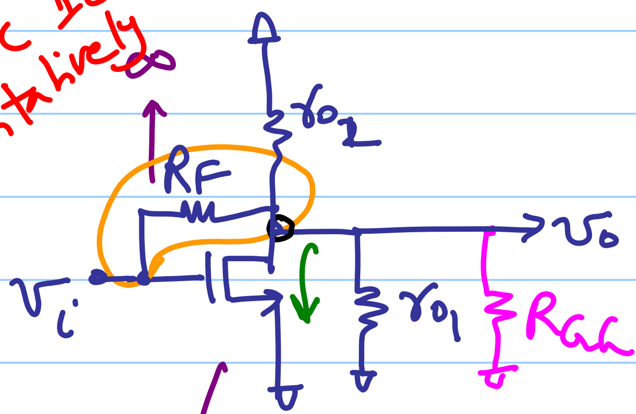
ECE 511 – Lecture 22

Note Title 4/17/2014

April 19 Saturday 2PM → "MEC 103" Tentatively

Help opamp session



$$\frac{v_o}{r_{o1}\|r_{o2}} + \frac{(v_o - v_i)}{RF} + g_{m1} v_{in} = 0$$

$$\frac{v_o}{r_{o1}\|r_{o2}\|R_F} = -g_{m1} v_{in} + \frac{v_{in}}{RF}$$

$R_F \to \infty$

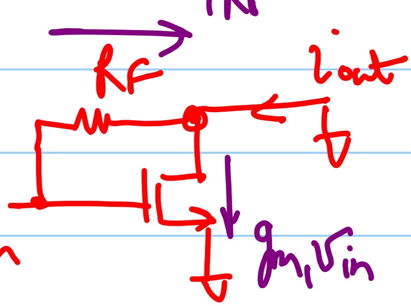
$$A_v = -g_{m1}(r_{o1}\|r_{o2})$$

$$\frac{v_o}{v_{in}} = -\left(g_{m1} - \tfrac{1}{R_F}\right)(r_{o1}\|r_{o2}\|R_F)$$

$R_F = \infty$

Method

$G_m R_{out}$



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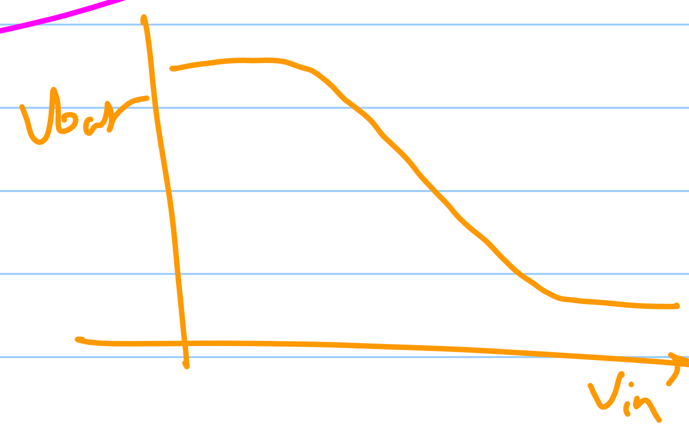
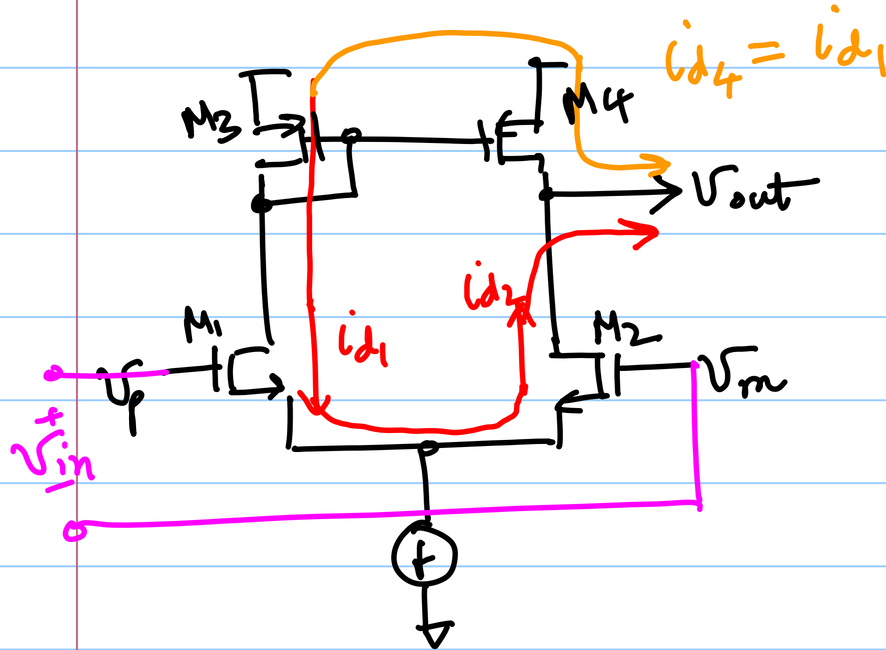
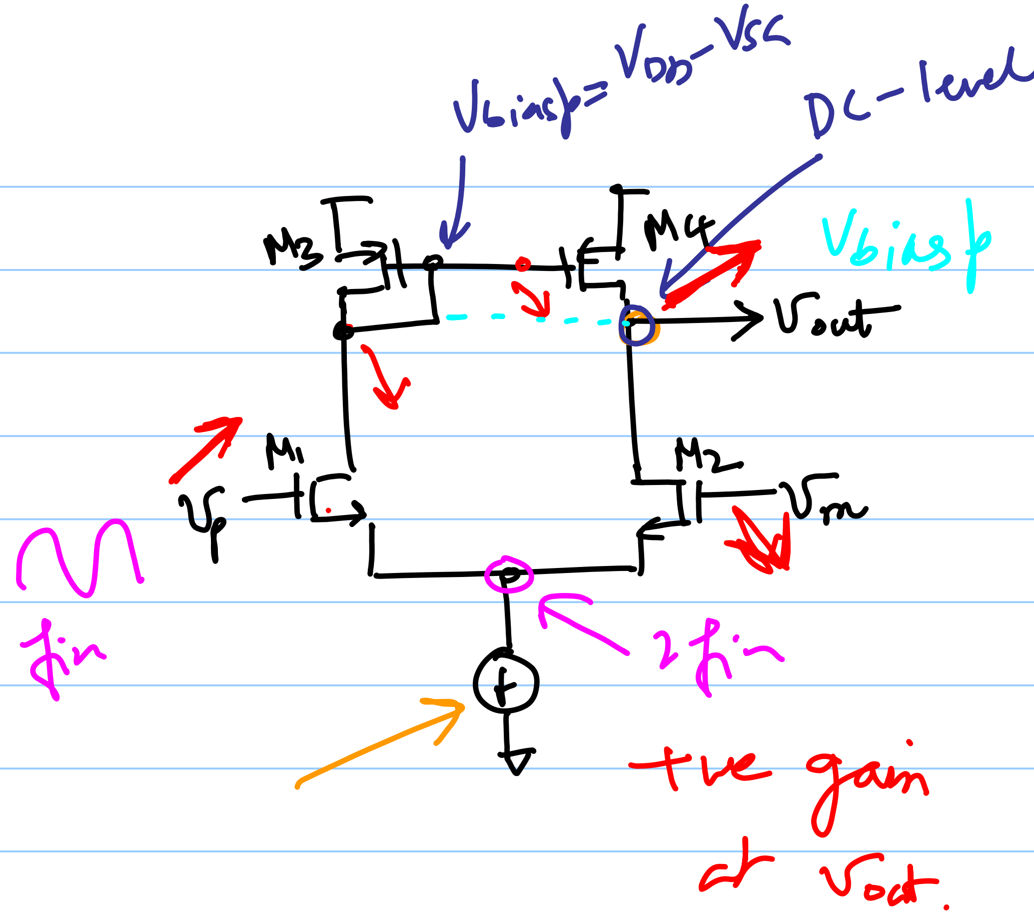
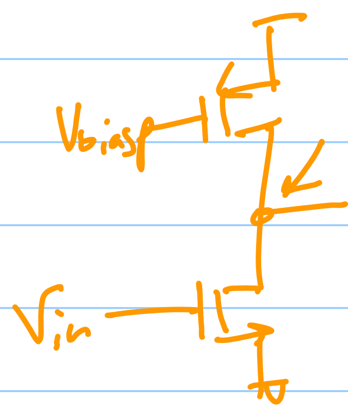
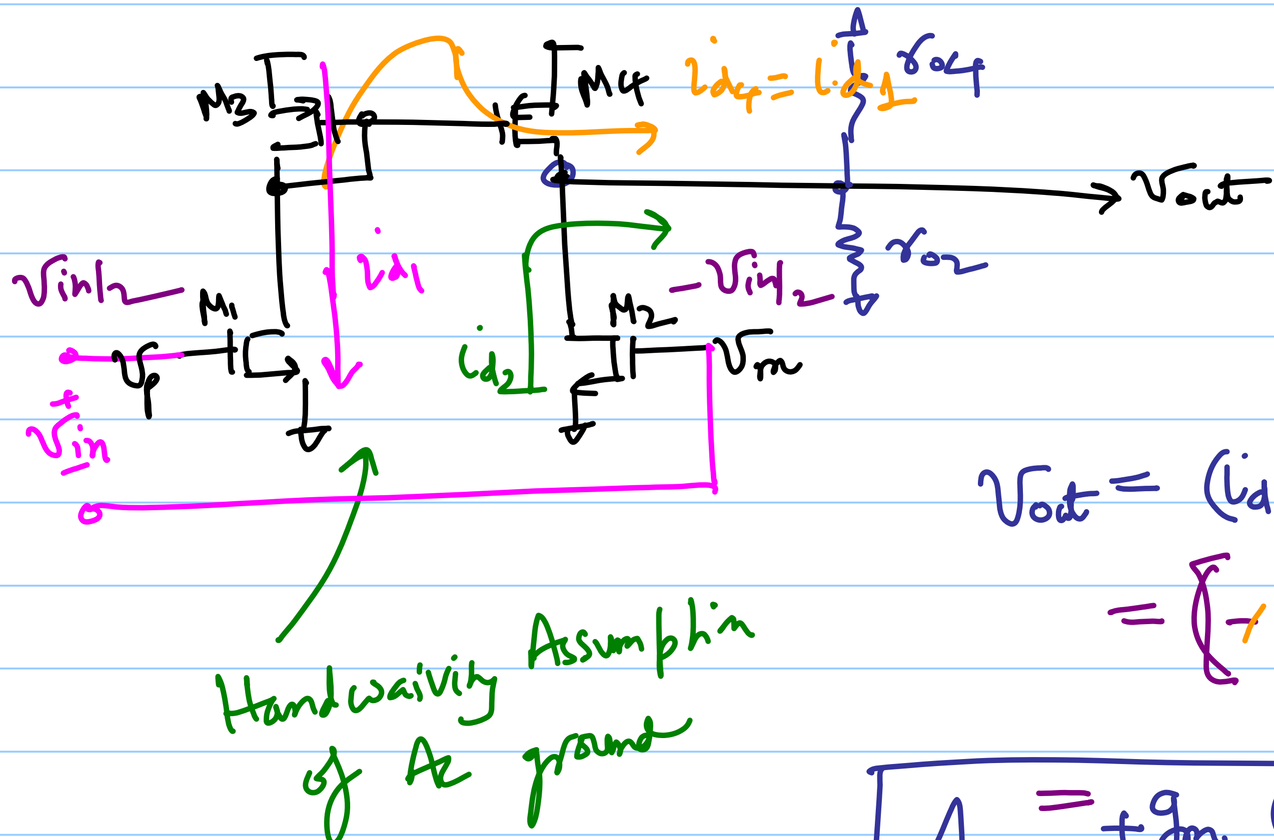
$$G_m = g_{m1} - \tfrac{1}{R_F}$$




id4 = id1
M3
M4
Vout
id2
id1
M1
M2
Vp
Vm
+
Vin
-


Vbiasp = VDD - VSG
DC - level
Vbiasp
M3
M4
Vout
M1
M2
Vp
Vm
fin
2fin
+ve gain at Vout.


Vbiasp
Vin



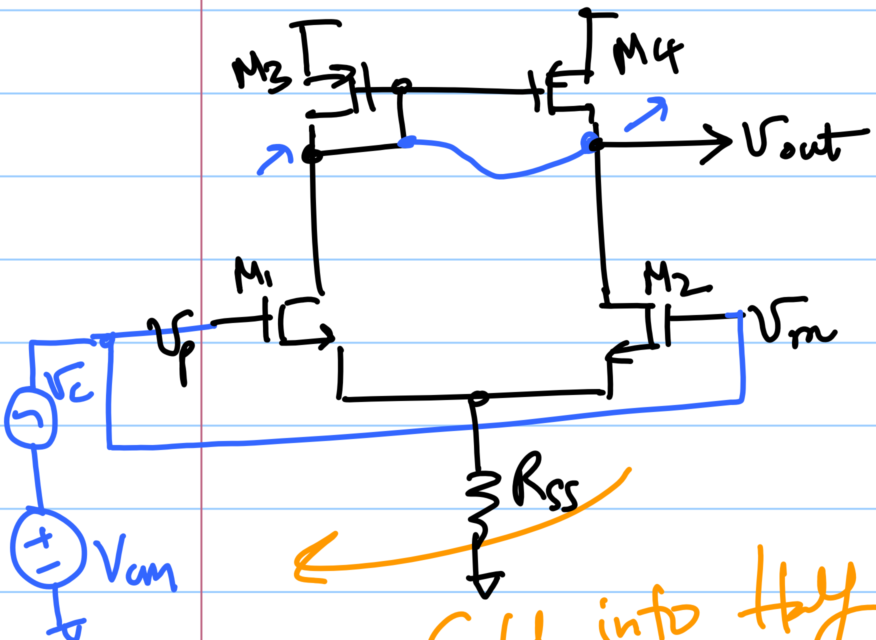
$$V_{out} = (i_{d_2} + i_{d_4})(r_{o2} \| r_{o4})$$

$$= \left[\cancel{-}\, g_{m_2}\left(\cancel{+}\frac{V_{in}}{2}\right) + g_{m_1}\frac{V_{in}}{2} \right] r_{o2} \| r_{o4}$$

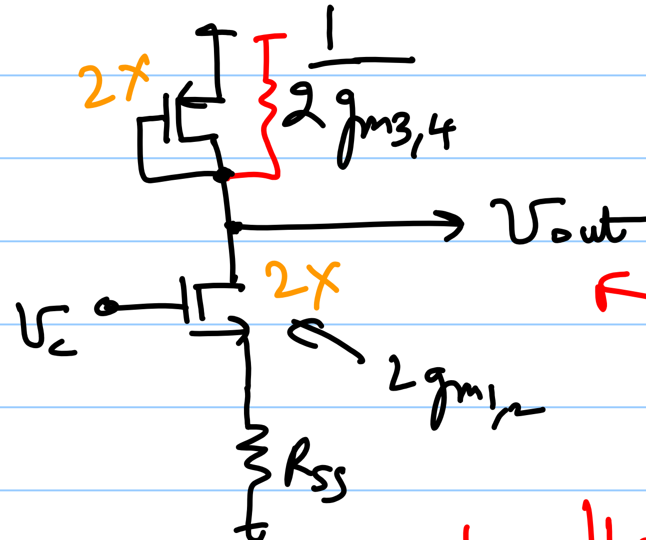
$$\boxed{A_v = +g_{m_{1,2}}(r_{o2} \| r_{o4})}$$

Small-signal voltage gain

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



Fold into this



Source Degen CS Topology

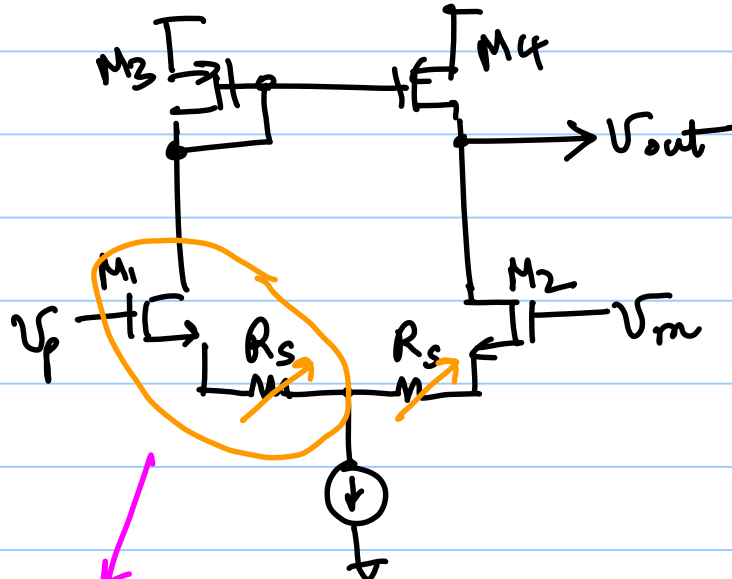
$$A_{cm} \simeq \frac{-\frac{1}{2g_{m3,4}} \| \frac{r_{o3,4}}{2}}{\frac{1}{g_{m1,2}} + R_{SS}}$$

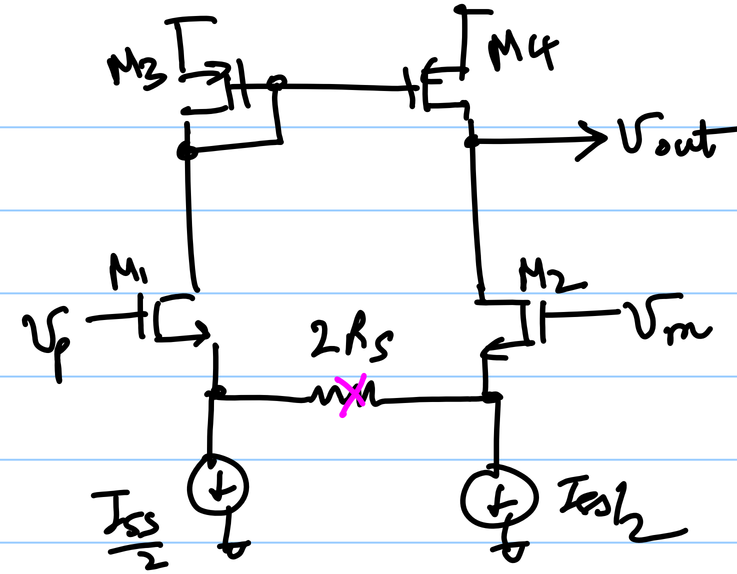
$$\simeq \frac{-1}{1+2g_{m1,2}R_{SS}} \cdot \left(\frac{g_{m1,2}}{g_{m3,4}}\right) \simeq -\frac{1}{2g_{m3,4}R_{SS}}$$

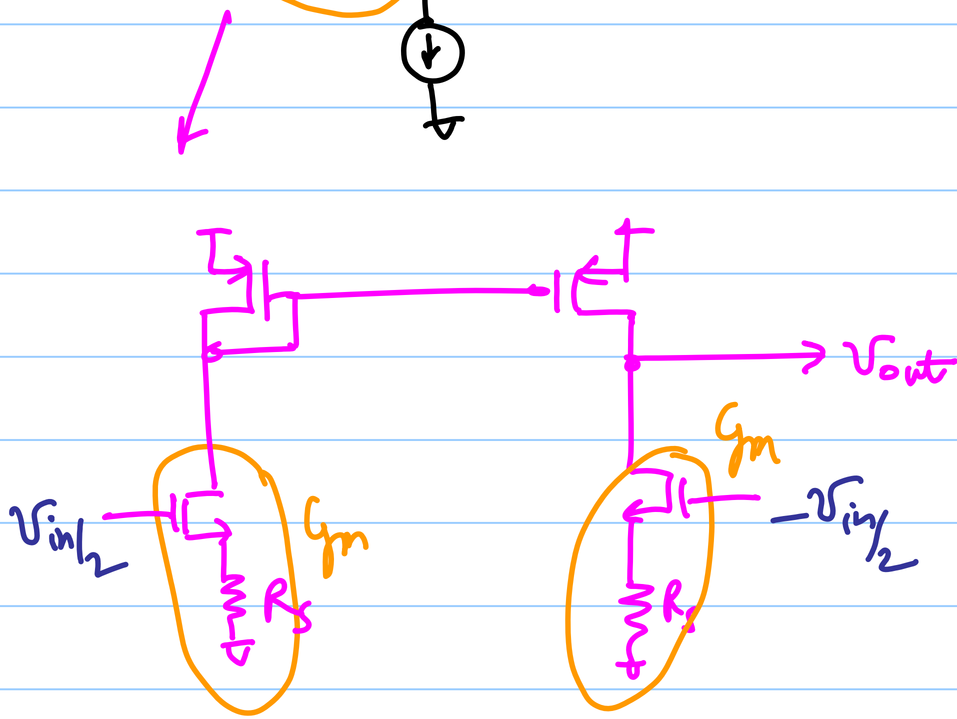
$$\mathrm{CMRR} = \left| \frac{A_{v,DM}}{A_{v,CM}} \right| = g_{m1,2}\left(r_{o1,2} \parallel r_{o3,4}\right) \cdot 2\, g_{m3,4} \cdot R_{SS}$$

$$\triangleq g_m r_o{}^2 \cdot 2 \cdot g_m R_{SS}$$

$$= \underline{\underline{2 g_m{}^2 r_o{}^2 R_{SS}}}$$



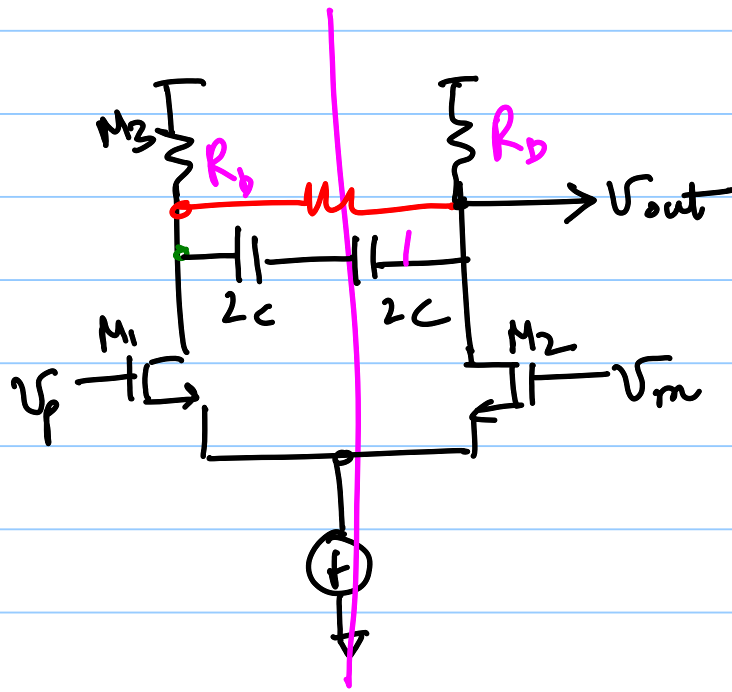




Half Circuit is

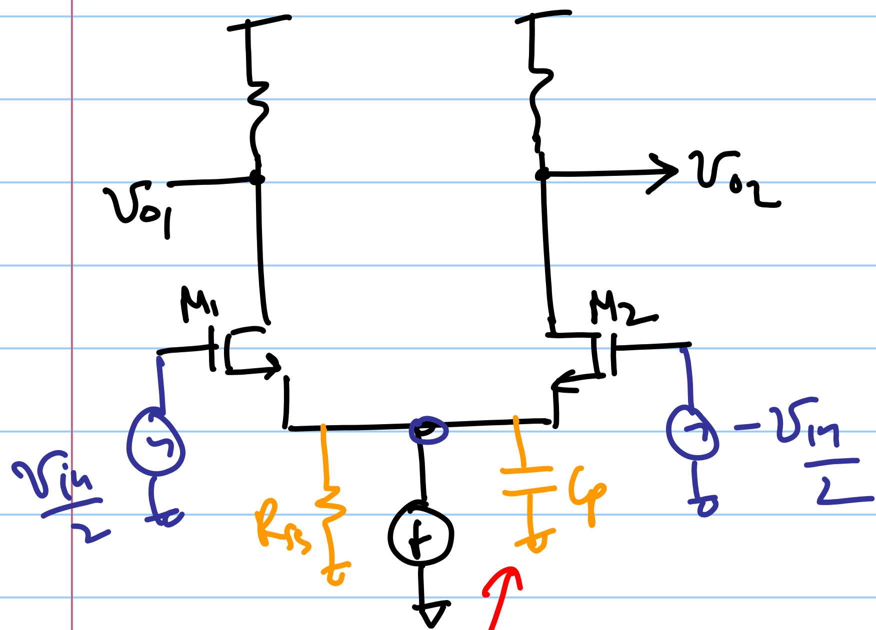
CS + Source

Degeneration

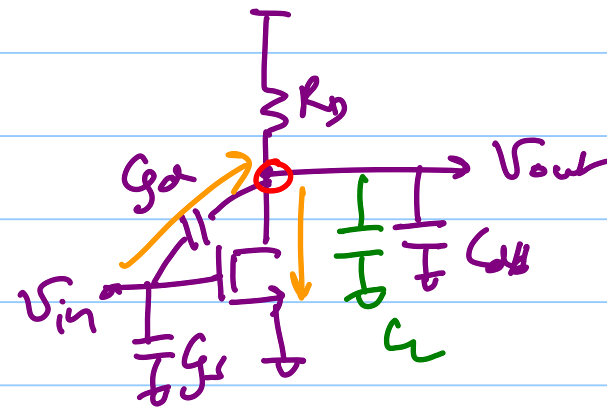

M3
RD
RD
Vout
2C
2C
M1
M2
Vp
Vn

Frequency Response

DM Analysis



DM Half Circuit



@ HF C_p shorts

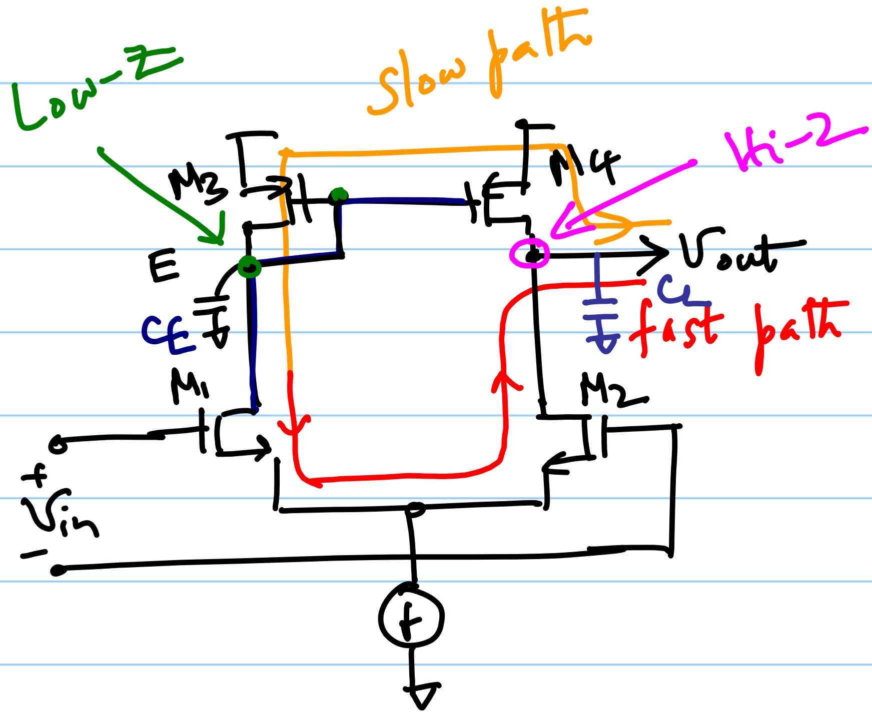
@ HF CMRR degrades

$g_{m1/2}R_D$

$+\frac{g_{m1/2}}{C_{gd1/2}}$

$$\frac{v_{out}}{v_{in}}(s) = -\frac{A_{v0}\left(1 - s/\omega_z\right)}{\left(1 + s/\omega_{p1}\right)}$$

$$\frac{1}{(r_o \| R_D)\,C_L}$$



Two signal paths to the output

↳ different transfer function

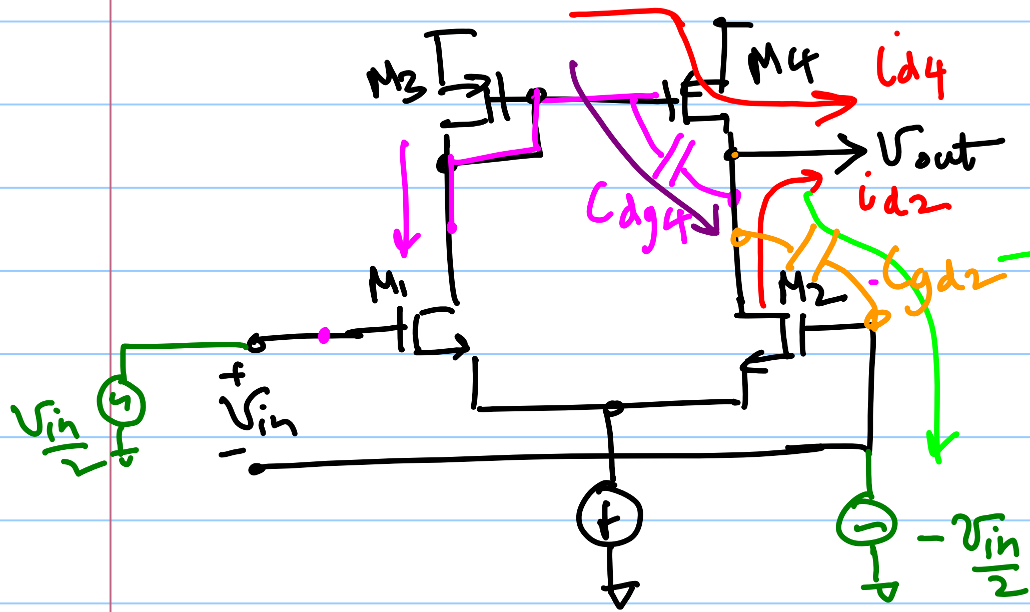
pole at node E

$\Rightarrow \omega_{p2} \simeq \dfrac{g_{m3}}{C_E}$ HF pole

Mirror pole

$$\omega_{p1} \simeq \frac{1}{(r_{o2} \| r_{o4}) C_L}$$

currents due to the $g_m v_{in}$



$\boxed{C_{gd1}}$ fast path

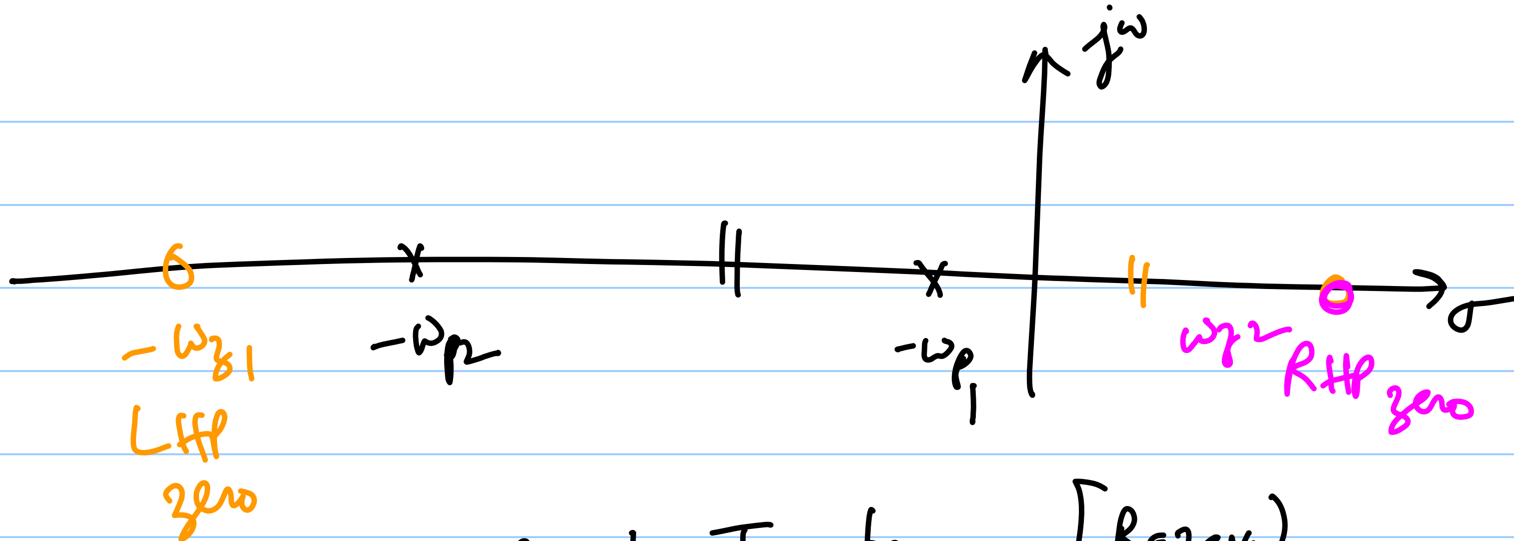
i_{d2} and $i_{ff,Cgd2}$ add in opposite signs at the output

$\Rightarrow$ RHP zero

$\boxed{C_{dg4}}$ slow path

i_{d4} & i_{ff} add with the same sign

$\Rightarrow$ LHP zero



Solving Exact Tr. fn [Razavi]

$$\omega_{p_1} = \frac{1}{(r_{op} \| r_{on})\, C_L}$$

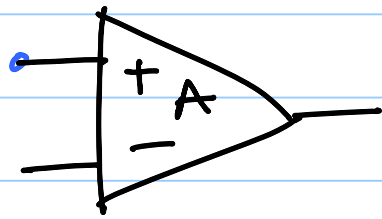
$$\omega_{p_2} \simeq \frac{g_{mp}}{C_E}$$

$$\omega_{z_2} = +\frac{g_{mn}}{C_{gd_1}} \quad \text{(RHP zero)}$$

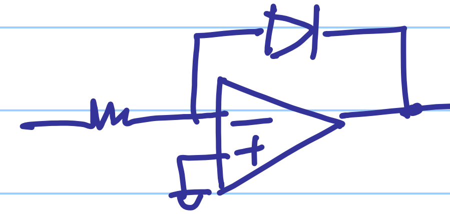
$$\boxed{\omega_{z_1} = -\frac{2 g_{mp}}{C_E} \quad \text{(LHP zero)}}$$

Interesting!

Operational Amplifier



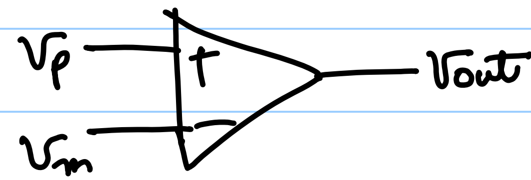
Virtual ground

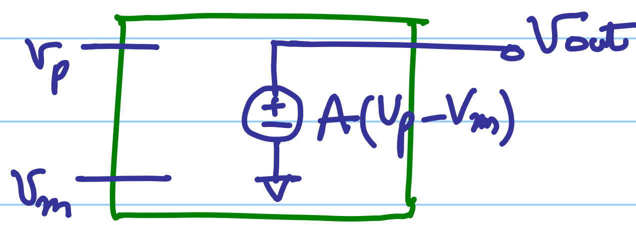


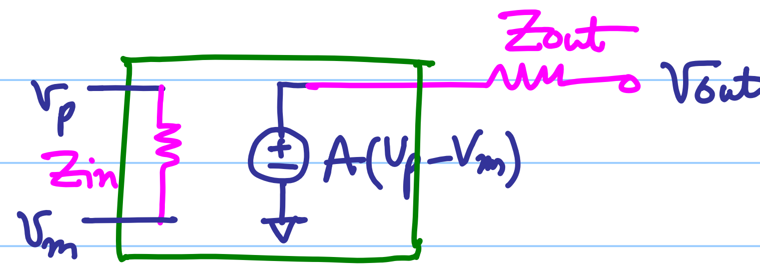
Fundamental Block

Control system

Opamp ⇒ VCVS with high gain







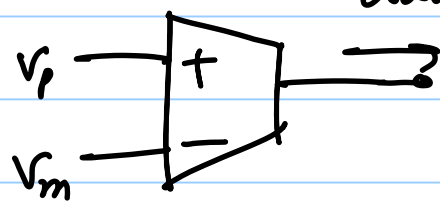
Ideal opamp

$A \to \infty$

$Z_{in} \to \infty$

$Z_{out} \to 0$

OTA : Operational Transconductance Amplifier



$i_{out} = g_m (v_p - v_m)$

VCCS
with high g_m

BJT / JFET / CMOS

* LM741 → Gray–Meyer

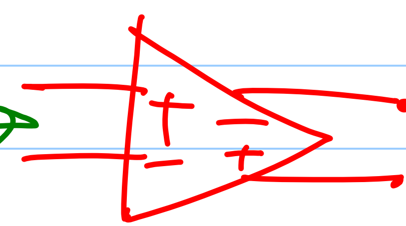
Analog IC Design (BJT)

ECE 511

On chip Opamp → Single-ended output ✓

→ fully-differential output

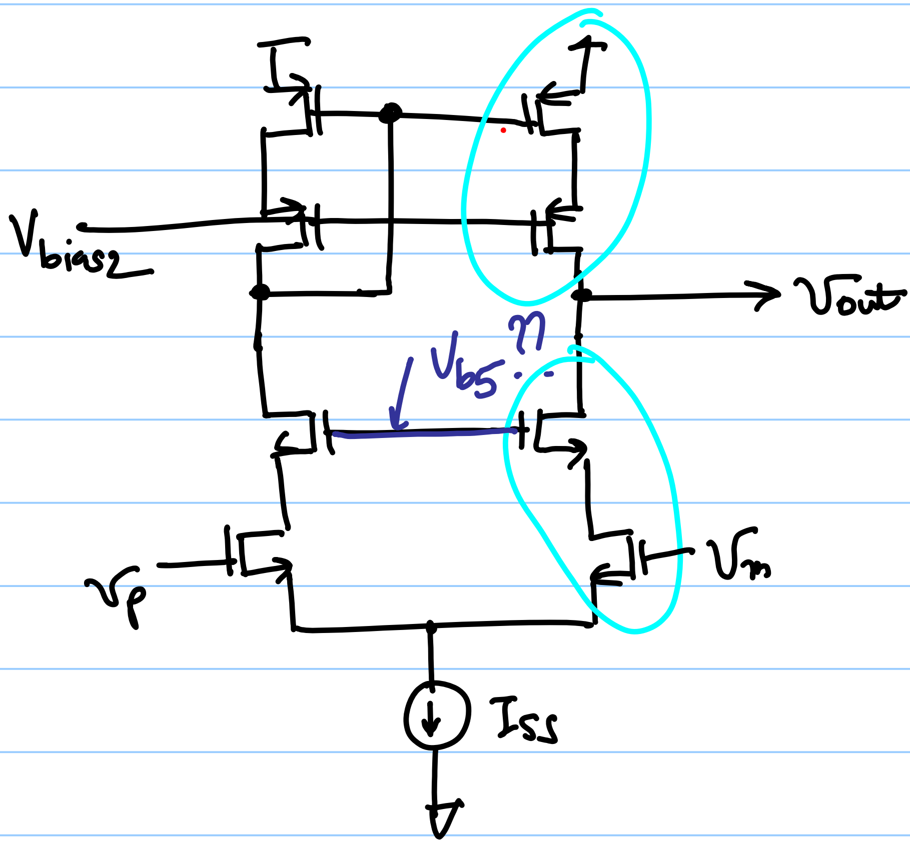
614 →



op amp

Performance Parameters :

Telescopic Diff amp
op amp
Stage



$$A_v = g_m \cdot (g_m r_o^2)_p \,||\, (g_m r_o^2)_n$$

$$\simeq g_m \cdot \left(\frac{g_m r_o^2}{2}\right)$$

$$= g_m^2 \frac{r_o^2}{2} = \frac{1}{2}(g_m r_o)^2$$