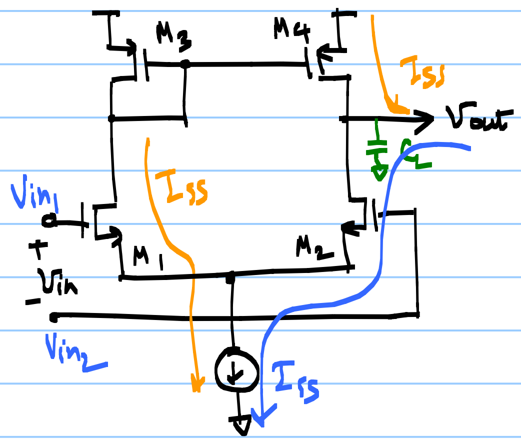
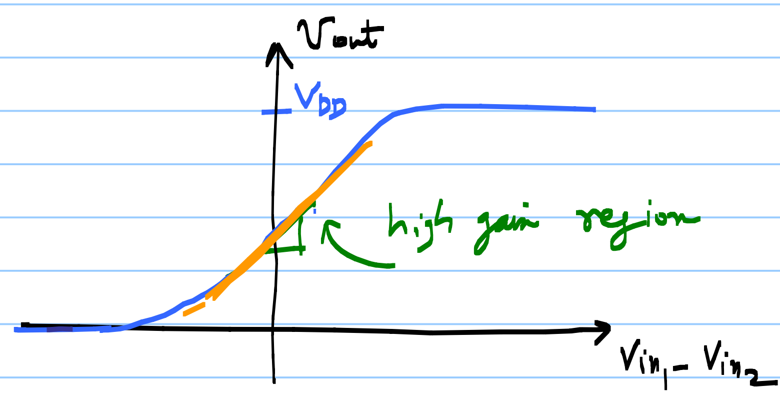
ECE 511 – Lecture 20

Note Title 4/9/2013





$(V_{in,cm})$ Input CMR $\in [V_{CCS} + V_{GS_1},\ V_{DD} - V_{SG_3} + V_{THN}]$

voltage reqd. to keep I_{SS} in saturation

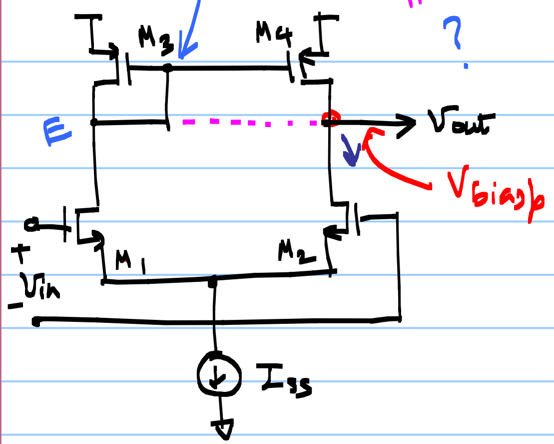
output range

$V_{out} \geq V_{in,cm} - V_{THN}$

$V_{DD} - V_{SG3} = V_{bias,p}$

mirrors ?

$V_E \triangleq V_{bias,p}$



let's say

$V_{out} < V_E$

$\Rightarrow V_{DS_2} < V_{DS_1}$

$I_{D_1} > \frac{I_{SS}}{2}$

$\Rightarrow I_{D_1} > I_{D_2}$ ①

$I_{D_3} = I_{D_1}$

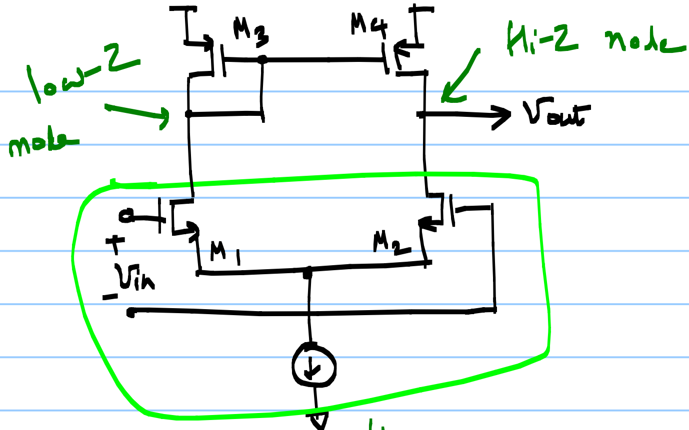
$\because V_{SD_4} > V_{SD_3} \Rightarrow I_{D_4} > I_{D_3}$

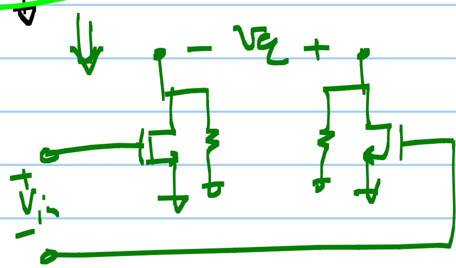
$I_{D_4} > \frac{I_{SS}}{2} \Rightarrow I_{D_2} > \frac{I_{SS}}{2}$

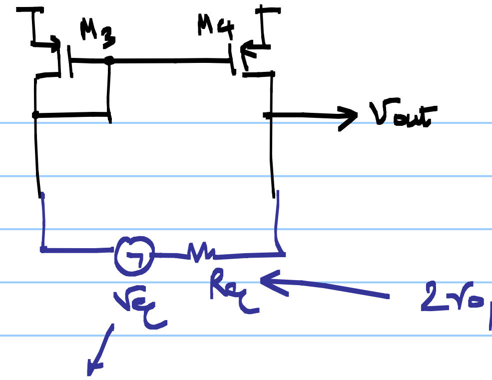
Contradiction

$\Rightarrow I_{D_1} = I_{D_2}$

$\Rightarrow V_{out}$ DC-level is well defined $\triangleq V_{bias,p}$

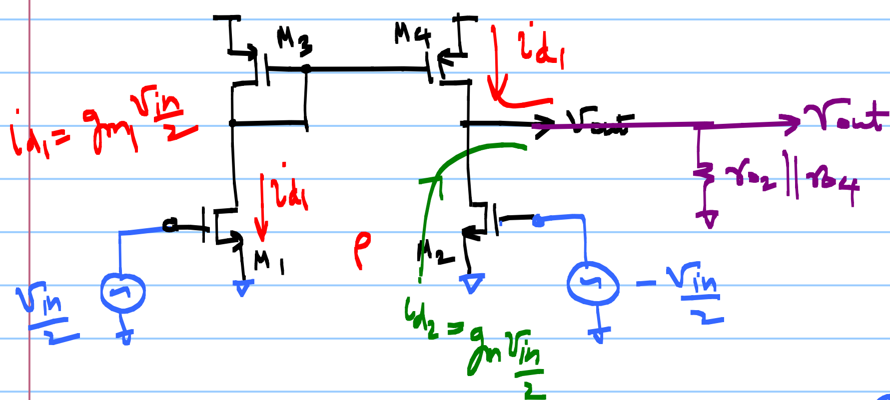






$V_{eq} = g_{m1} r_o V_{in}$

"Handwaving Method" AC, DM circuit



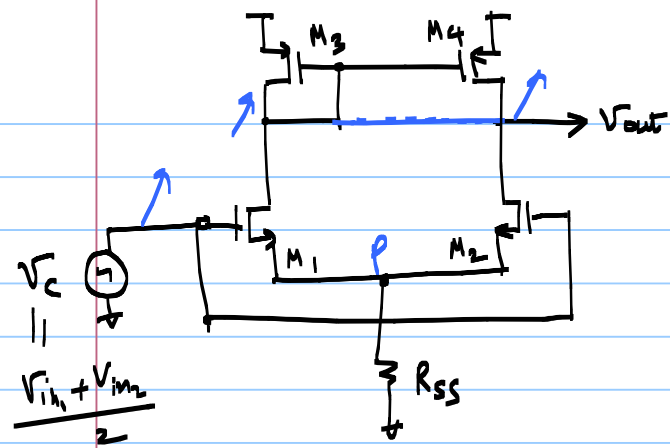
$$\boxed{A_{v,DM} = g_{m1,2}(r_{o2} \| r_{o4})}$$

$$v_{out} = (i_{d1} + i_{d2})(r_{o2} \| r_{o4})$$

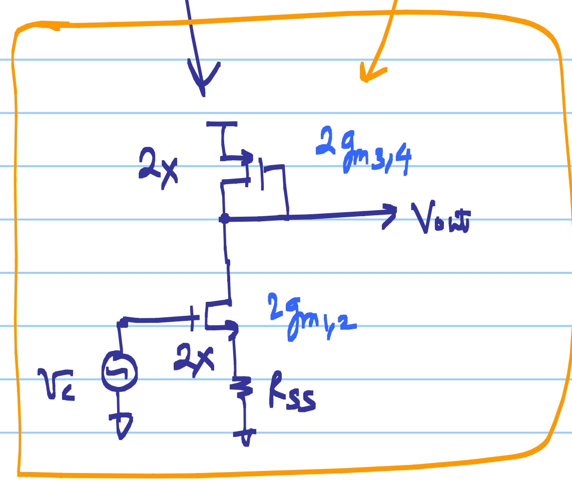
$$\Rightarrow \boxed{\frac{v_{out}}{v_{in}} = g_{m1,2}(r_{o2} \| r_{o4})}$$

2x gain due to the current mirror

$$g_{m1,2} = g_{m1} = g_{m2}$$



AC, CM equivalent circuit



$$A_{v,cm} = -G_m \cdot \left(R_{out} \parallel \frac{1}{2g_{m3,4}}\right)$$

$$\left(\cancel{2}g_{m1,2} \cdot \frac{r_{o1,2}}{\cancel{2}}\right) R_{SS}$$

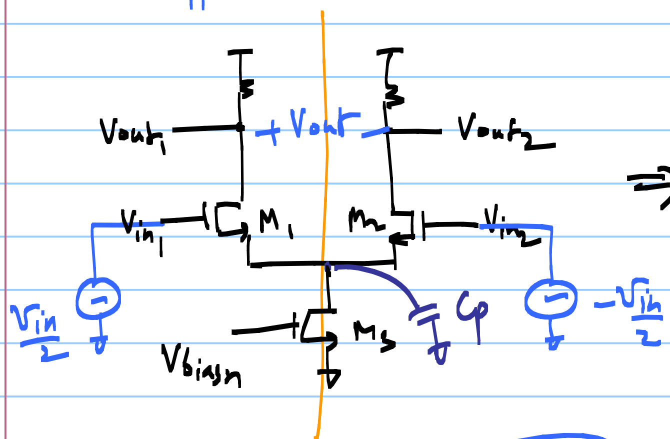
$$\simeq -\frac{1}{\cancel{1}+2\cancel{g_{m1,2}}R_{SS}} \cdot \frac{\cancel{g_{m1,2}}}{g_{m3,4}}$$

$$\boxed{A_{v,cm} \simeq -\frac{1}{2g_{m3,4}R_{SS}}}$$

$$CMRR = \left| \frac{A_{v,DM}}{A_{v,cm}} \right| = g_{m_{1,2}} \left(r_{o_{1,2}} \| r_{o_{3,4}} \right) \cdot 2\, g_{m_{3,4}} \cdot R_{SS}$$

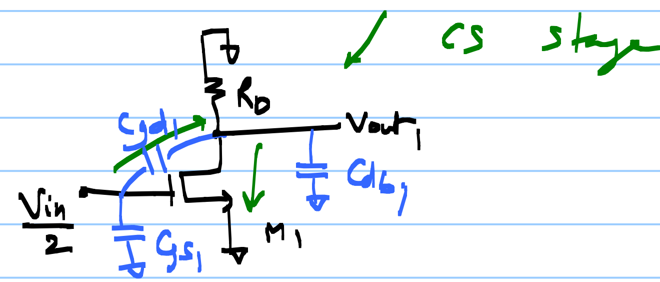
Diffamp Frequency Response

Differential Mode Circuit



$\Rightarrow$

DM Half Circuit



$V_{out_1} - V_{out_2}$

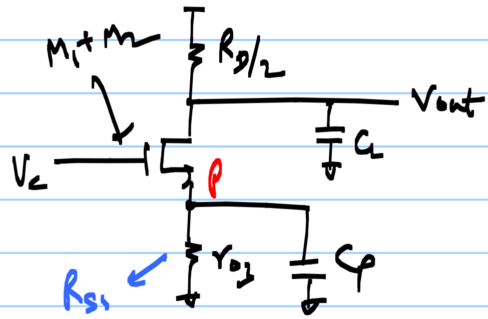
$$\frac{V_{out}}{V_{in}}(s) = -\frac{A_{v_0}\left(1 - s/\omega_z\right)}{\left(1 + s/\omega_{p1}\right)}$$

$A_{v_0} = g_m R_D$

$V_{in_1} - V_{in_2}$

$$\omega_{p1} = \frac{1}{(r_o \| R_D) C_L}, \quad \omega_z = \frac{g_{m1,2}}{C_{gd_{1,2}}}$$

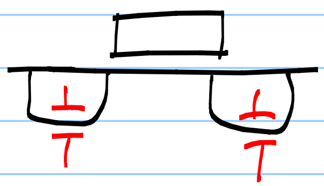
CM picture

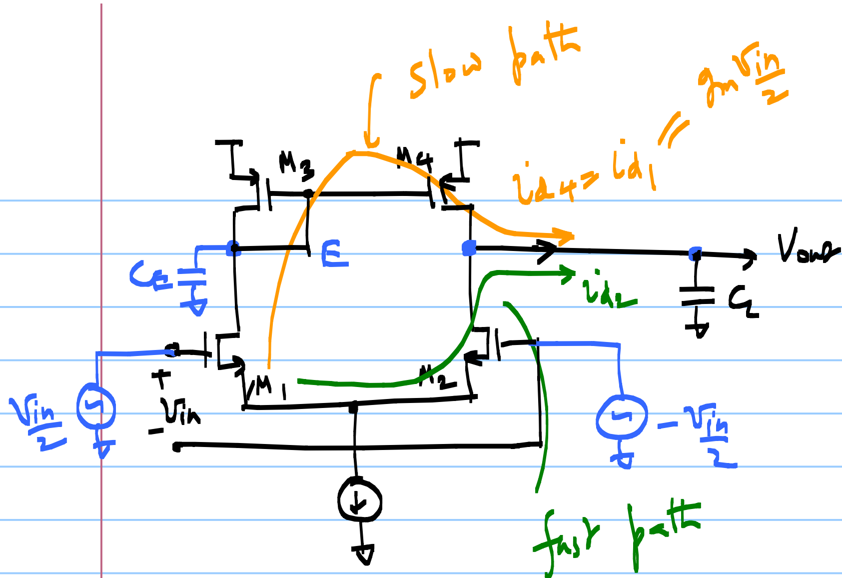


$$A_{v,cm}(s) = -\frac{\frac{R_D}{2} \parallel \frac{1}{sC_L}}{\frac{1}{2g_{m1,2}} + \left(r_{o3} \parallel \frac{1}{sC_P}\right)}$$

@ high frequencies

CMRR degrades





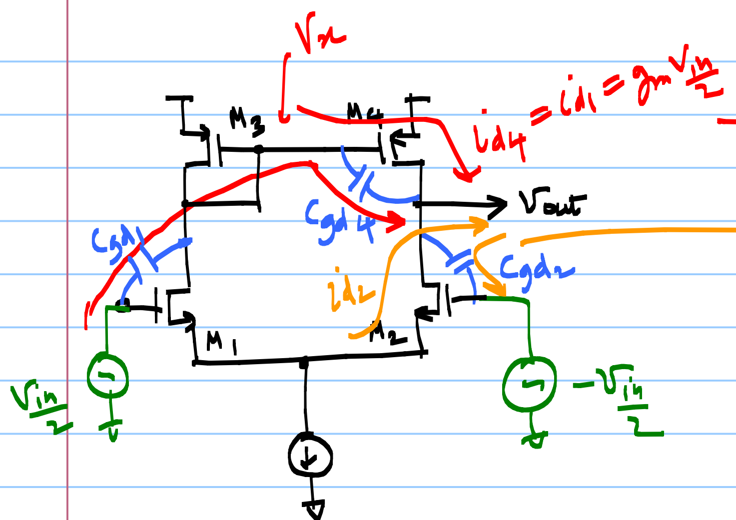
$i_{d2} = g_m \frac{v_{in}}{2}$

$C_E = C_{gs_3} + C_{gs_4} + C_{db_3} + C_{db_1}$
+ Miller Caps from C_{gd_1} & C_{gd_4}

* Sum of two frequency responses

$$\omega_{p_1} \simeq \frac{1}{(r_{o2} \| r_{o4})\, C_L}, \quad \omega_{p_2} \simeq \frac{g_{m_3}}{C_E} \simeq \frac{g_{m_3}}{3\, C_{gs}} \simeq \frac{\omega_T}{3}$$

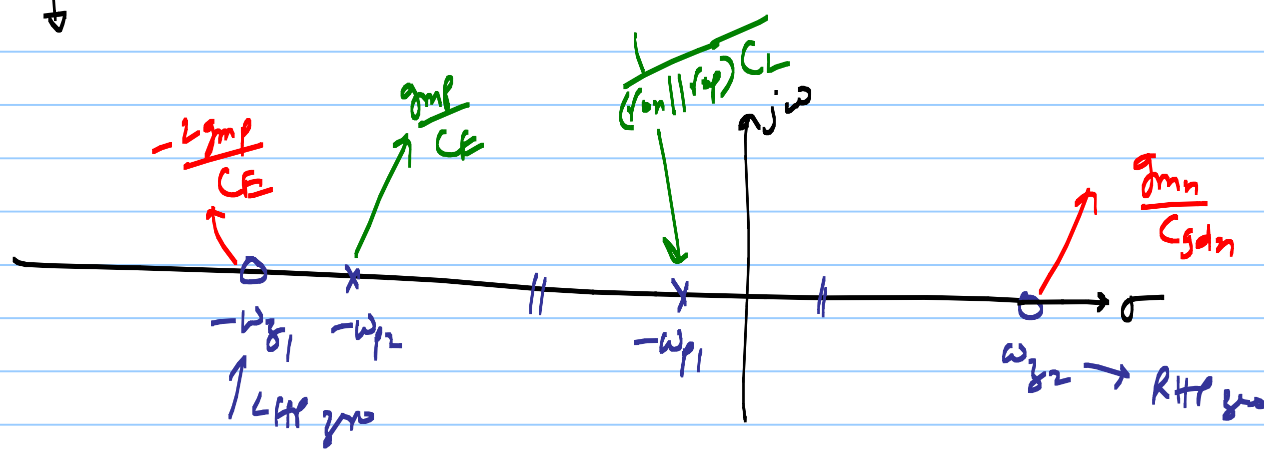
"Mirror pole" @ high frequency



$M_2 \Rightarrow C_{gd}$

LHP zero

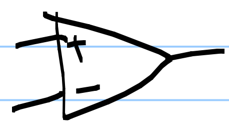
RHP zero

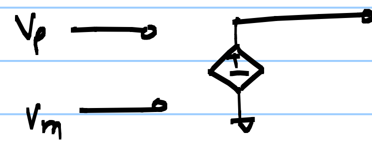


Operational Amplifiers (opamps)

* integral block in any Mixed-Signal

* Opamp ⇒ high gain VCVS



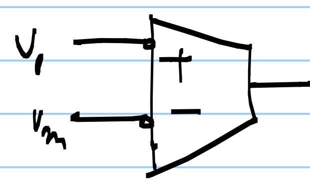


$V_{out} = A(v_p - v_m)$

$A_v \to \infty$
$Z_{in} \to \infty$
$Z_{out} \to 0$

VCVS

* OTA (op. transconductance Amplifier) ⇒ high g_m VCCS



$i_{out} = g_m(V_p - V_m)$

$Z_{in} \to \infty$
$g_m \to \infty$

$Z_{out} \to \infty$