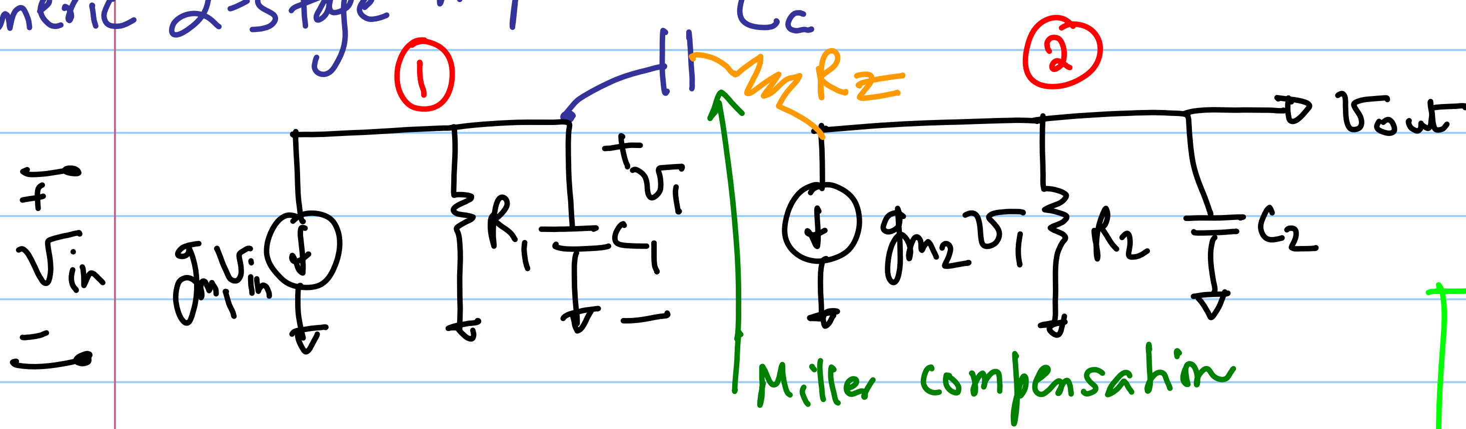
ECE 511 – Lecture 21

Note Title 4/10/2014

Generic 2-stage Amp Model



$$\boxed{\omega_z = +\frac{g_{m2}}{C_c}}$$

Small-signal gain @ low-freq.

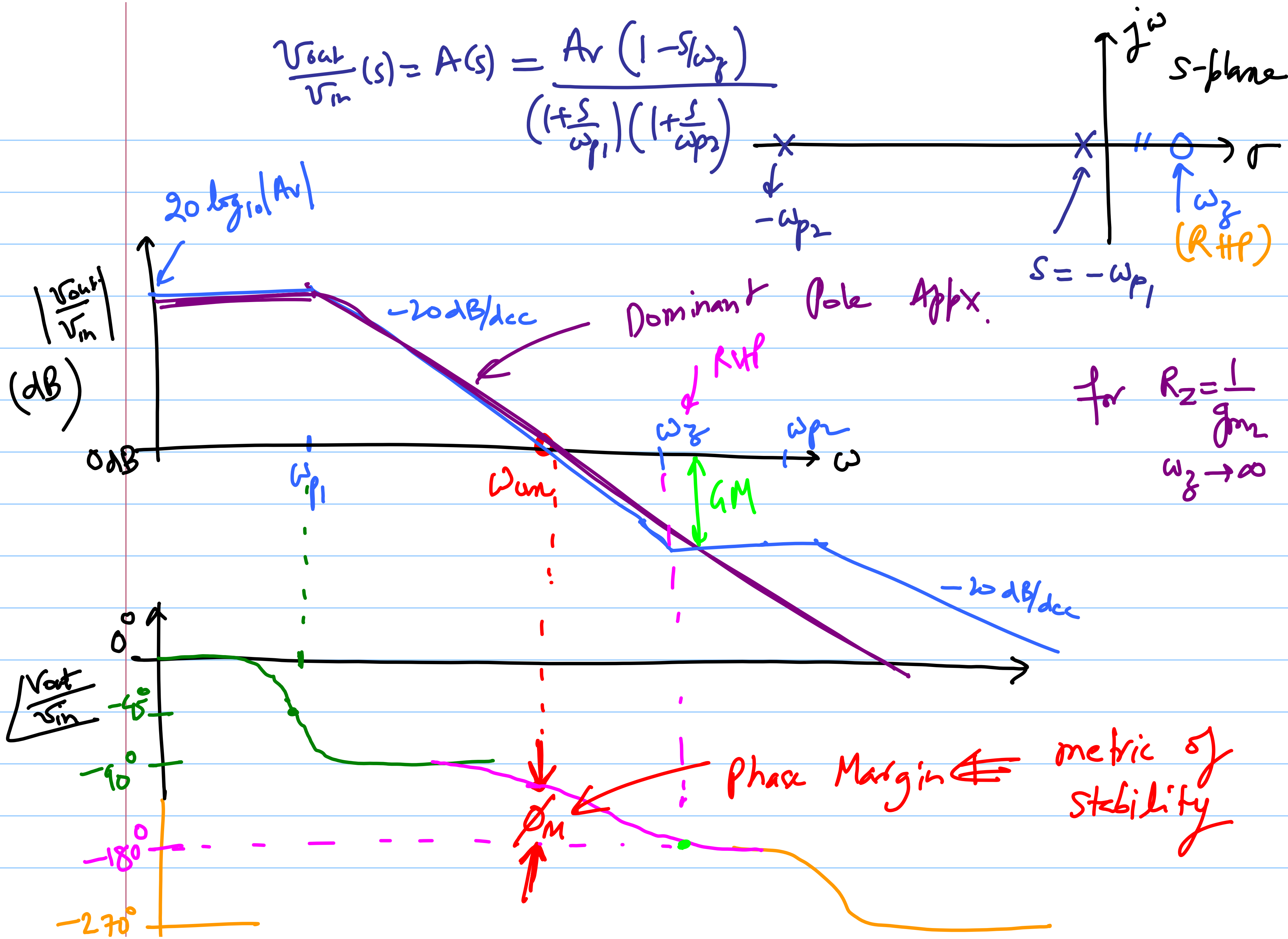
$$A_v = (g_{m1}R_1)(g_{m2}R_2)$$

$$\boxed{\omega_{p1} \simeq \frac{1}{R_2(C_2+C_c) + R_1\left(C_1 + C_c\left(1+\underbrace{g_{m2}R_2}_{\text{large}}\right)\right)}} \simeq \frac{1}{g_{m2}R_2R_1C_c}$$

$$\boxed{\omega_{un} \simeq \frac{g_{m1}}{C_c}}$$

$$\boxed{\omega_{p2} \simeq \frac{g_{m2}C_c}{C_cC_1 + C_1C_2 + C_cC_2}} \propto \frac{g_{m2}}{C_2} \text{ for } C_c \simeq C_2 >> C_1$$

$$\frac{V_{out}}{V_{in}}(s) = A(s) = \frac{A_v\left(1 - s/\omega_z\right)}{\left(1+\frac{s}{\omega_{p1}}\right)\left(1+\frac{s}{\omega_{p2}}\right)}$$



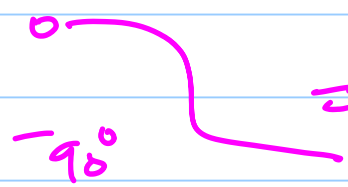
$$\frac{V_{out}}{V_{in}}(s) = A(s) = \frac{A_V\left(1 - s/\omega_z\right)}{\left(1+\frac{s}{\omega_{p1}}\right)\left(1+\frac{s}{\omega_{p2}}\right)}$$

$s \to j\omega$

$N_r = 1 - j\frac{\omega}{\omega_z}$

$$|A(j\omega)| = \frac{|A_V|\sqrt{1+\left(\frac{\omega}{\omega_z}\right)^2}}{\sqrt{1+\left(\frac{\omega}{\omega_{p1}}\right)^2}\sqrt{1+\left(\frac{\omega}{\omega_{p2}}\right)^2}}$$

$$\angle A(j\omega) = \tan^{-1}\left(-\frac{\omega}{\omega_z}\right) - \left\{\tan^{-1}\left(\frac{\omega}{\omega_{p1}}\right) + \tan^{-1}\left(\frac{\omega}{\omega_{p2}}\right)\right\}$$

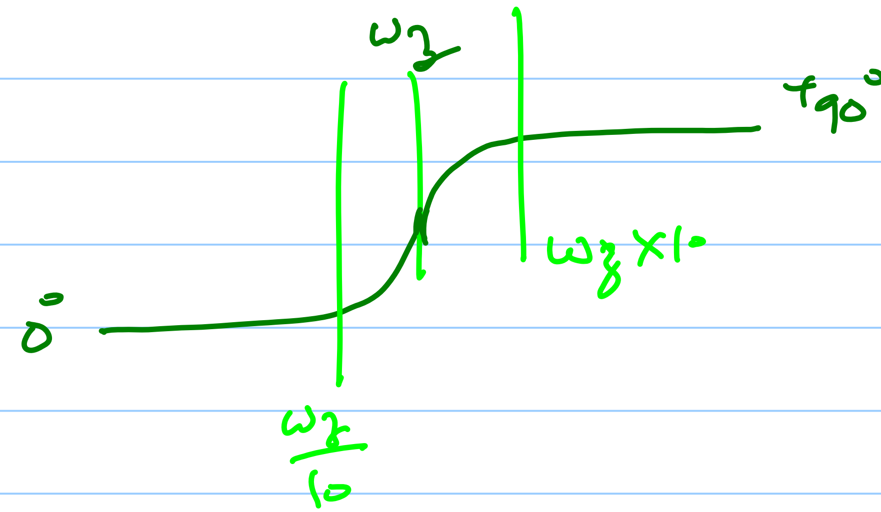


$$= \underbrace{-\tan^{-1}\left(\frac{\omega}{\omega_z}\right)}_{\text{RHP zero}} \underbrace{-\tan^{-1}\left(\frac{\omega}{\omega_{p1}}\right) - \tan^{-1}\left(\frac{\omega}{\omega_{p2}}\right)}_{\text{poles}}$$

LHP zero

$N_z = \left(1 + \frac{s}{\omega_z}\right)$

$+\tan^{-1}\left(\frac{\omega}{\omega_z}\right)$

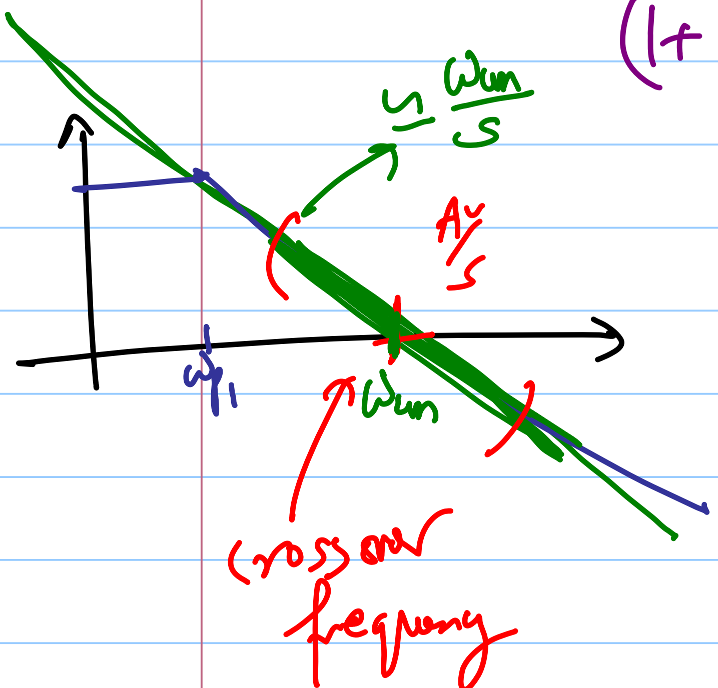


In the frequencies of interest

$$A(s) \simeq \frac{A_{v0}}{\left(1+ s/\omega_{p_1}\right)} \quad : \text{dominant pole model}$$

$$\omega_{3dB} = \omega_{p_1} \simeq \frac{1}{g_{m2} R_2 R_1 C_c} \Leftarrow \text{open-loop 3-dB BW}$$

$$f_{3dB} = \frac{1}{2\pi\, g_{m2} R_2 R_1 C_c}$$



for $\omega >> \omega_{3dB}$

$$A(s) \simeq \frac{A_{v0}}{s/\omega_{3dB}} = \frac{\overbrace{A_{v0}\,\omega_{3dB}}}{s} = \frac{\omega_{un}}{s}$$

$$\left|\frac{A_{v_0}\,\omega_{3dB}}{s}\right| = 1$$

$$\Rightarrow \boxed{\omega_{un} = A_{v_0}\,\omega_{3dB}}$$

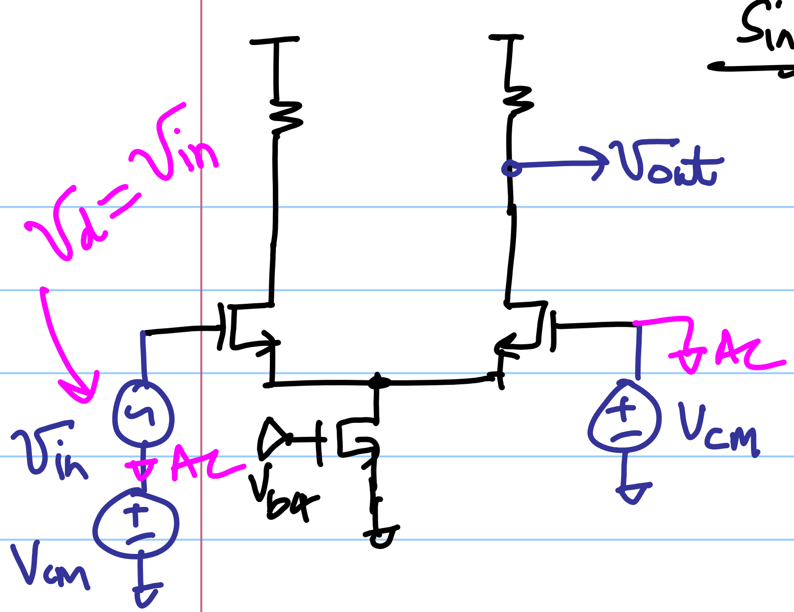
Dominant pole opamp

$$\boxed{GBW = \text{Gain} \times BW}$$

$$\omega_{un} = A_{v_0} \times \omega_{3dB}$$

$$= \left(g_{m1}\cancel{R_1}\,\cancel{g_{m2}}\,\cancel{R_2}\right) \times \left(\frac{1}{\cancel{g_{m2}}\cancel{R_2}\,\cancel{R_1}\,C_c}\right)$$

$$\boxed{\omega_{un} \simeq \frac{g_{m1}}{C_c}}$$



Single-ended

$A_{v,DM}$

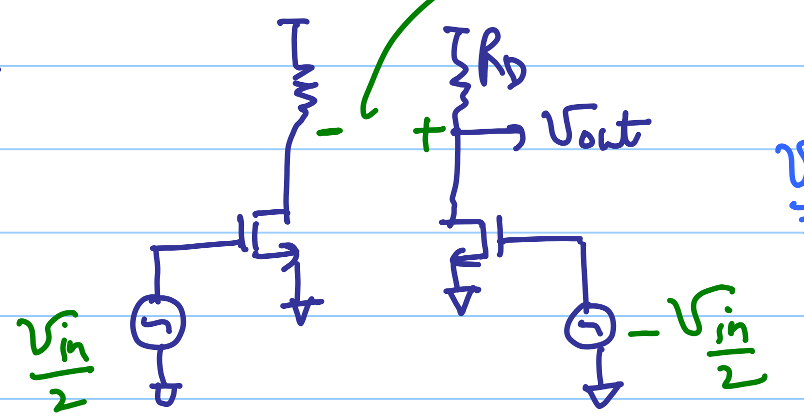
$A_{v,CM}$

CMRR

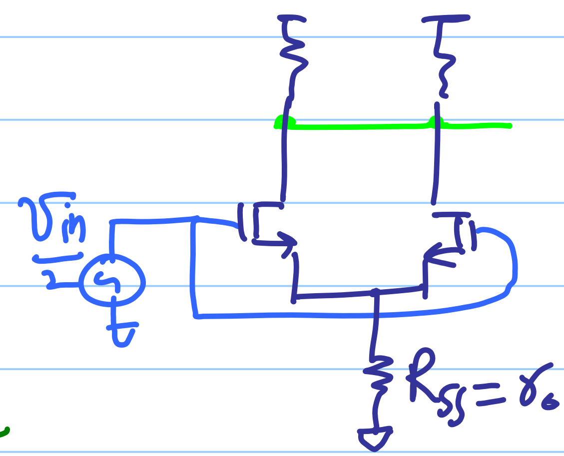
Half-Circuit Analysis

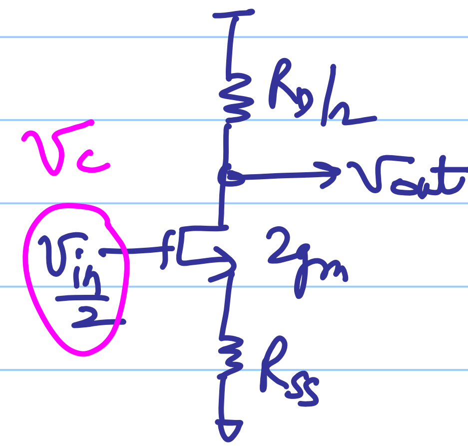
DM

$A_{v,diff} = g_m R_D$



CM





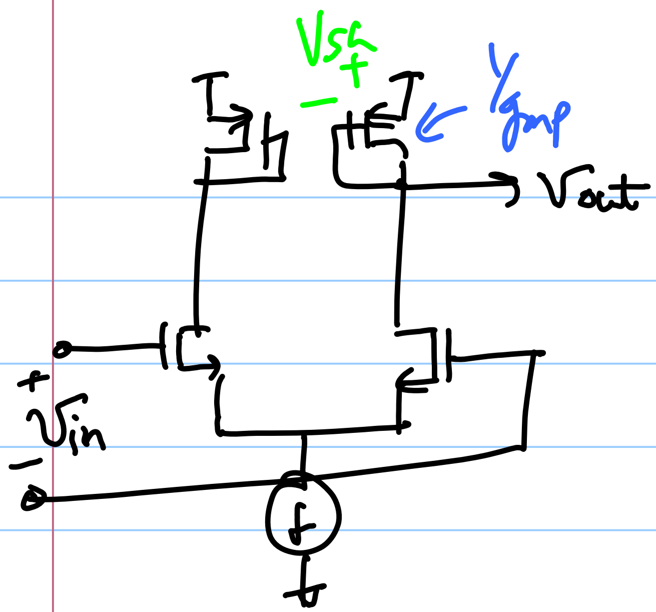
$$A_{v,DM} = +g_m \frac{R_D}{2}$$

$$A_{v,cm} = -\frac{R_D/2}{\frac{1}{2g_m} + R_{SS}}$$

$$\mathrm{CMRR} = \left| \frac{A_{v,dm}}{A_{v,cm}} \right| = \left| \frac{\frac{g_m R_D}{2}}{\frac{g_m R_D}{1 + 2 g_m R_{SS}}} \right|$$

$$= \frac{1}{2} + g_m R_{SS}$$

$$\simeq \underline{\underline{g_m R_{SS}}}$$



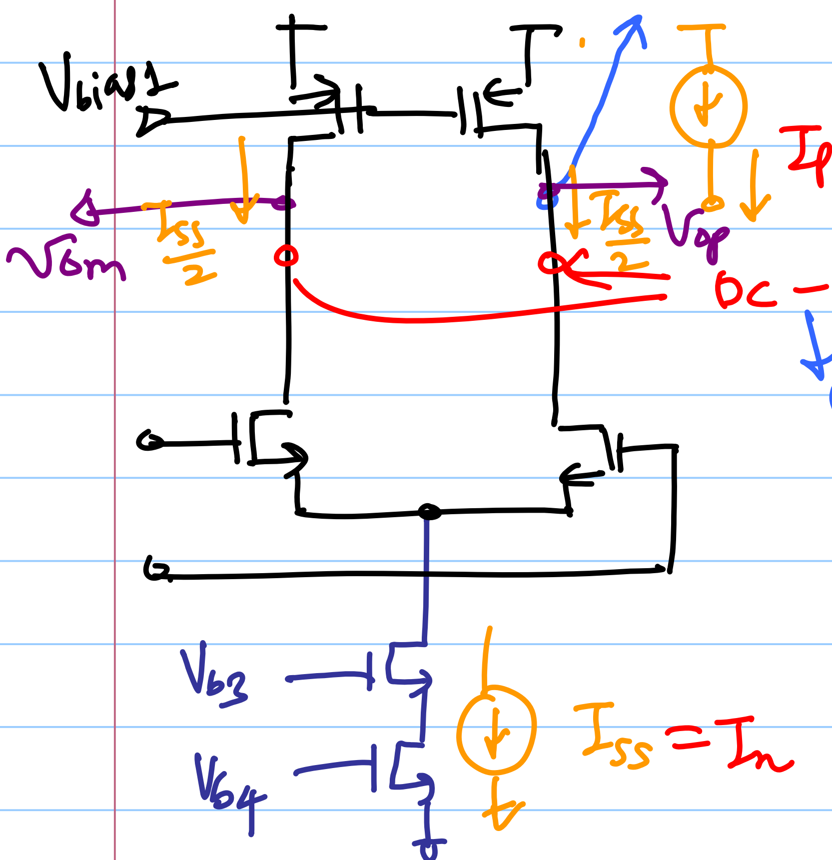
$\frac{1}{2} g_{mn} \times \frac{1}{g_{mp}}$

$\left(\frac{1}{g_{mp}}\right) \uparrow$ by $L_p \uparrow$

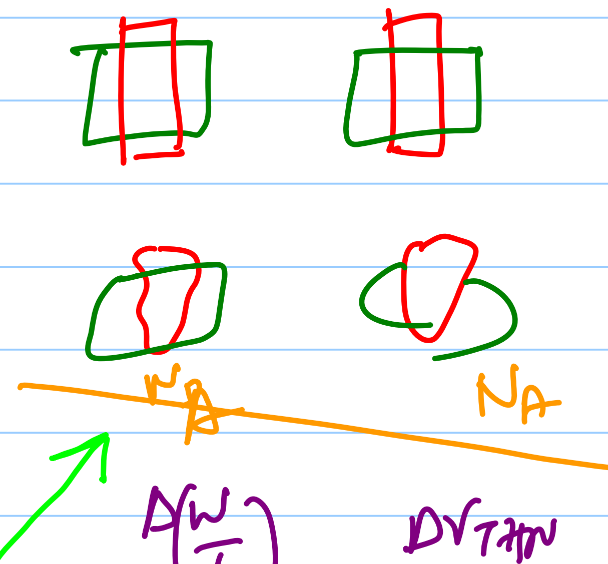
$V_{SG} \uparrow$

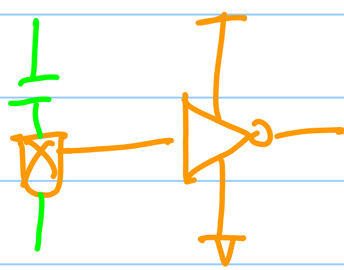
restrict the voltage headroom

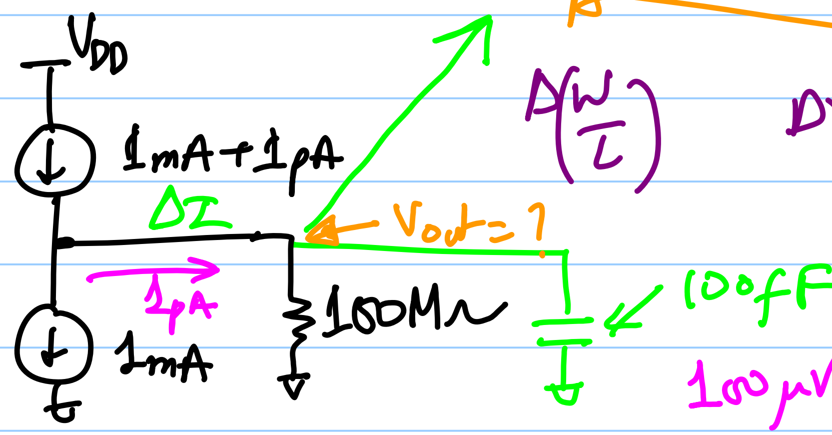
* Two indep. current sources fighting

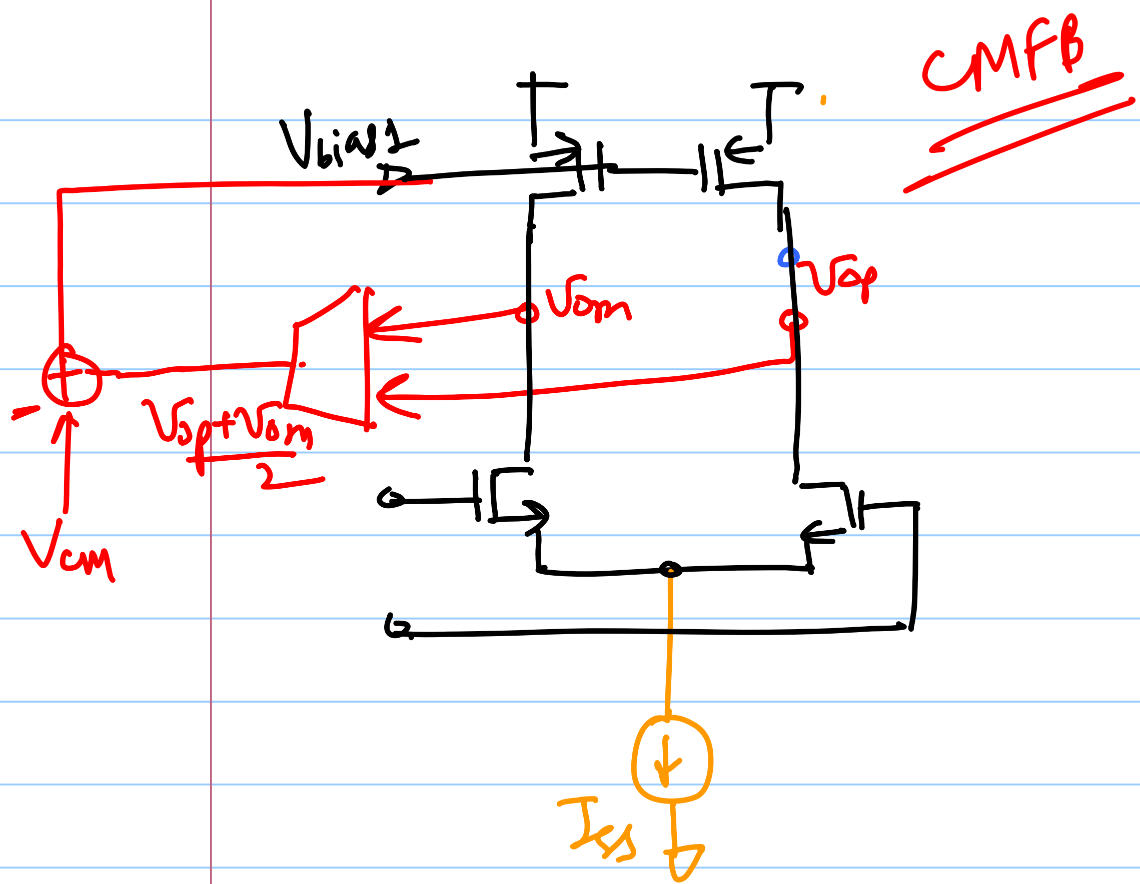


DC-level ?
undefined



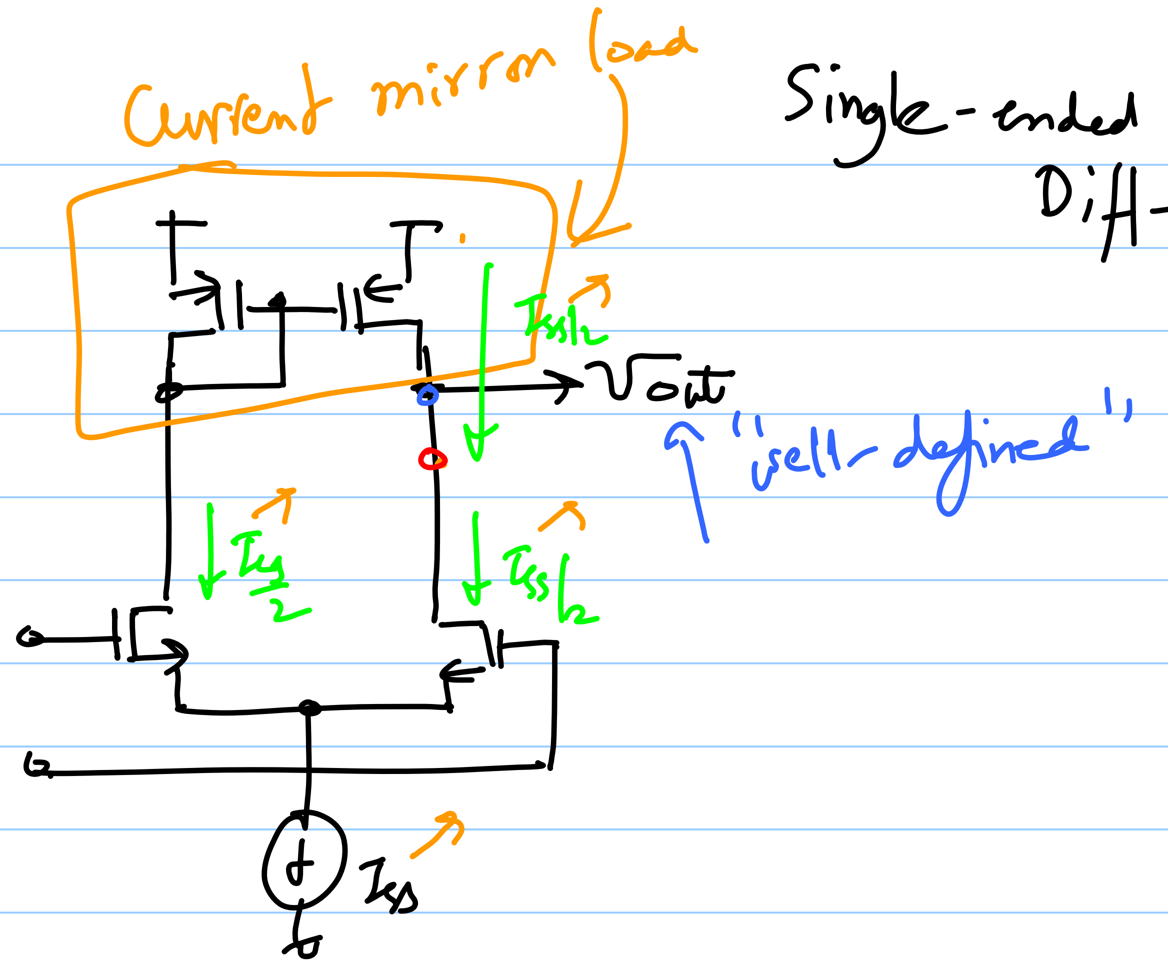


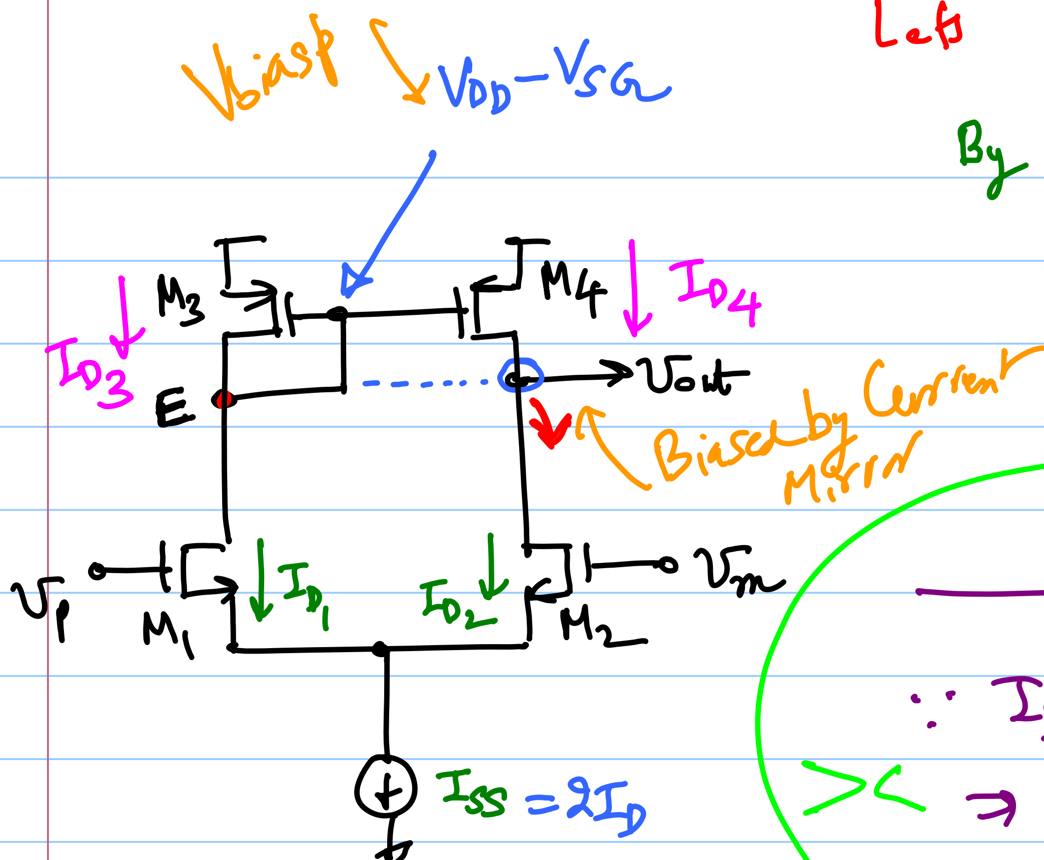




CMFB
V_{bias1}
V_{om}
V_{op}
$\frac{V_{op}+V_{om}}{2}$
V_{cm}
I_{SS}

Single-ended CMOS
Diff-amp





Lets say $V_{out} < V_E$

By CLM $V_{D2} < V_{D1}$

$\Rightarrow I_{D_2} < I_{D_1} \longrightarrow (1)$

$V_{SD_4} > V_{SD_3}$

$\Rightarrow I_{D_4} > I_{D_3} \longrightarrow (2)$

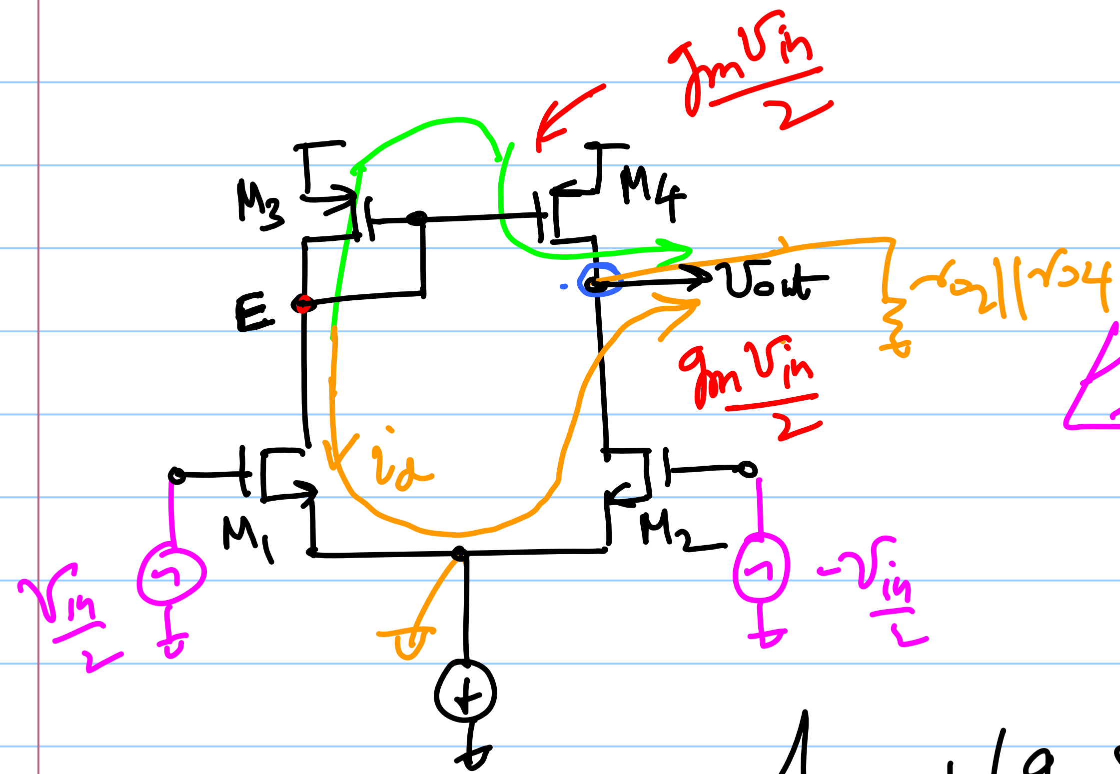
$\because I_{D_1} > I_{D_2}$

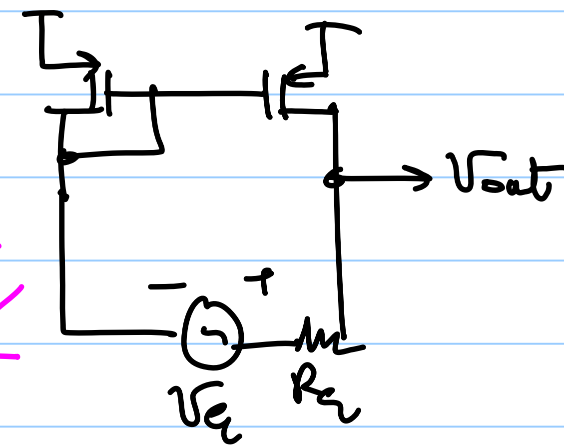
$>< \quad \Rightarrow I_{D_1} > \frac{I_{SS}}{2} \Rightarrow I_{D_3} > \frac{I_{SS}}{2}$

$\Rightarrow I_{D_4} < \frac{I_{SS}}{2}$

Contradiction

$\Rightarrow I_{D_1} = I_{D_2} \Rightarrow V_{out} = V_E = V_{DD} - V_{SG_3}$





$$A_v = +\left(g_{m_{1,2}} r_{o2} \| r_{o4}\right) \simeq \frac{g_m r_o}{2}$$