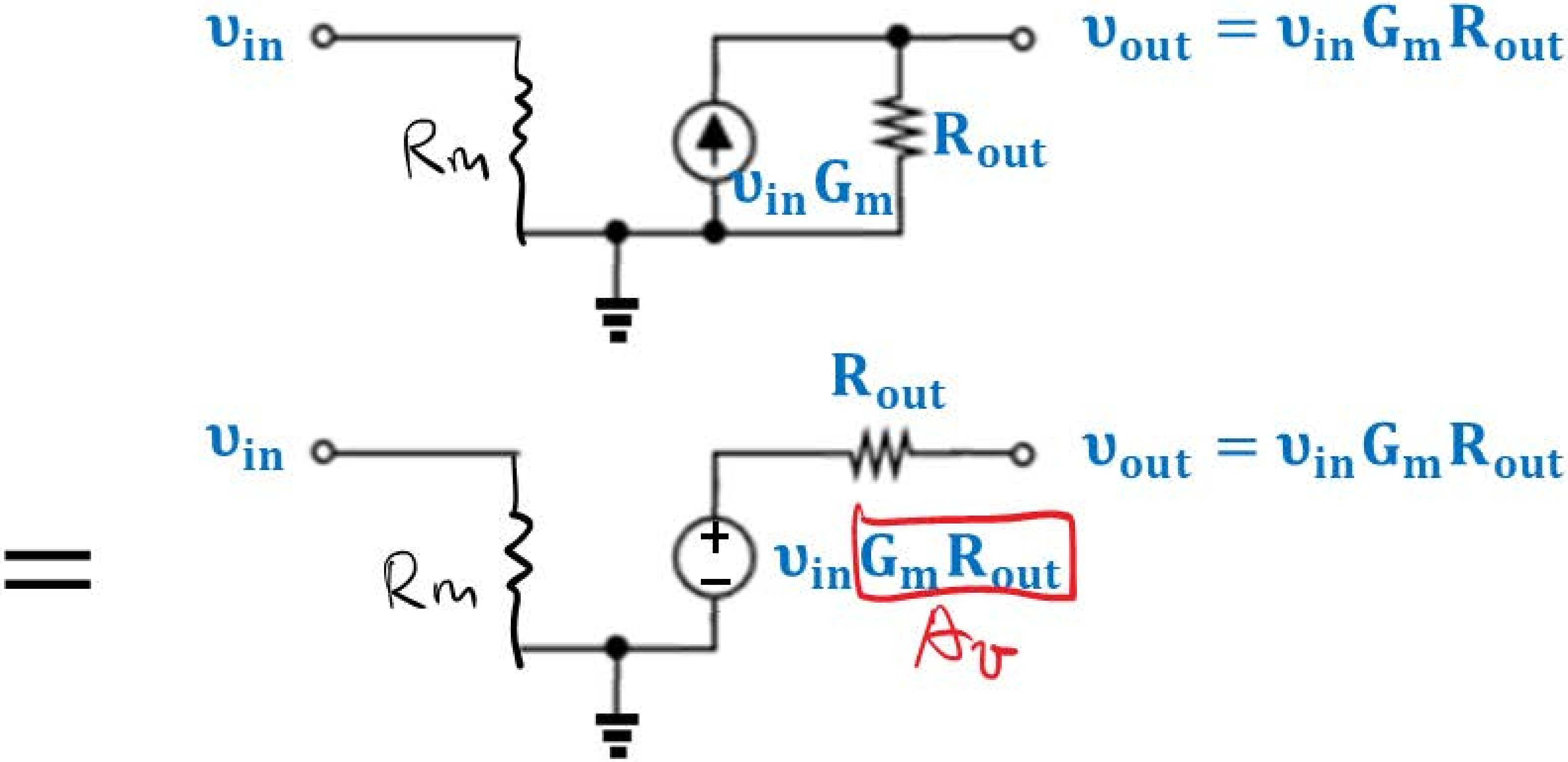
$$gm_1 = \mu_n C_{ox} \left(\frac{W}{L_{eff}}\right) \boxed{(V_{GS} - V_{TH})} (1 + \lambda V_{DS})$$

- $V_{out,\,max} = V_{DD} - (V_{SG2} - |V_{TH2}|)$
- $V_{out,\,min} = (V_{GS1} - V_{TH1})$
- For high gm_1 and small $(V_{GS1} - V_{TH1})$, W of M_1 needs to be large.
- For high r_{o1} and r_{o2}, L of M_1 and M_2 need to be large and L of M_1 and M_2 needs to be increased proportionally. The cost is the **large parasitic drain junction capacitance** at the output.

Degeneration

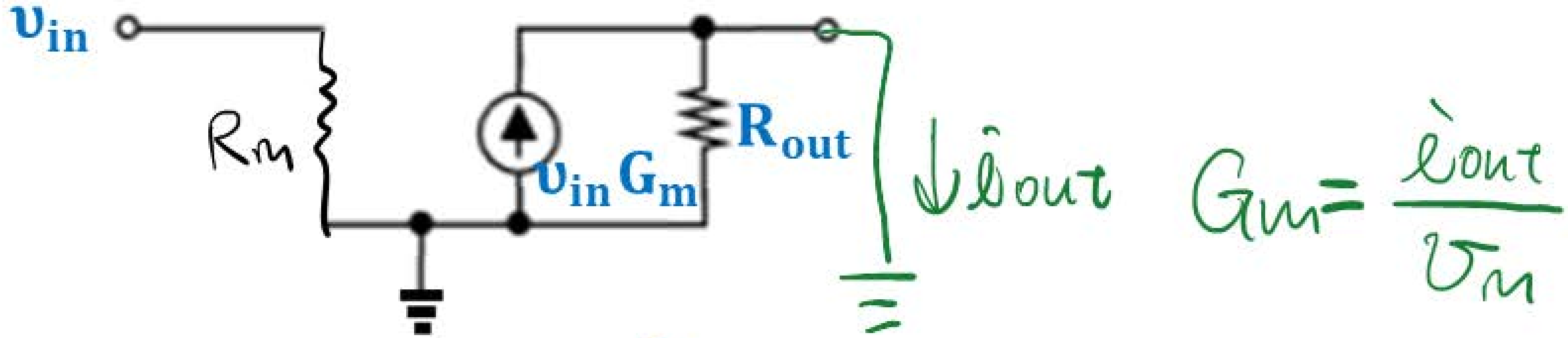
Common-Source with Source Degradation

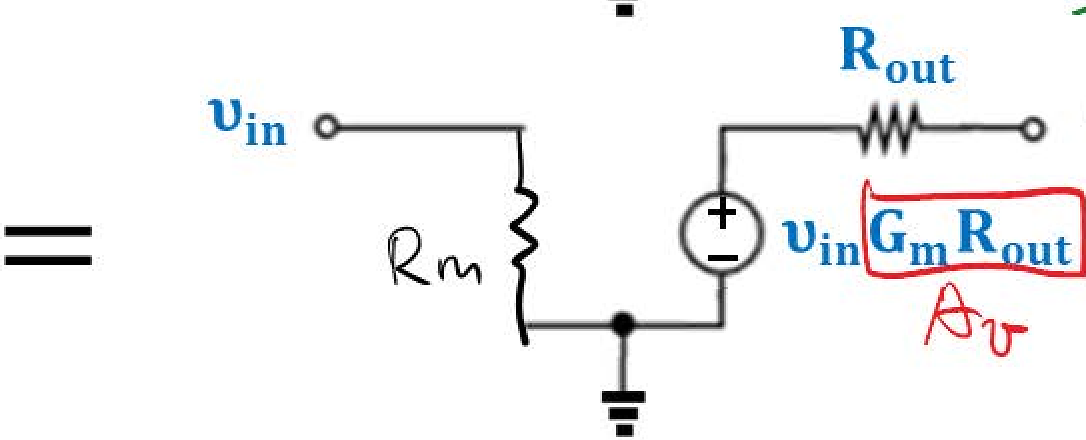
Amplifier Equivalent Circuit



- How to calculate G_m? υ_{out} shorted to ground. $\mathbf{G_m = i_{out}/\upsilon_{in}}$
- How to calculate R_{out}? υ_{in} shorted to ground and υ_{out} connected to υ_{test}. $\mathbf{R_{out} = \upsilon_{test}/i_{test}}$

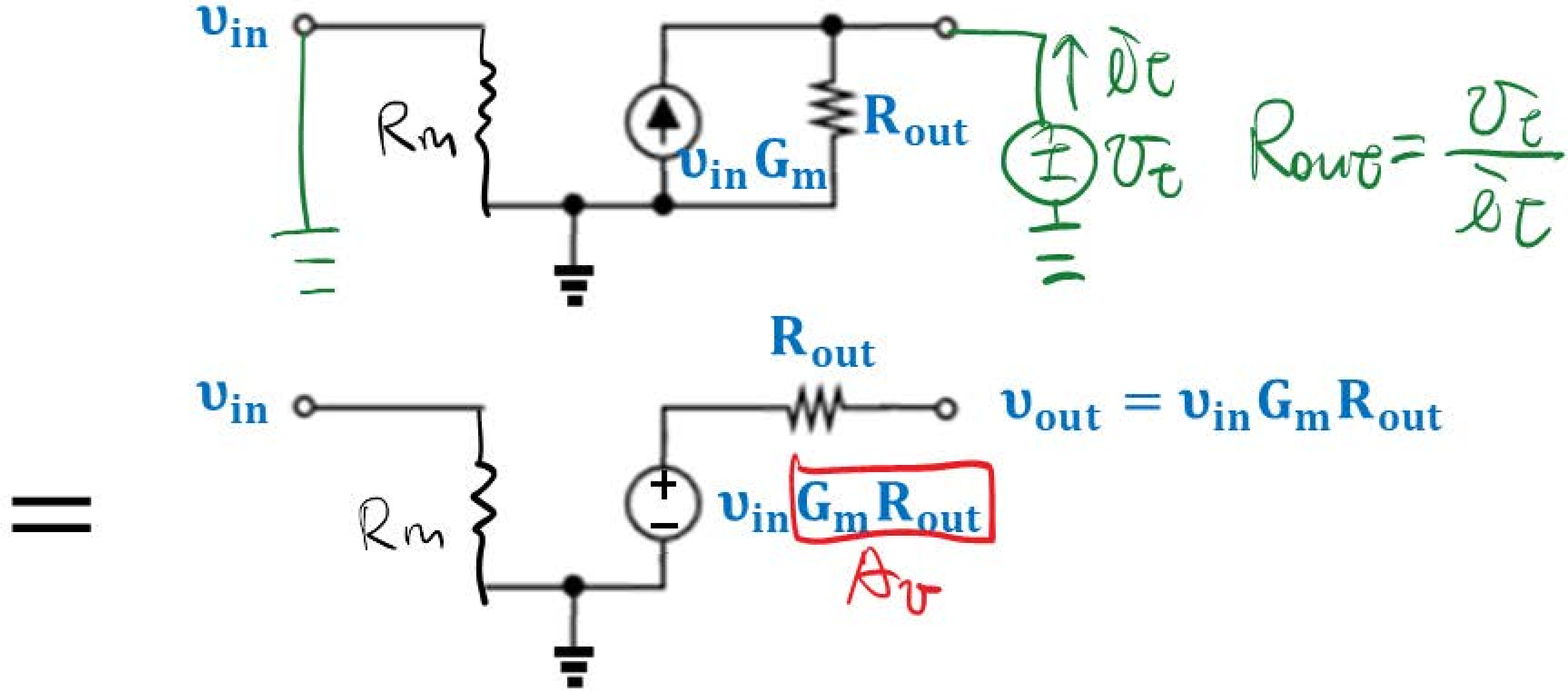
Amplifier Equivalent Circuit



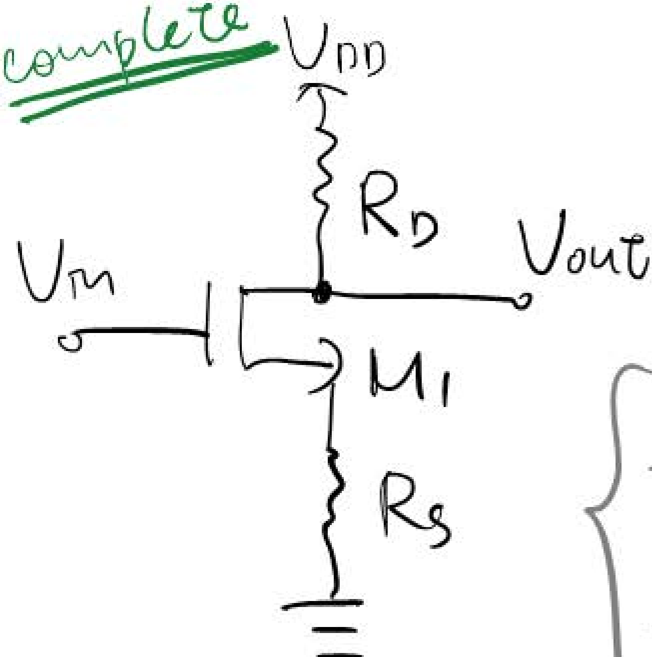


$v_{out} = v_{in} G_m R_{out}$

Amplifier Equivalent Circuit



complete



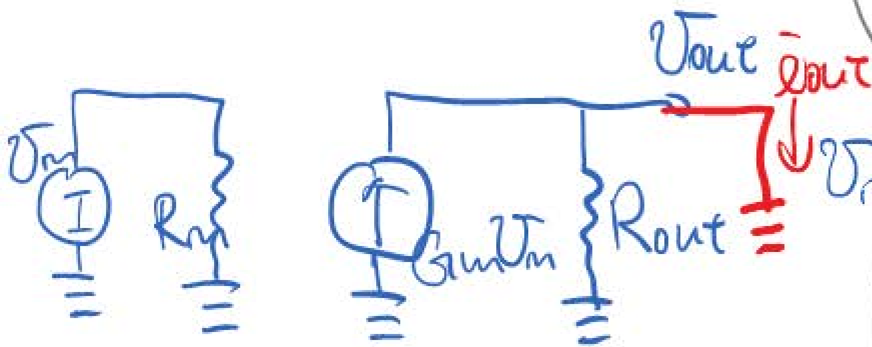
$\lambda \neq 0,\ \gamma \neq 0$

$A_v = ?$

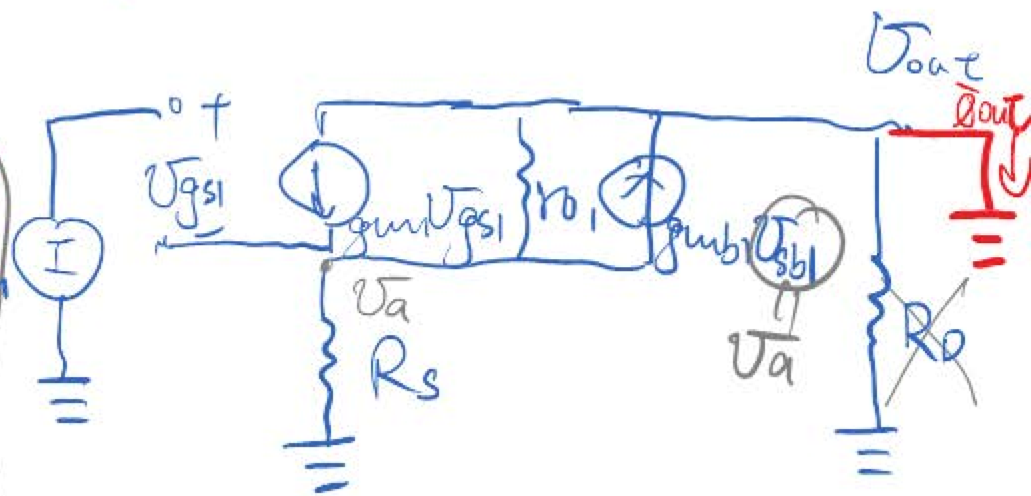
$G_m = i_{out} / v_{in}$

$$\begin{cases} \dfrac{v_a}{R_S} + (v_a - v_{in}) g_{m1} + \dfrac{v_a}{r_{o1}} + g_{mb1} v_a = 0 \\ -\dfrac{v_a}{R_S} = i_{out} \end{cases}$$

Equivalent small signal



small signal

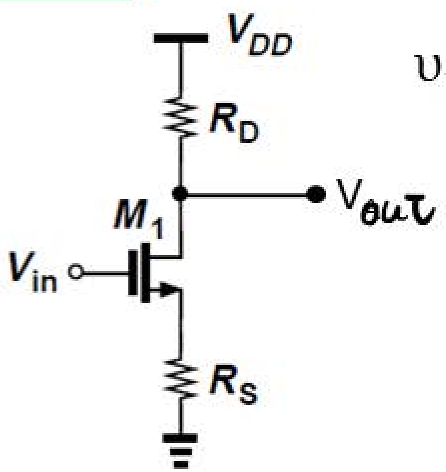


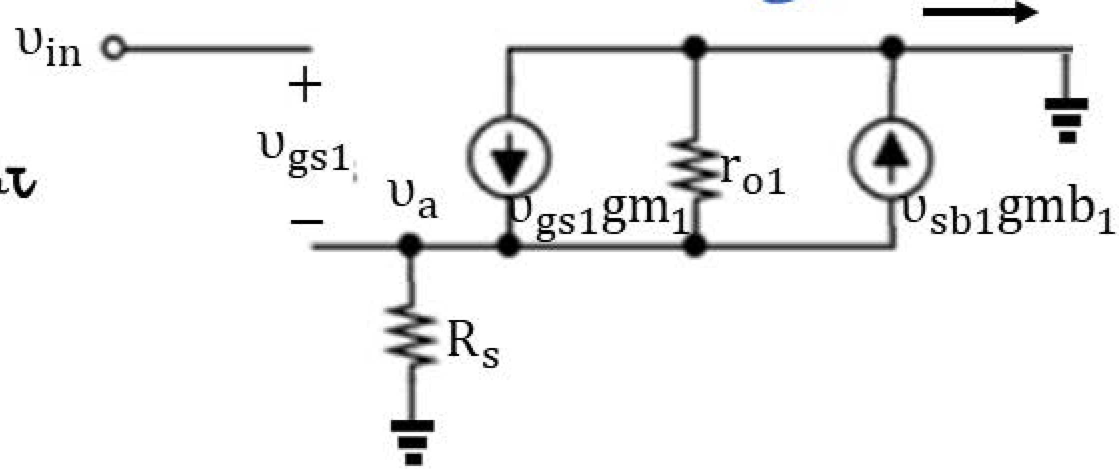
Common-Source with Source Degradation

Small-signal Analysis

$\lambda \neq 0 \quad \gamma \neq 0$

small signal circuit for calculating Gm





$$\begin{cases} i_o = \dfrac{-\upsilon_a}{R_S} \\ (\upsilon_{in} - \upsilon_a)gm_1 + i_o = \dfrac{\upsilon_a}{r_{o1}} + \upsilon_a gmb_1 \end{cases}$$

$$G_m = \frac{i_o}{\upsilon_{in}} = \frac{-gm_1 r_{o1}}{R_S + r_{o1} + \boxed{(gm_1 + gmb_1)r_{o1}}R_S} \approx -\frac{1}{R_S}$$

intrinsic gain of M1

if $gmb_1 \ll gm_1$

If $(gm_1 + gmb_1)r_{o1}R_S$ >> r_{o1} and R_S