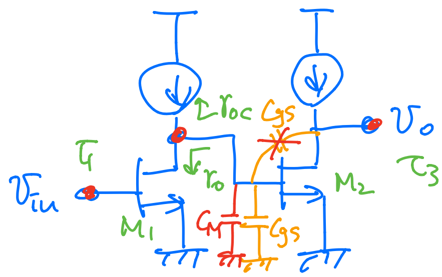
# CS–CS



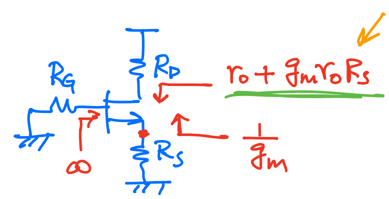

$R = r_o // r_{oc} \rightarrow$ large $R$

$C = C_{gs} + C_M = C_{gs} + (1 - A_v) C_{gd} \rightarrow$ large $C$ $\quad // \; C_{gs} + g_{m2} r_{o2} \cdot C_{gd}$

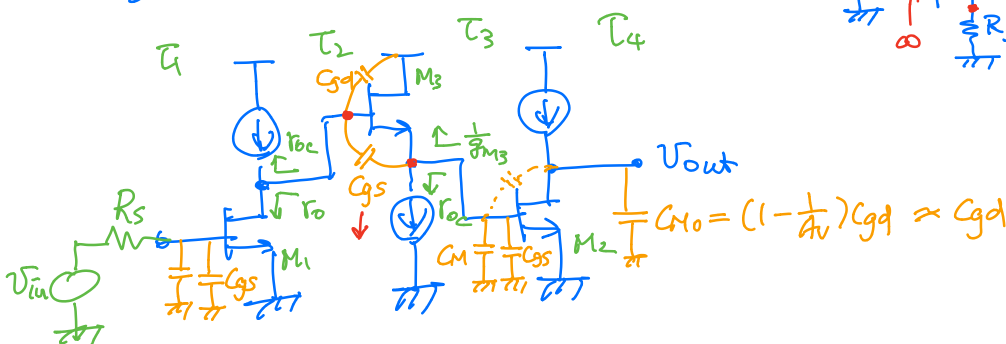
$\quad\quad\quad (1-A_v) \downarrow -g_{m2}(R_L // r_{oc} // r_o)$

$\tau_2 = RC \rightarrow$ Large

$$\omega_H = \frac{1}{\sum_i \tau_i} \approx \frac{1}{\tau_2}$$




# CS – CD – CS




$A_{v2} \approx 1$

$\tau_1 = R_S \cdot (C_{gs} + C_M) \rightarrow \tau_3$

$\tau_4 = (r_o // r_{oc}) \cdot C_{gd}$

$\sim \tau_2$

Total $A_v$ unchange

$\tau_2$ : $\quad R_2 = r_o // r_{oc}$ .

$\quad\quad C_2 = C_{gd} + (1 - A_{v3}) C_{gs} \approx C_{gd}$ . $\quad (A_{v3} = 1)$

$\quad\quad \tau_2$ substantially reduced.

$\tau_3$ : $\quad R_3 = \frac{1}{g_{m3}} // r_{oc} = \frac{1}{g_{m3}}$ .

$\quad\quad C_3 = C_{gs} + (1 - A_{v2}) C_{gd} \cong C_{gs} + g_{m2}(r_{o2} // r_{oc} // R_L) C_{gd}$ .

$\quad\quad \tau_3$ substantially reduce

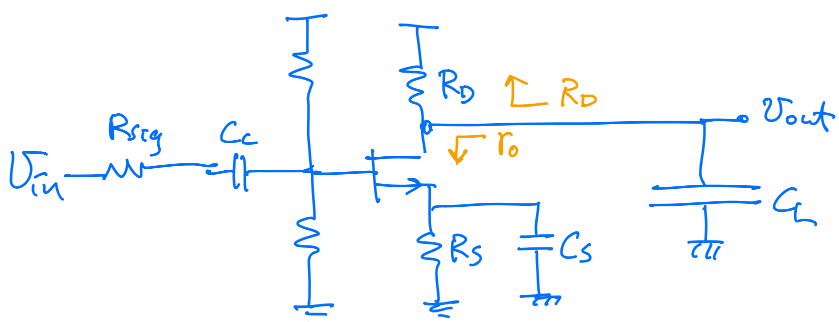
$$\omega_H = \frac{1}{\sum_i \tau_i} \cong \frac{1}{\tau_2 + \tau_3} \Rightarrow \text{Extended BW without lowering gain}$$

## Miller Cap


$C_{Mi} = (1 - A_v) \cdot C_f$

$C_{Mo} = (1 - \frac{1}{A_v}) C_f$

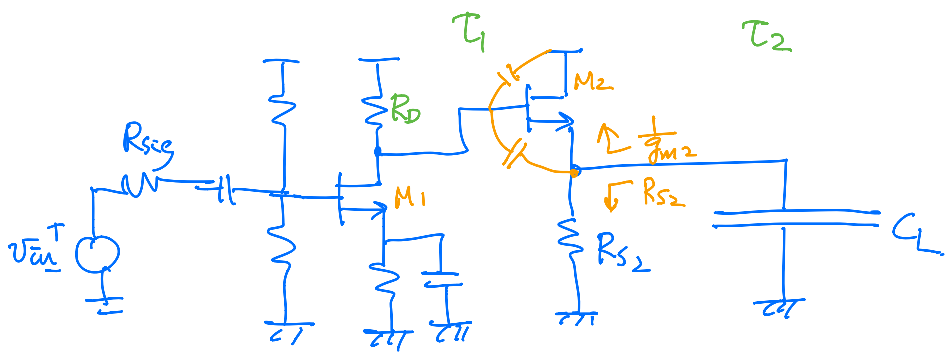
## Example CS w/ Large $C_L$




$R = R_D // r_o \approx R_D$

$C = C_L$

$\omega_H = \frac{1}{RC} = \frac{1}{R_D C_L}$




$\tau_2$: $C \approx C_L$

$R = \frac{1}{g_{m2}} // R_{S2} \approx \frac{1}{g_{m2}}$

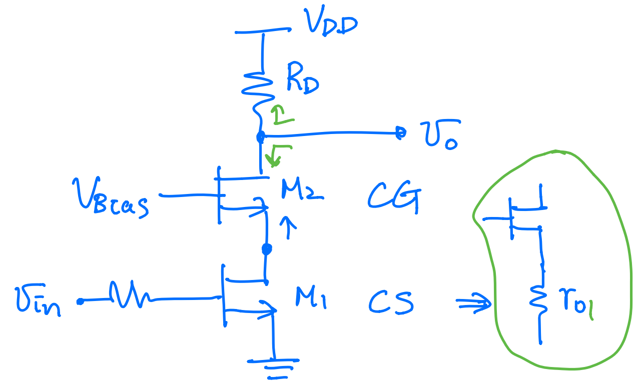
$\tau_2 = R \cdot C$ substantially reduce

$\tau_1$ : $R = R_D // r_o = R_D$

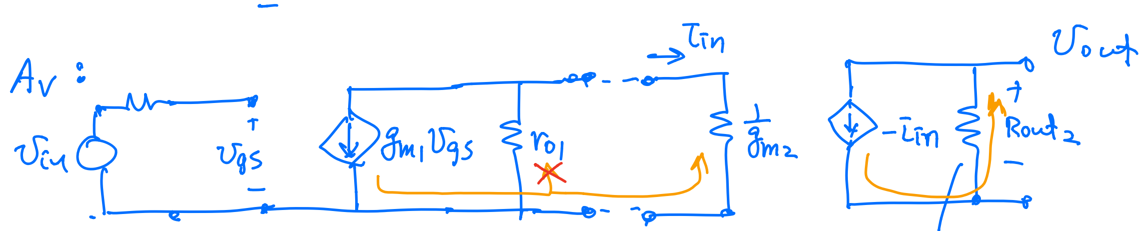
$C = C_{gd} + (1 - A_{v2}) C_{gs} \approx C_{gd}$

$\tau_1 = R_D \cdot C_{gd} \ll$ before

## Cascode Amplifier = CS + CG




$A_v$ :




$R_D // (r_{o2} + g_{m2} r_{o2} r_{o1})$

$\approx R_D$

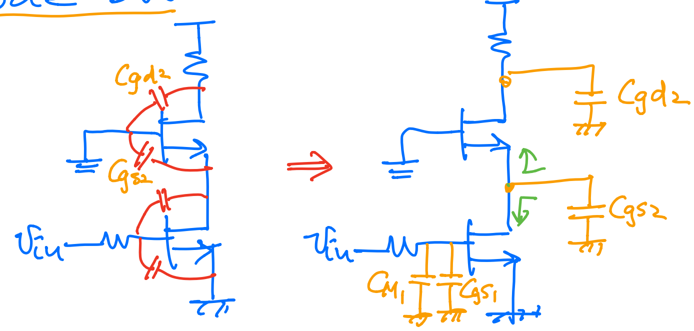
$v_{out} = -(-i_{in}) \cdot R_{out2} = i_{in} \cdot R_{out2}$, where $R_{out2} = R_D$

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

$v_{out} = -g_{m1} v_{gs} \cdot R_D = v_{in} (-g_{m1} R_D)$

$A_v = -g_{m1} R_D$

## Cascode BW



$C_{M1} = (1 - A_{v1}) \cdot C_{gd1}$

$A_{v1} = -g_{m1} R_{out1}$

$R_{out} = r_{o1} \parallel \frac{1}{g_{m2}} = \frac{1}{g_{m2}}$ $\Big\}$ $A_{v1} = -g_{m1} \cdot \left(\frac{1}{g_{m2}}\right) = -\frac{g_{m1}}{g_{m2}}$

If $M_1$ and $M_2$ are the same (same $\left(\frac{W}{L}\right)$)

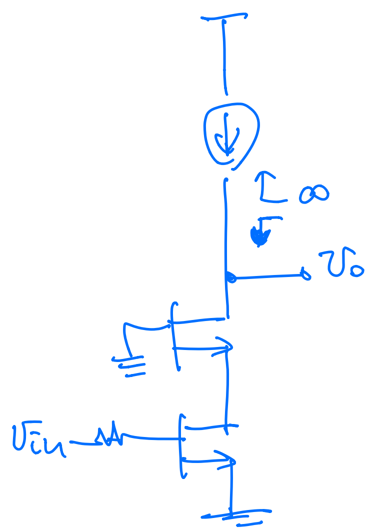
$\Rightarrow g_{m1} = g_{m2}$

$A_{v1} = -1$

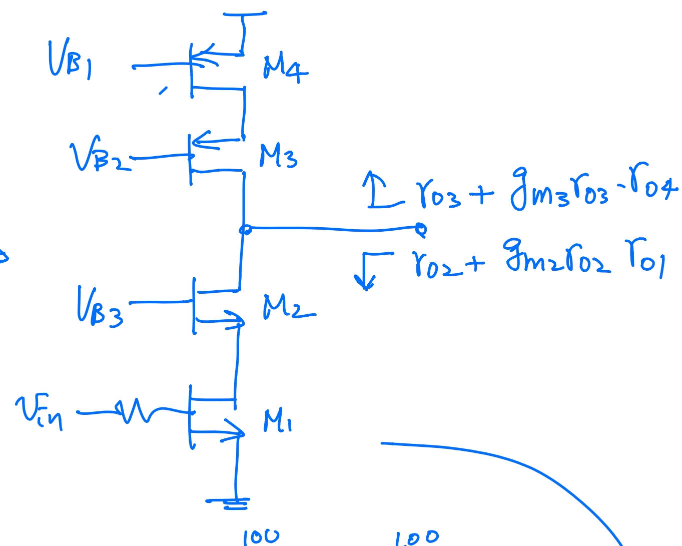
$C_{M1} = (1 - (-1))\, C_{gd} = 2C_{gd1}$

$\tau_1 = R_{sig} \cdot (C_{gs1} + 2C_{gd1})$

## Cascode with Cascode current mirror bias




$\Rightarrow$




$A_v = -g_{m1} \cdot (r_{o2} + \underline{g_{m2} r_{o2} \cdot r_{o1}}) \approx -(g_{m1} r_{o1})(g_{m2} r_{o2})$

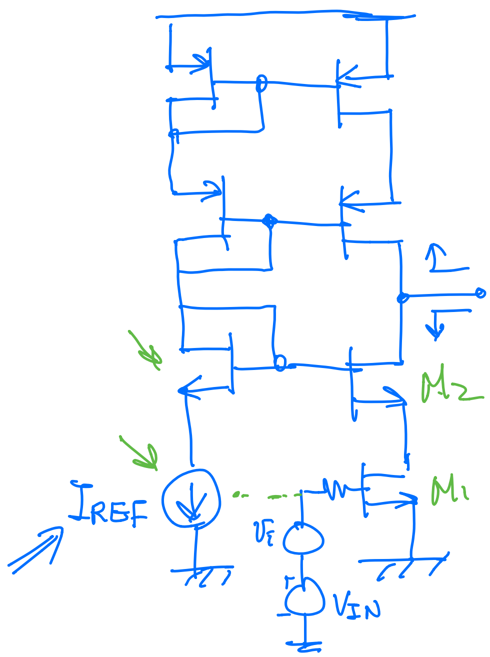
super high gain

$A_v = -g_{m1} \left[ (r_{o2} + g_{m2} r_{o2} r_{o1}) \parallel (r_{o3} + g_{m3} r_{o3} r_{o4}) \right]$

$= -g_{m1} \left[ (g_{m2} r_{o2} r_{o1}) \parallel (g_{m3} r_{o3} r_{o4}) \right]$

If $r_{o1} \approx r_{o2} \approx r_{o3} \approx r_{o4}$ $\quad g_{m2} \approx g_{m3}$

$$A_v = -\frac{1}{2} g_{m1} g_{m2} r_{o2} r_{o1}$$




## Design Example

$M_1, M_2$: $k_n' = 0.1\ mA/V^2$

$\lambda = 0.1\ V^{-1}$

$V_{tn} = 0.5V$

Goal: $g_{m1} = 1\ mS$

$R_{out} = 5M\Omega$

$\Rightarrow A_v = -g_{m1} R_{out} = -5000$

Find $\left(\frac{W}{L}\right)_1$

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$$R_{out} = \frac{1}{2} g_m r_o^2 = 5\times10^6$$

For simplicity, all transistors have the $g_m$, $r_o$

$$g_m = 10^{-3}$$

$$r_o^2 = \frac{5\times10^6 \times 2}{10^{-3}} = 10^{10}$$

$$r_o = 100{,}000\ \Omega = \frac{1}{\lambda I_{DS}} = 10^5$$

$$I_{DS} = \frac{1}{\lambda \cdot 10^5} = \frac{1}{0.1\times10^5} = \frac{1}{10^4} = 10^{-4}$$

$$= 100\mu A$$

$$I_{DS} = \frac{1}{2} k_n V_{ov}^2$$

$$= \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{ov}^2$$

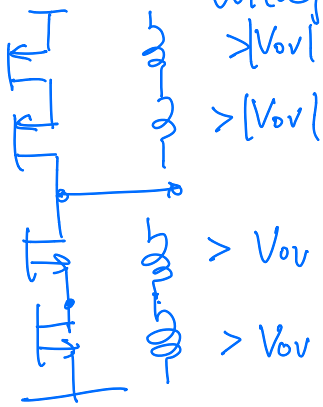
$$g_m = k_n V_{ov} = \sqrt{2 \cdot k_n I_{DS}}$$

$$2 \cdot k_n' \cdot \left(\frac{W}{L}\right) \cdot I_{DS} = g_m^2 = 10^{-6}$$

$k_n' \rightarrow 10^{-4}$, $I_{DS} \rightarrow 10^{-4}$

$$\left(\frac{W}{L}\right) = \frac{10^{-6}}{10^{-4} \cdot 10^{-4} \cdot 2} = \frac{100}{2} = 50$$

Voltage swing ?




$g_m = V_{ov} \cdot k_n$

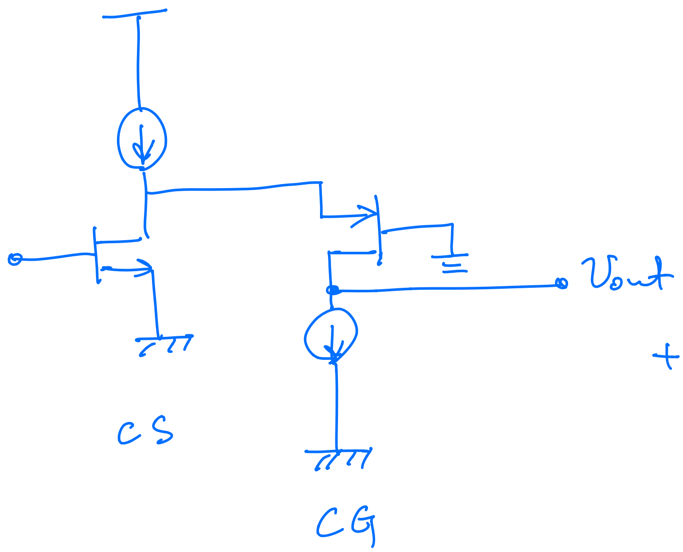
$V_{ov} = \frac{g_m}{k_n'\left(\frac{W}{L}\right)} = \frac{10^{-3}}{10^{-4} \cdot 50} = 0.2V$

$V_{out,min} = 2V_{ov} = 0.4V$

$V_{out,max} = V_{DD} - 2|V_{ov}|$

$= V_{DD} - 0.4V$

# Lab 6 : Folded Cascode




+ CD

to drive $C_L$