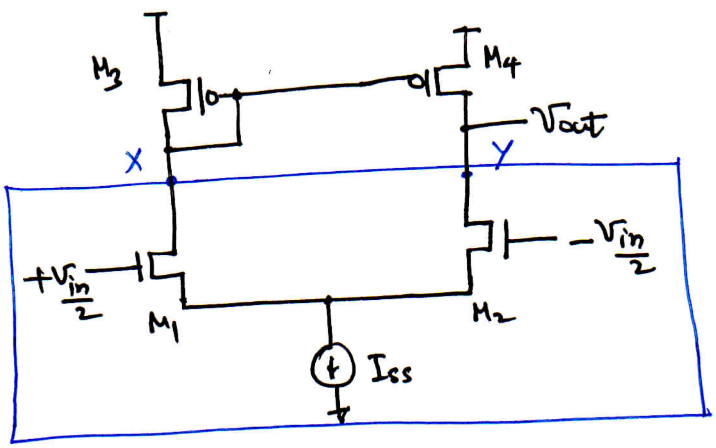
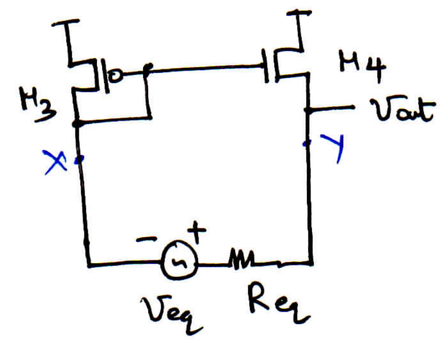
Current Mirror Load Diff-Amp

* Exact Analysis for small-signal gain:

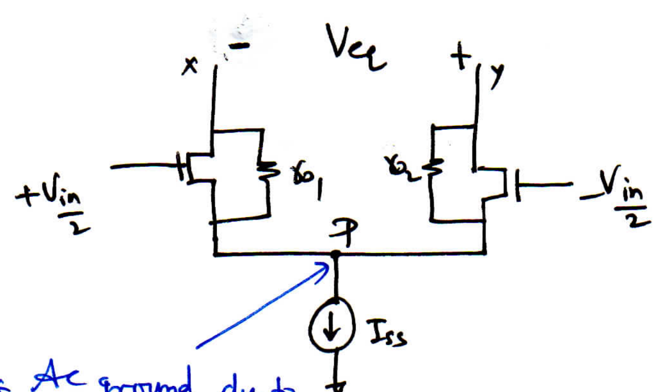
• Substitute the input diff-pair by its Thevenin Equivalent.



⇒

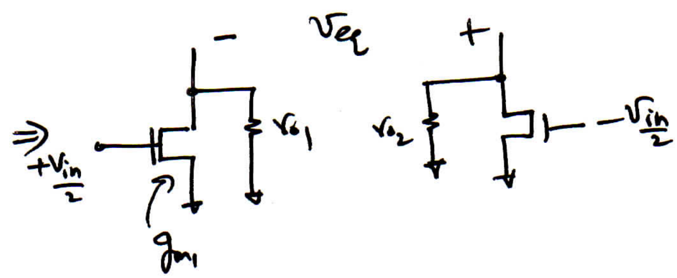


↳ Calculation of the Thevenin equivalent circuit.



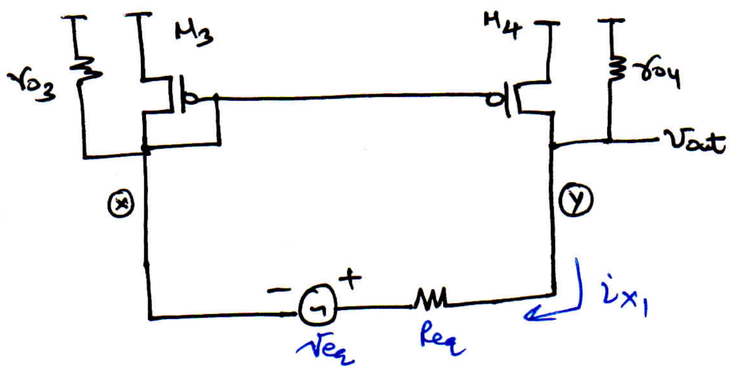
* Ac ground due to symmetry

⇒



$$\Rightarrow \quad V_{eq} = g_{m1,2} \, r_{o1,2} \, V_{in}$$

$$\& \quad R_{eq} = 2 r_{o1,2}$$



* Assuming ideal tail current source.

↳ Current through R_{eq} is $i_{x_1} = \dfrac{V_{out} - V_{eq}}{R_{eq} + \frac{1}{g_{m3}} \| r_{o3}}$

$$\Rightarrow \quad i_{x_1} = \frac{V_{out} - g_{m1,2} r_{o1,2} V_{in}}{2 r_{o1,2} + \frac{1}{g_{m3}} \| r_{o3}}$$

* The fraction of this current which flows through $1/g_{m3}$ is mirrored into M_4 with unity gain

⇒ @ node y

$$i_x \left(\frac{r_{o3}}{r_{o3} + 1/g_{m3}} \right) = - \frac{V_{out}}{r_{o4}}$$

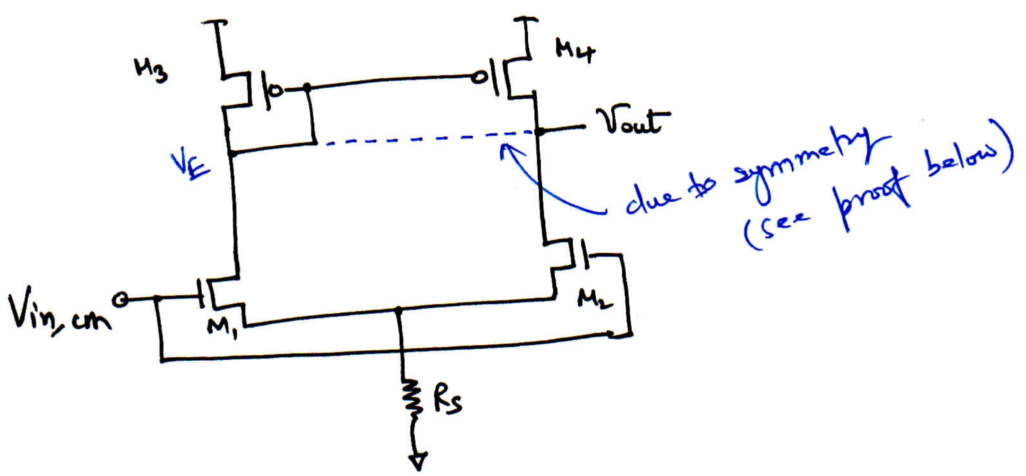
$$\Rightarrow \quad \frac{V_{out} - g_{m1,2} r_{o1,2} V_{in}}{2 r_{o1,2} + \frac{1}{g_{m3}} \| r_{o3}} \cdot \frac{r_{o3}}{r_{o3} + 1/g_{m3}} = - \frac{V_{out}}{r_{o4}}$$

Assuming $2 r_{o1,2} \gg \left(\frac{1}{g_{m3,4}} \| r_{o3,4} \right)$, we get

$$\frac{V_{out}}{V_{in}} = \frac{g_{m1,2} r_{o3,4} \cdot r_{o1,2}}{r_{o1,2} + r_{o3,4}} = g_{m1,2} \left(r_{o1,2} \| r_{o3,4} \right)$$

$$\triangleq + g_{mn} \left(r_{op} \| r_{on} \right).$$

Common Mode Properties :



We first require to prove that the circuit is symmetric for CM analysis, i.e. V_{out} tracks V_E.

Proof by Contradiction :

let $V_{out} < V_E$

↳ then due to channel length modulation, M_1 must carry greater current than M_2 ($\Rightarrow I_{D_1} > I_{D_2}$)

$\Rightarrow$ M_4 carries greater current than M_3 ($I_{D_4} > I_{D_3}$)

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

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

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

contradiction

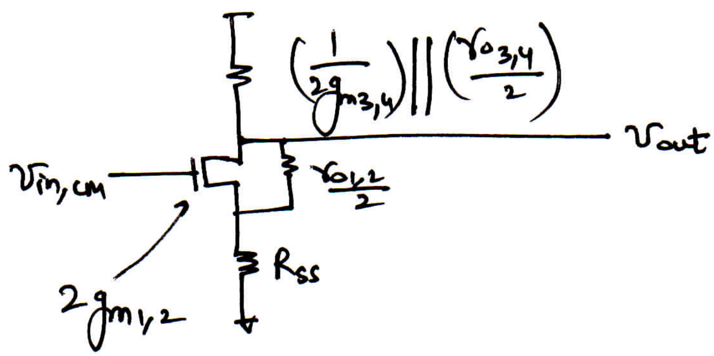
$\Rightarrow I_{D_1}$ must be equal to I_{D_2}

$\Rightarrow V_{out} = V_E = \underline{V_{DD} - V_{SG_3}}$.

* However, asymmetries in circuit may result in a large deviation in V_{out}.

↳ circuit is rarely used in open-loop.

⇒ CM Half ~~...~~ Circuit is shown below!



$$\Rightarrow \quad A_{v,CM} = \frac{-\frac{1}{2g_{m3,4}} \| \frac{r_{o3,4}}{2}}{\frac{1}{g_{m1,2}} + R_{SS}}$$

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

$$\simeq \frac{-1}{2g_{m3,4}R_{SS}}$$

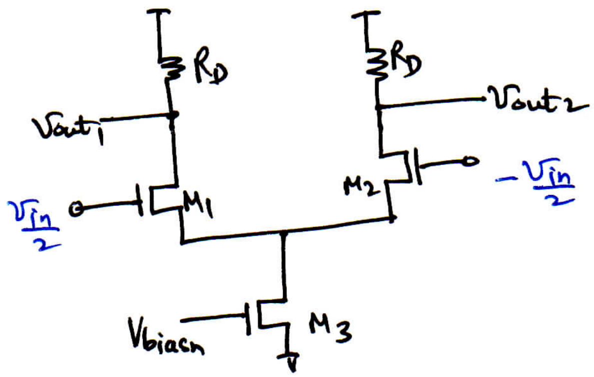
$$\Rightarrow \quad CMRR = \left| \frac{A_{v,DM}}{A_{v,CM}} \right| = g_{m1,2}(r_{o1,2} \| r_{o3,4}) \cdot 2g_{m3,4} \cdot R_{SS}$$

⇒ Even with perfect symmetry in devices the output signal is corrupted by input CM variations.

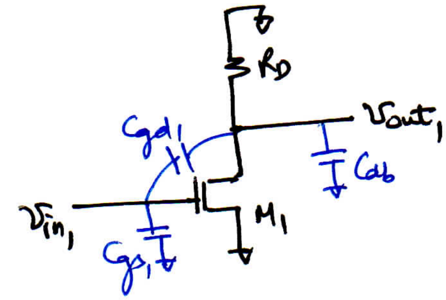
↳ This drawback doesn't exist in fully-differential devices.

Diffamp Frequency Response.

Differential mode circuit



DM Half Circuit



$\Rightarrow$ frequency response is same as the CS amplifier (with $R_S=0$).

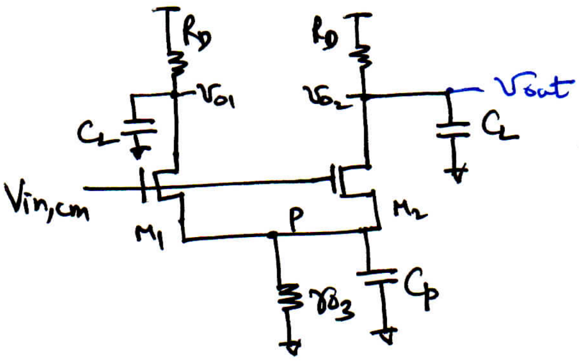
* Both the signal paths get multiplied by the same transfer-function

$\Rightarrow$ poles in $\frac{V_{out}}{V_{in}}$ are same as in each of the signal paths

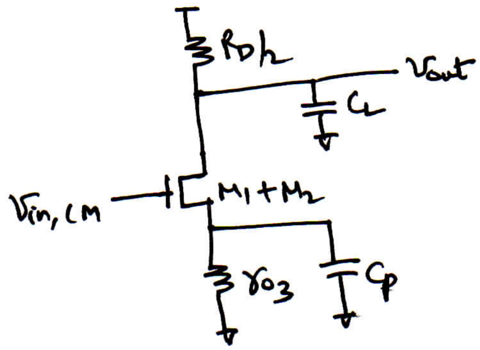
$$\Rightarrow \quad \frac{V_{out}}{V_{in}}(s) = -\frac{A_{v_0}\left(1 - s/\omega_z\right)}{\left(1 + s/\omega_{p1}\right)}$$

$$\omega_{p1} = \frac{1}{(r_o \parallel R_D)C_L}, \quad \omega_z = +\frac{g_{m1,2}}{C_{gd1,2}}$$

Common Mode Response :



$\Rightarrow$

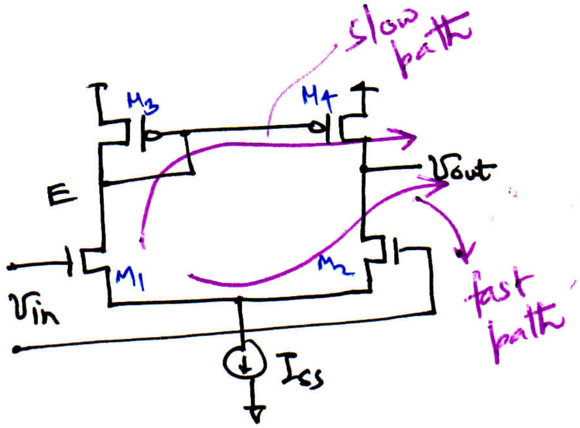


$$\Rightarrow \quad A_{v,cm}(s) = -\frac{\frac{R_D}{2} \parallel \frac{1}{sC_L}}{\frac{1}{2g_{m1,2}} + \left(r_{o3} \parallel \frac{1}{sC_p}\right)}$$

$\Rightarrow$ If the pole due to P is at lower frequency than output ω_{p1}

↳ common mode rejection degrades at high-frequencies.

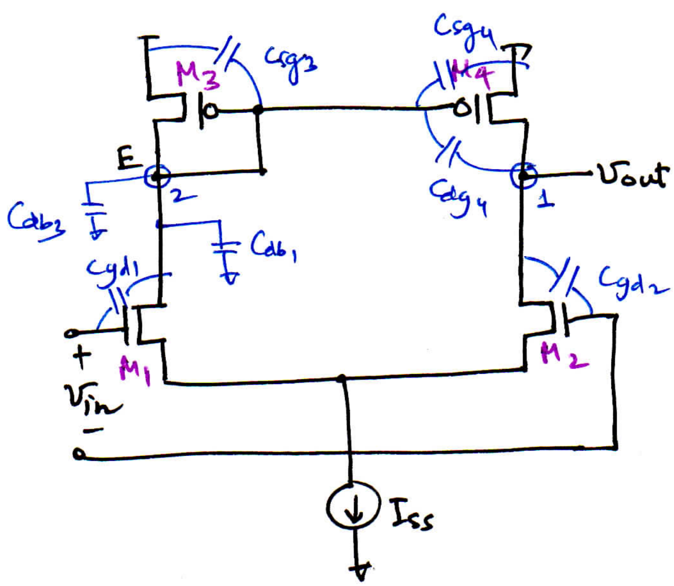
Current Mirror load Diffamp:



* The topology contains two signal paths to the output with different transfer functions.

* path $M_3-M_4 \rightarrow$ pole at node $E \Rightarrow \omega_{p2} \simeq \frac{g_{m3}}{C_E} \leftarrow$ "Mirror pole"

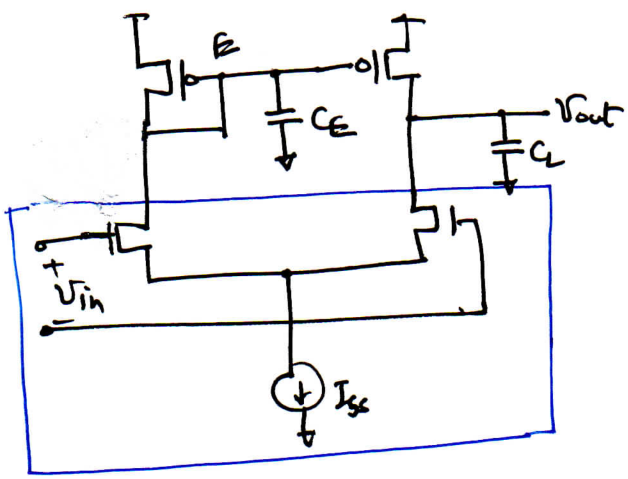
Here $C_E = C_{gs3} + C_{gs4} + C_{db3} + C_{db1} +$
+ Miller contributions from C_{gd1} & C_{gd4}



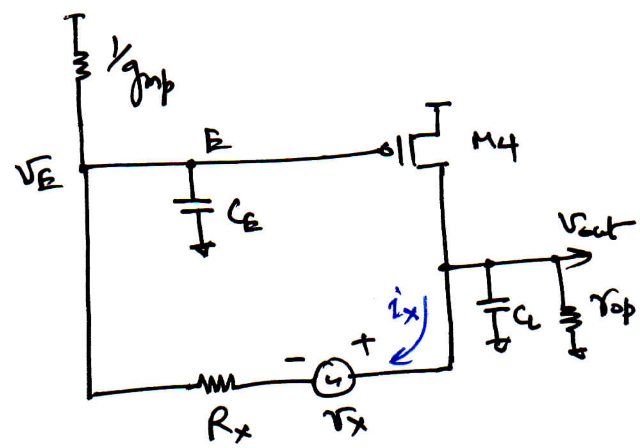
⇒ Both signal paths contain a pole at the output node ①
↳ the slow path contains extra pole at ②

⇒ Two zeros due to both the paths. RHP or LHP ??

* In order to estimate frequency response of this Diff-amp
  - ↳ 1) Replace v_{in}, M_1 & M_2 by a Thevenin Equivalent
  - 2) All other caps than C_E are ignored.
    - ↳ the RHP zero due to $C_{gd1,2}$ is not captured in this model.



⇒



Assume $1/g_{mp} \ll r_{op}$.

Here, $V_x = g_{mN} r_{on} V_{in}$

$R_x = 2 r_{on}$

$$\Rightarrow V_E = (V_{out} - V_x) \frac{\frac{1}{sC_E + g_{mp}}}{\frac{1}{sC_E + g_{mp}} + R_x}$$

$$\Rightarrow i_{d4} = g_{m4} V_E$$

Using $-g_{m4} V_E - i_x = V_{out}\left[sC_L + 1/r_{op}\right]$, we get.

$$\Rightarrow \frac{V_{out}}{V_{in}}(s) = \frac{g_{mn} r_{on} (2g_{mp} + sC_E)}{2 r_{op} r_{on} C_E C_L s^2 + [(2r_{on}+r_{op}) C_E + r_{op} (1+2g_{mp} r_{on}) C_L] s + 2g_{mp}(r_{on}+r_{op})}$$

* Since the mirror pole is typically quite higher in magnitude than the output pole (ie $|\omega_{p2}| \gg |\omega_{p1}|$), we get

$$\omega_{p1} \simeq \frac{1}{\text{Coeff}^n \text{ of } s'} = \frac{2g_{mp}(r_{on}+r_{op})}{(2r_{on}+r_{op})C_E + r_{op}(1+2g_{mp} r_{on}) C_L}$$

neglecting the first term and assuming $2g_{mp} r_{on} \gg 1$,

$$\omega_{p1} \simeq \frac{1}{(r_{on} \| r_{op}) C_L}$$

$$\omega_{p2} \simeq \frac{g_{mp}}{C_E}$$

$$\omega_{z2} = + \frac{g_{mn}}{C_{gdn}} \quad \text{(RHP zero)}$$

$$\omega_{z1} = - \frac{2g_{mp}}{C_E} \quad \text{(LHP zero)}$$ interesting!

* The origin of the LHP can be seen as follows:

The transfer functions of the slow and fast paths are given by

$$A_{slow}(s) = \frac{A_o}{(1+s/\omega_{p1})(1+s/\omega_{p2})}$$

$$A_{fast}(s) = \frac{A_o}{(1+s/\omega_{p1})}$$

→

$$\frac{V_{out}}{V_{in}}(s) = A_{slow}(s) + A_{fast}(s)$$

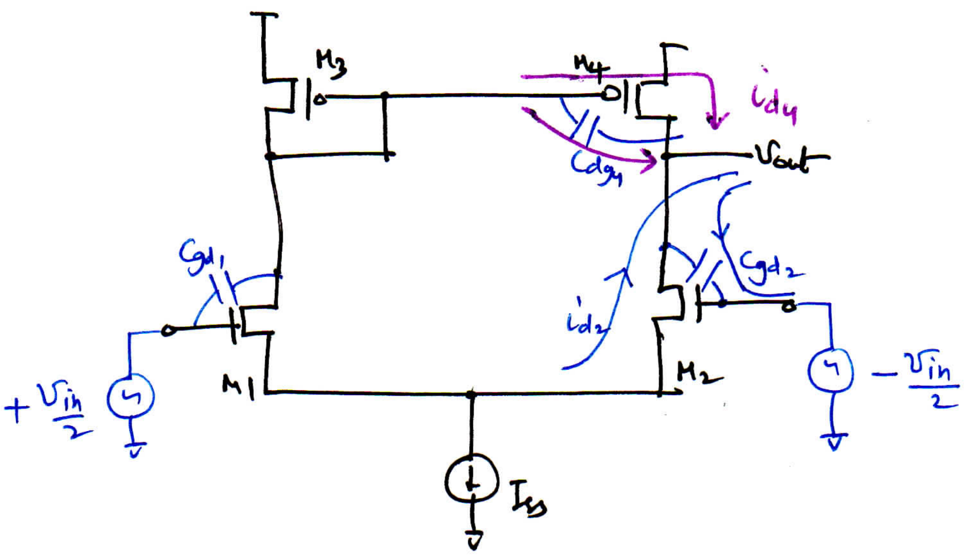
$$= \frac{A_o}{(1+s/\omega_{p1})}\left[\frac{1}{(1+s/\omega_{p2})}+1\right]$$

$$= \frac{A_o(2+s/\omega_{p2})}{(1+s/\omega_{p1})(1+s/\omega_{p2})}$$

→ The resulting system exhibits an LHP. zero at $2\omega_{p2}$

$$\omega_{z1} = -2\omega_{p2} = -\frac{2g_{mp}}{C_E}.$$

Zero Discussion !



fast path : Currents adding in opposite polarity at the output

⇒ RHP zero

slow path : Currents adding in the same polarity at the output

⇒ LHP zero !