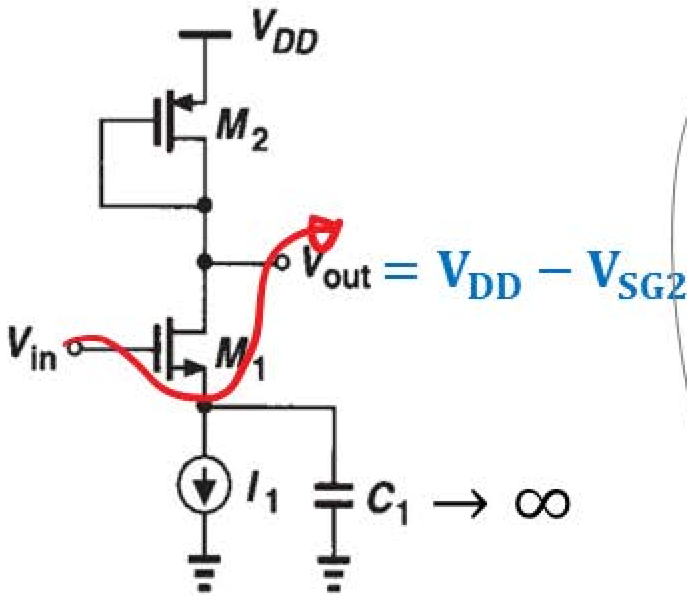
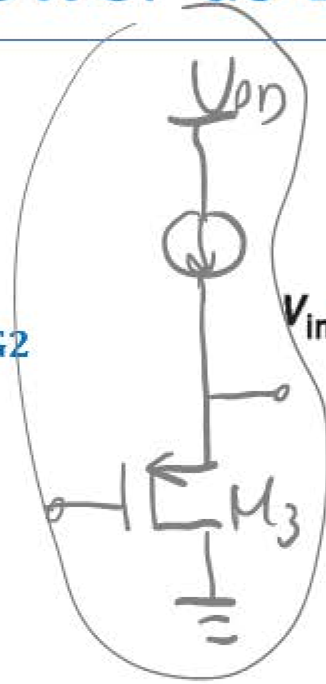
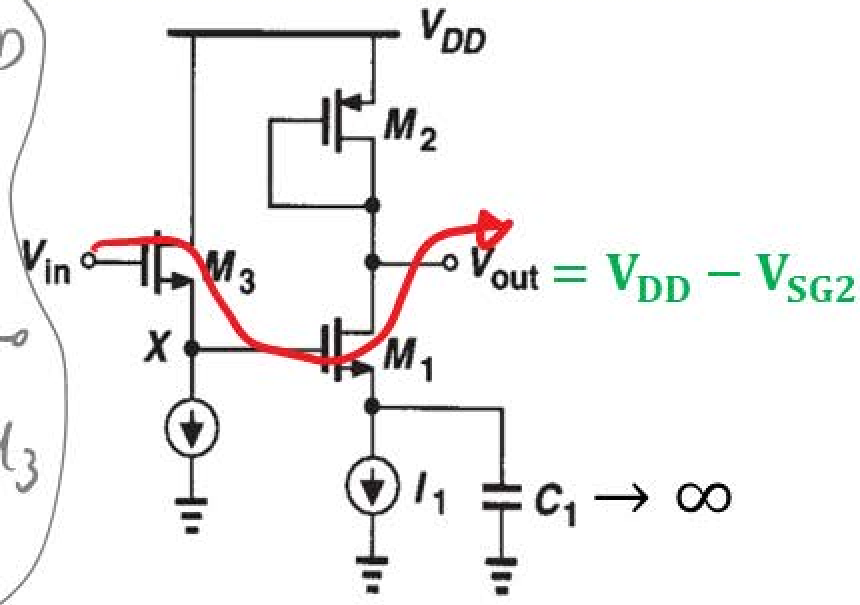
Source Follower as Level Shifter







$$V_{in} \le V_{DD} - V_{SG2} + V_{TH1}$$

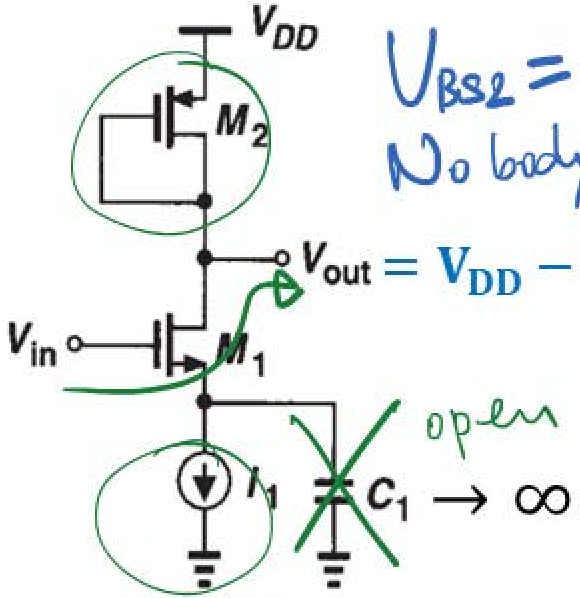
$$V_{in} - V_{GS3} \le V_{DD} - V_{SG2} + V_{TH1}$$

$$\begin{cases} G_m = -gm_1 \\ R_{out} = r_{o1} \parallel r_{o2} \parallel \dfrac{1}{gm_2} \end{cases}$$

$$\begin{cases} G_{m(left)} = gm_3 \\ R_{out(left)} = r_{o3} \parallel \dfrac{1}{gm_3 + gmb_3} \end{cases}$$

$$\begin{cases} R_{in(right)} = \infty \\ G_{m(right)} = -gm_1 \\ R_{out(right)} = r_{o1} \parallel r_{o2} \parallel \dfrac{1}{gm_2} \end{cases}$$

Source Follower as Level Shifter



$V_{out} = V_{DD} - V_{SG2}$

$V_{BS2} = 0$
No body effect

$V_{in} \le \underbrace{V_{DD} - V_{SG2}}_{V_{OUT}} + V_{TH1}$

When V_{in} higher than $V_{OUT} + V_{TH1}$, M_1 will be driven into triode.

1° DC biasing analysis

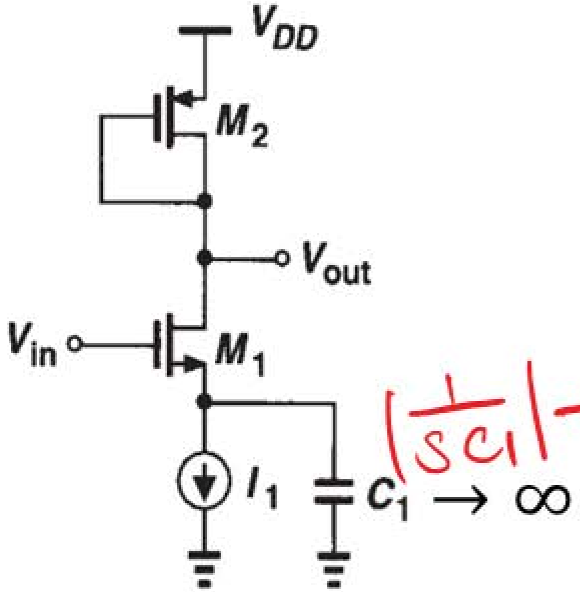
$I_1 = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L_{eff}}\right)_2 \cdot$

$(V_{DD} - V_{OUT} - |\underbrace{V_{TH2}}_{0.8}|)^2 \cdot$

$[1 + \lambda(V_{DD} - V_{OUT})]$

$V_{OUT} = ?$

Source Follower as Level Shifter

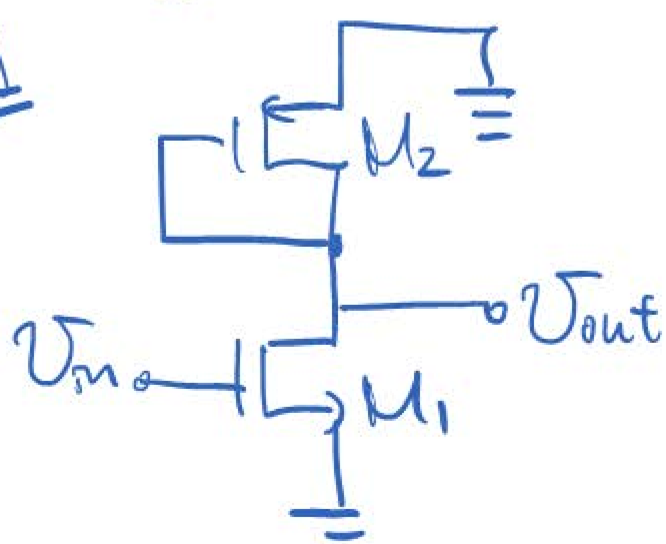


$\left|\frac{1}{sC_1}\right| \to 0$

2° small signal analysis

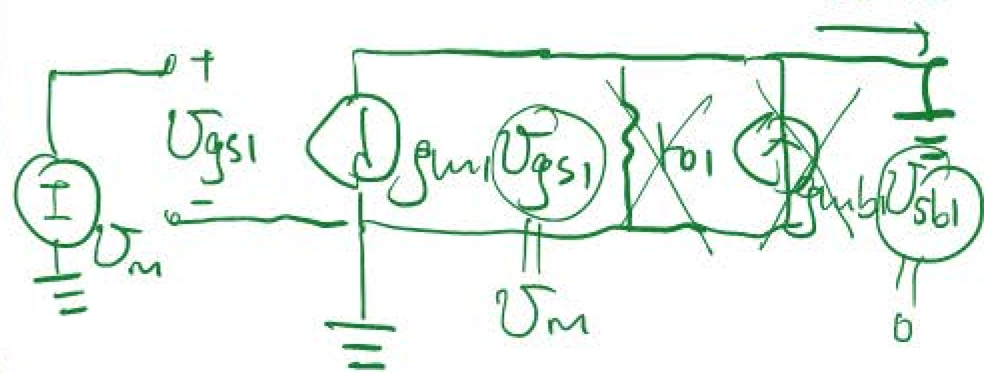
$$\begin{cases} G_m = -gm_1 \\ R_{out} = r_{o1} \parallel r_{o2} \parallel \dfrac{1}{gm_2} \\ R_{in} = \infty \end{cases}$$

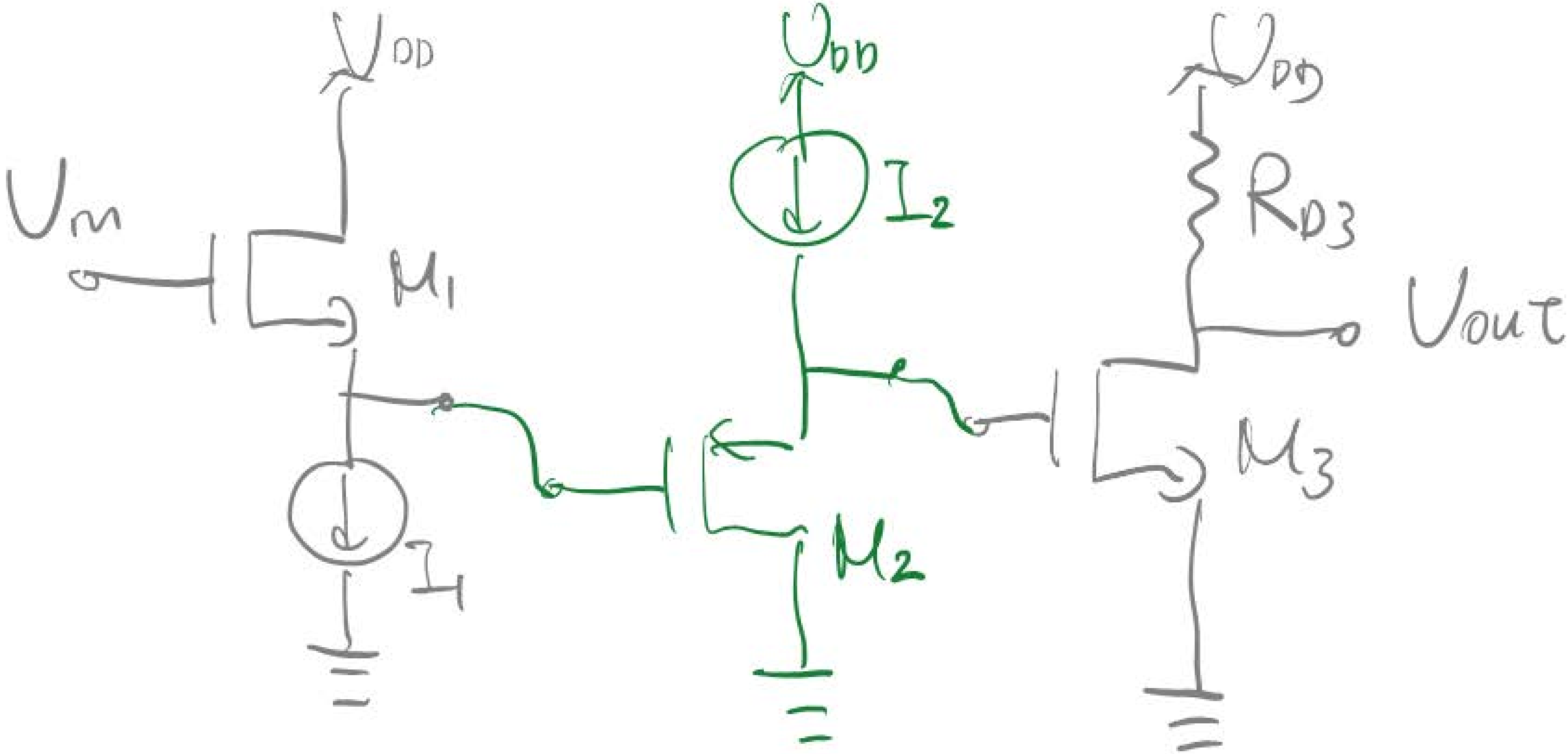
small signal



$$G_m = \frac{i_{out}}{v_{in}}$$

$-g_{m1}v_{in} = i_{out}$

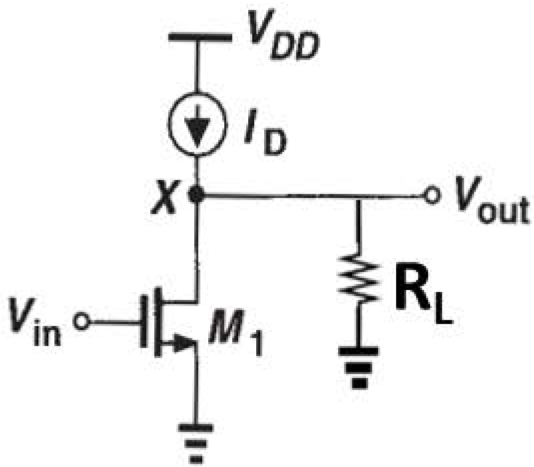




Assume $\lambda = \gamma = 0$, $A_v = ?$

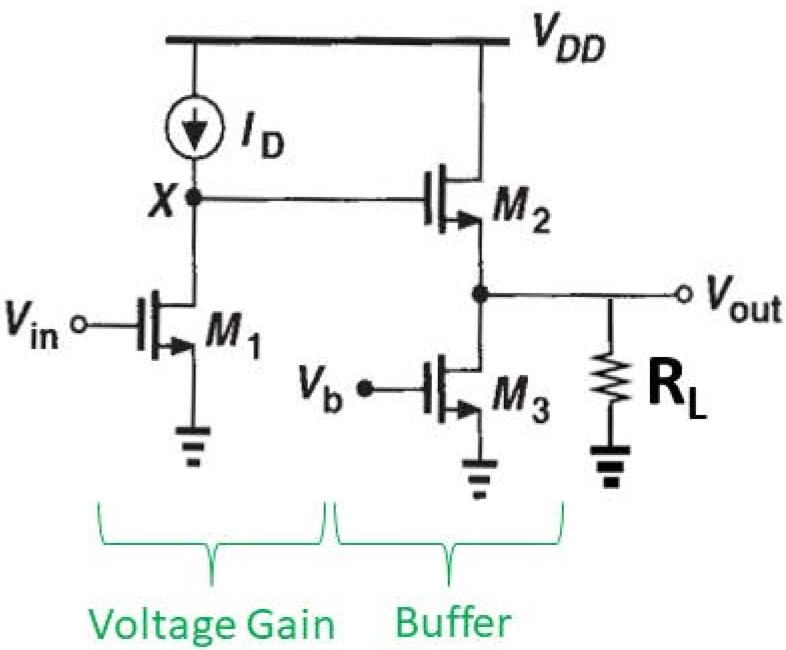
$$A_v = 1 \times 1 \times (-g_{m3} R_{D3})$$

CS + Source Follower



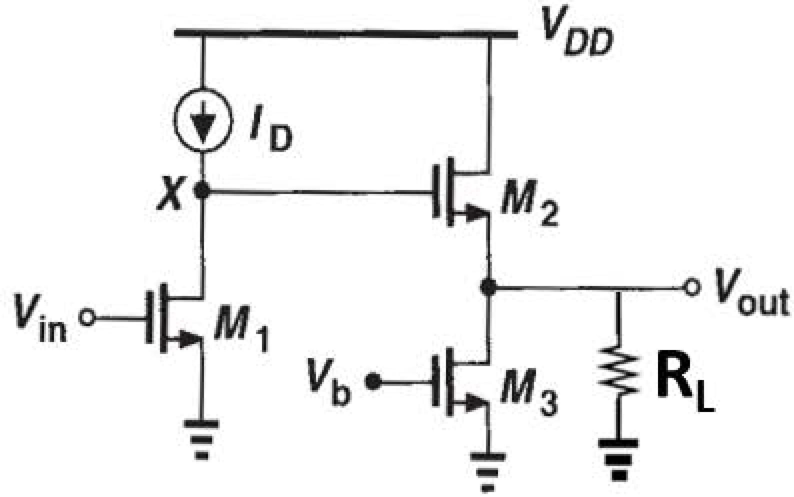
$$A_v = -gm_1(r_{o1} \parallel R_L)$$

- Voltage gain severely reduced when R_L very small

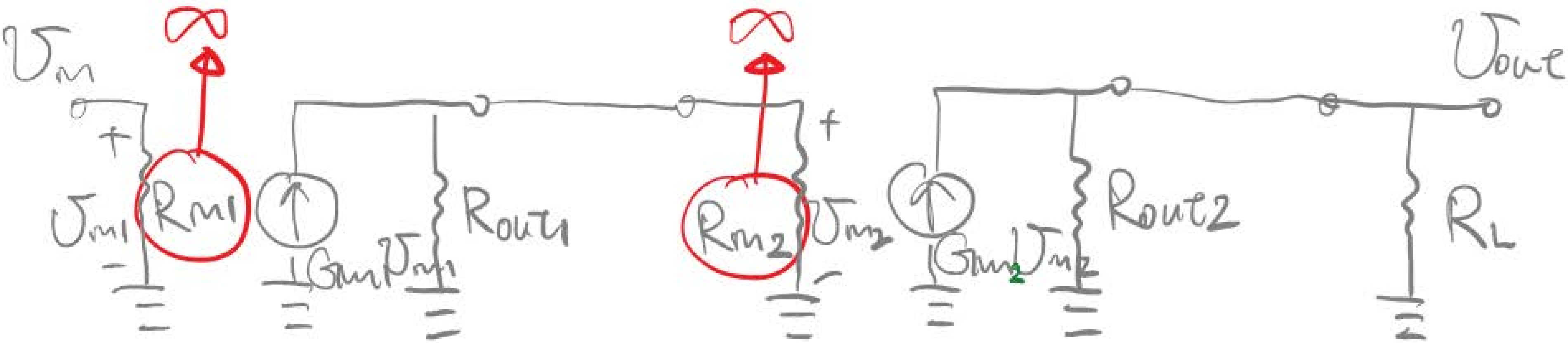


$$A_v = -gm_1 r_{o1} \times gm_2\left(r_{o2} \parallel \overbrace{\frac{1}{gm_2 + gmb_2}}^{\text{small}} \parallel r_{o3} \parallel R_L\right)$$

- Voltage gain maintained when R_L very small



$$A_v = -g_{m1} r_{o1} \times g_{m2}\left(r_{o2} \parallel \frac{1}{g_{m2}+g_{mb2}} \parallel r_{o3} \parallel R_L\right)$$



$G_{m1} = -g_{m1}$

$R_{out1} = r_{o1}$

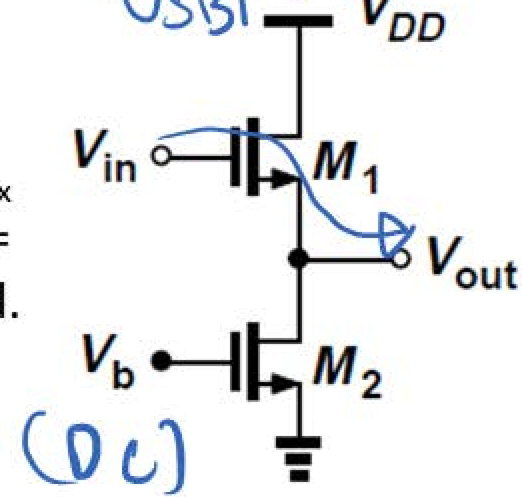
$G_{m2} = g_{m2}$

$R_{out2} = r_{o2} \parallel \frac{1}{g_{m2}+g_{mb2}} \parallel r_{o3}$

Example

$V_{Sb1} \neq 0$

$V_{SB1} \neq 0$



$(W/L)_1$ = 20/0.5, I_D = 0.2 mA, V_{THO} = 0.6 V, $2\phi_F$ = 0.7 V, $\mu_n C_{ox}$ = 50 $\mu A/V^2$, γ = 0.4 $V^{1/2}$ and λ = 0. (a) Calculate V_{out} for V_{in} = 1.2 V. (b) Minimum $(W/L)_2$ for which M_2 remains saturated.

Solution:

(a)

$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L_{eff}}\right)_1 (V_{in} - V_{out} - \overset{V_{TH1}}{V_{THO}})^2 \rightarrow V_{out} = 0.153\ \text{V} = V_{SB1}$$

$$V_{TH1} = V_{THO} + \gamma\left(\sqrt{2\Phi_F + V_{out}} - \sqrt{2\Phi_F}\right) = 0.635\ \text{V} \rightarrow V_{out} \approx 0.118\ \text{V}$$

(b)

$$V_{out} = 0.118\ \text{V} \geq V_{GS2} - V_{TH2}$$ for M_2 to stay in sat.

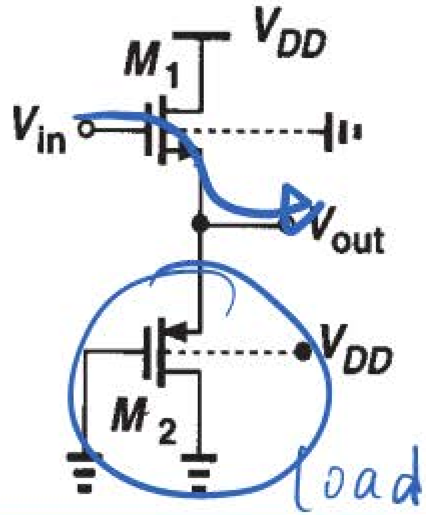
$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS2} - V_{TH2})^2 \rightarrow \left(\frac{W}{L}\right)_2 \geq \frac{283}{0.5}$$

Example

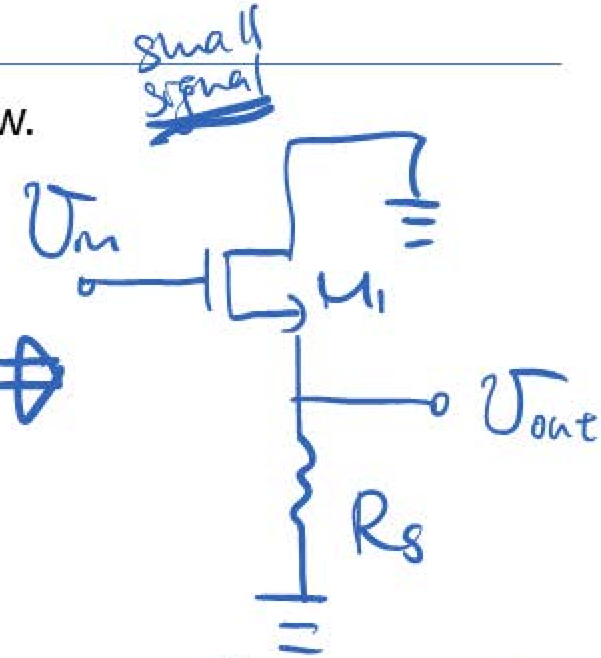
Calculate the small signal voltage gain of the circuit below.

Assume all in sat.

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



$\Rightarrow$



Solution:

$R_S = r_{o2} // \left(\frac{1}{g_{m2} + g_{mb2}}\right)$

$$G_m = gm_1$$

$$R_{out} = \frac{1}{gm_1 + gmb_1} \parallel r_{o1} \parallel \frac{1}{gm_2 + gmb_2} \parallel r_{o2}$$

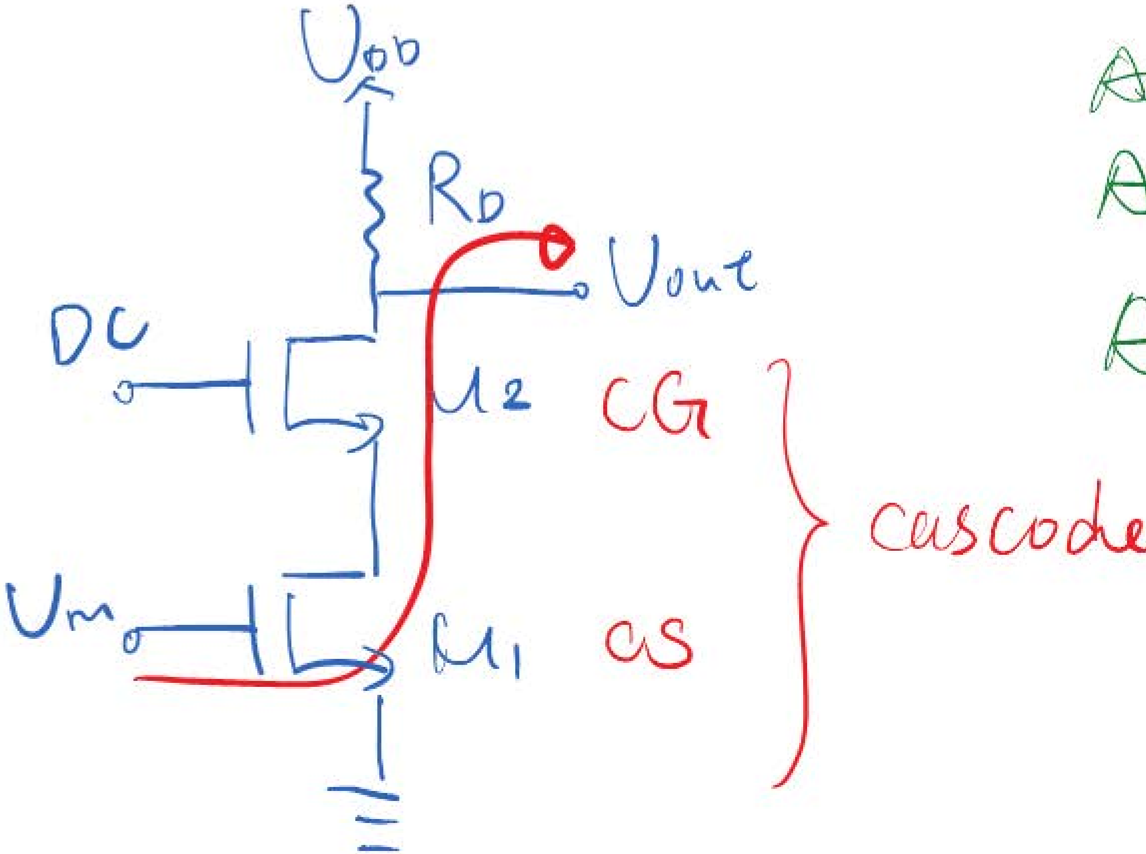
$$A_v = G_m R_{out}$$

CS
SF

both are voltage-in-voltage-out amplifiers.

Common-Gate (CG)

Current-in-voltage-out

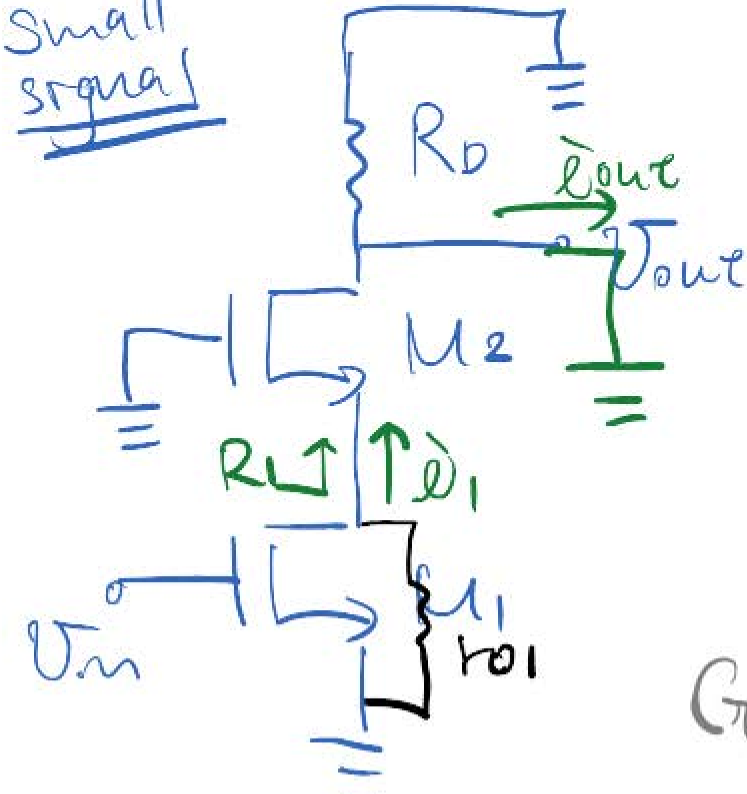


Assume M_1 and M_2 in sat.

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

$A_v = ?$

small signal



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

$$i_1 = i_{out}$$

$$R_1 = r_{o2} \,//\, \frac{1}{g_{m2}+g_{mb2}}$$

$$i_1 = (-g_{m1} v_{in}) \frac{r_{o1}}{r_{o1} + R_1}$$

$$G_m = -g_{m1} \frac{r_{o1}}{r_{o1} + \left(r_{o2} \,//\, \frac{1}{g_{m2}+g_{mb2}} \right)}$$