ECE 515- lecture 21

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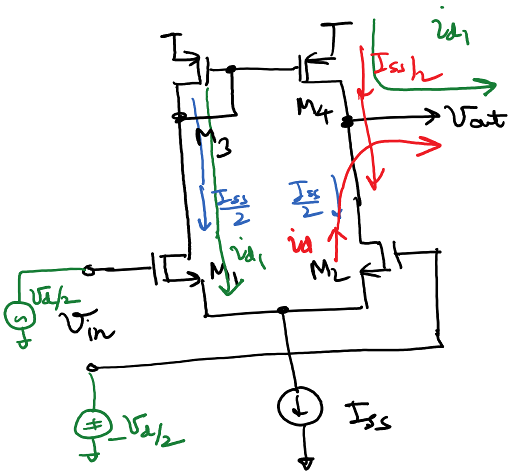
Diff-amp with Current Mirror Load

$V_{CM} \in$ ICMR of the diff amp so that all transistors are biased



Single-ended output

$i_{d_1} = g_{m_1} \frac{v_d}{2}$

$i_{d_2} = g_{m_2} \frac{v_d}{2}$

$$v_{out} = (i_{d_1} + i_{d_2}) R_{out} = \left(g_{m_1}\frac{v_d}{2} + g_{m_2}\frac{v_d}{2}\right) r_{o2} \| r_{o4}$$

$$= g_{m_{1,2}} (r_{o2} \| r_{o4}) \cdot v_d$$

$$A_{v,DM} = g_{m_{1,2}} (r_{o2} \| r_{o4})$$

contribution from two paths

* Excellent for converting differential inputs to single-ended output.

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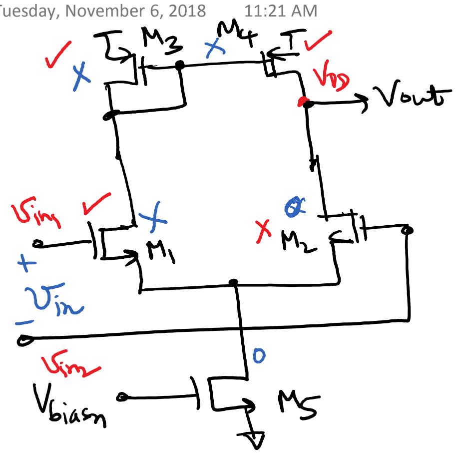

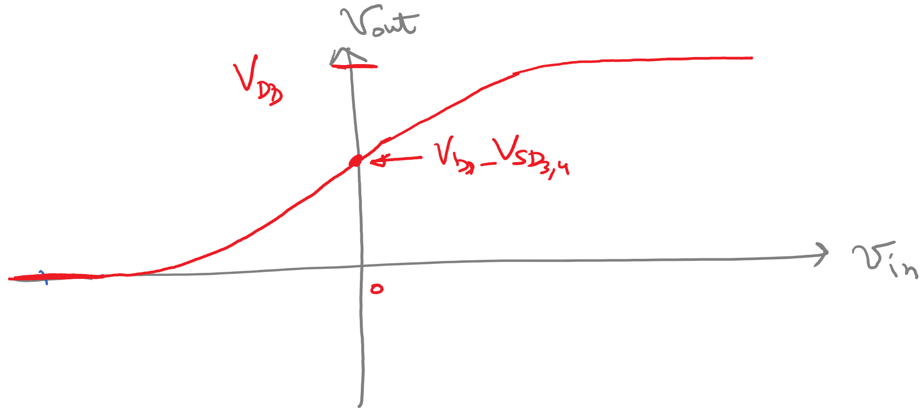

* v_{in} is large negative voltage — M_1 off ⇒ M_3 & M_4 are off; M_2 & M_5 are $V_{DS} \simeq 0$ deep triode

* v_{in} approaches 0 ⇒ V_{in_1} & V_{in_2} getting close to each other
  ↳ M_1 turns on, draws part of I_{SS} ⇒ M_3 mirrors that current
  ⇒ M_4 turns on

* $v_{in} >> 0$

$$\text{gain} = + g_{m_{1,2}} \cdot (r_{o2} \| r_{o4}) \leftarrow \frac{g_m r_o}{2}$$

Cascode will provide much higher gain

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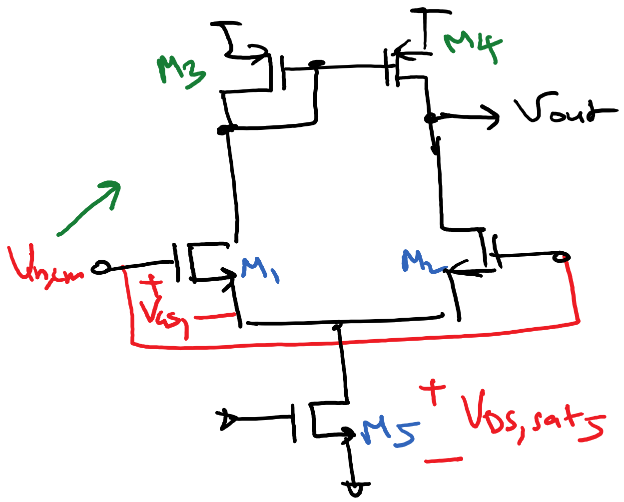

$V_{in,cm} \geq V_{GS1,2} + V_{DS,sat5}$

$\Rightarrow 2V_{DS,sat} + V_{THN}$

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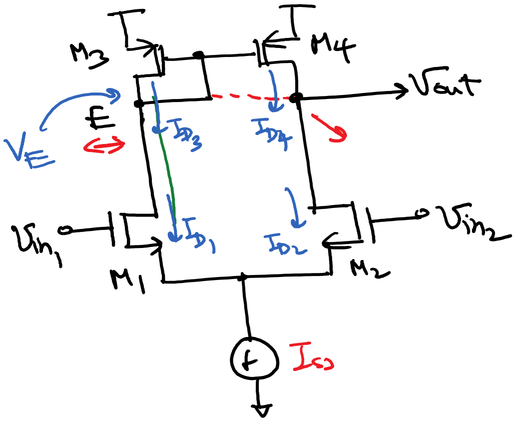


Let $V_{out} < V_E$

$\Rightarrow$ by CLM

$I_{D_1} > I_{D_2}$ $\quad (\because V_{D_3} > V_{D_2})$

$\because I_{D_3} = I_{D_1}$

I_{D_4} mirrors $I_{D_3} \Rightarrow I_{D_4} = I_{D_3}$

$\Rightarrow I_{D_2} = I_{D_4}$

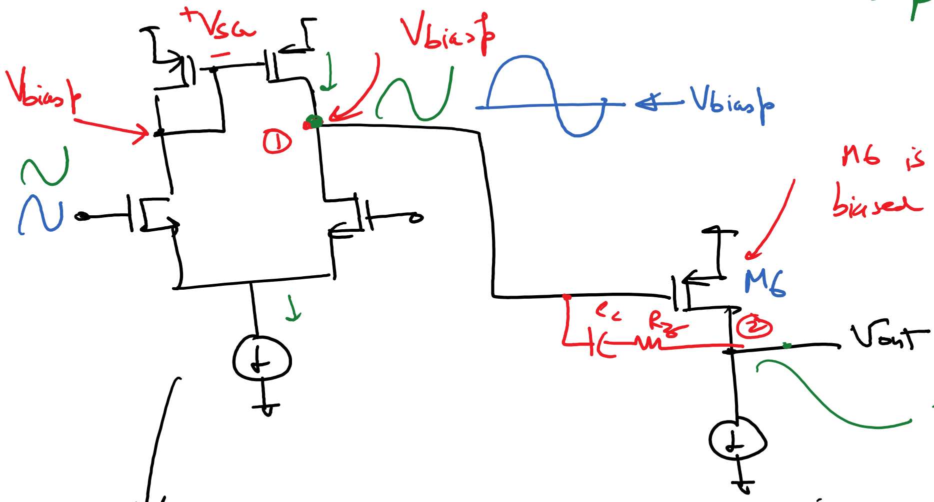
$\Rightarrow I_{D_2} > I_{D_1}$

Contradiction.

* $V_{out} \stackrel{\Delta}{=} V_E$ if no differential input is applied

Also biased at Vbias p ⇒

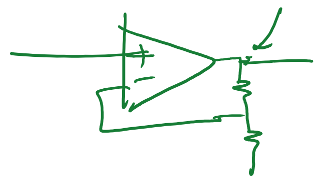
Top current source (M4) is actually dependent on Iss
↳ no current sources are fighting



M6 is properly biased

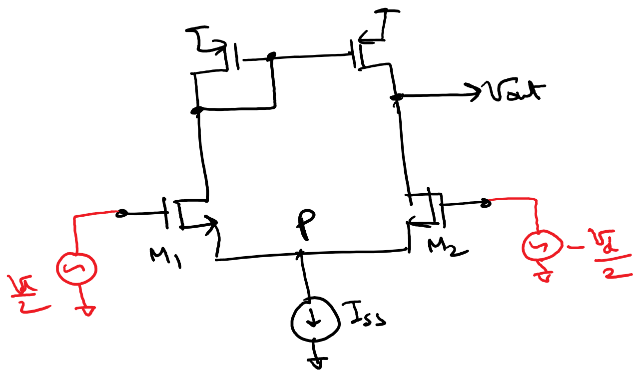
Two stage opamp

Voltage not well defined but will be biased properly in a feedback loop.



CS stage

\+ provides transfer of ac signal but also biases the second stage.
↳ Very Important!



Circuit is not symmetric

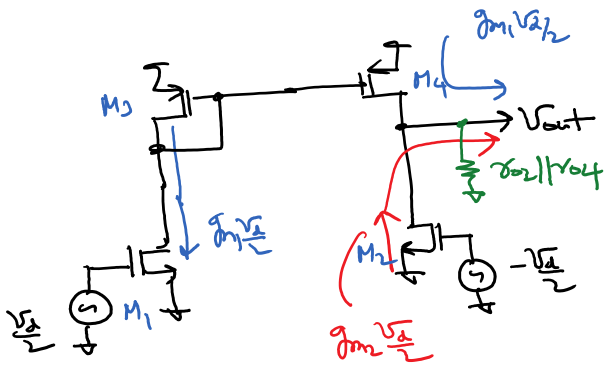
Ideally P is not AC ground in differential picture

* Detailed analysis can be performed on this circuit (see Razavi and notes)

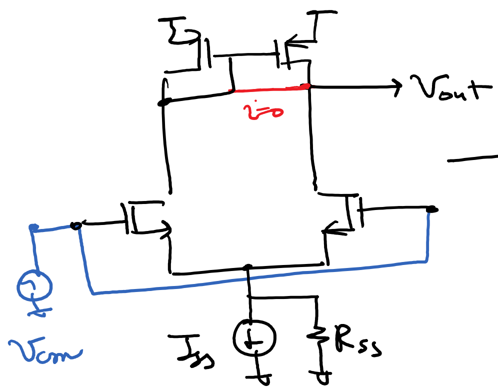
↳ Results are same (with approximations) as if P was AC ground.

* If we make the approximation that node P is AC ground.

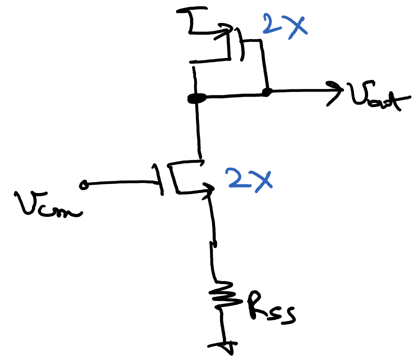
Differential Equivalent Circuit



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



fold the circuit



CS + SD

$$A_{v,cm} = -\frac{2g_{m1,2}\cdot\left(\frac{1}{2g_{m3,4}} \,\|\, r_{o1,2}\right)}{1+2g_{m1,2}\cdot R_{SS}}$$

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

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

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

$$CMRR = \left|\frac{A_{v,DM}}{A_{v,cm}}\right| = g_{m1,2}\cdot\left(r_{o2}\,\|\,r_{o4}\right)\cdot 2g_{m3,4}\cdot R_{SS}$$

better to use cascode tail current source

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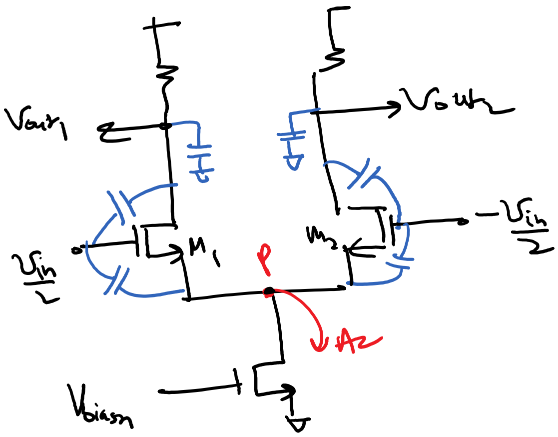
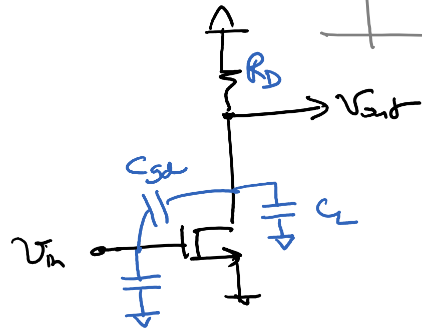
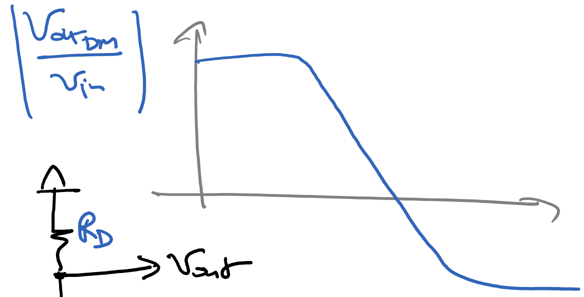
Diffamp Frequency Response:



$\Rightarrow$





1-pole
1-zero

$\because R_S = 0 \Rightarrow$ no input pole

$$\omega_p \simeq \frac{1}{(R_D \| r_o)\left[C_L + C_{gd}\right]}$$

$$\omega_z = +\frac{g_m}{C_{gd}}$$ RHP zero

* Can also look at CM frequency response $\Rightarrow$ CMRR degrades with frequency

* Diffamp Response $\Rightarrow$ Half circuit frequency response
  ↳ symmetry

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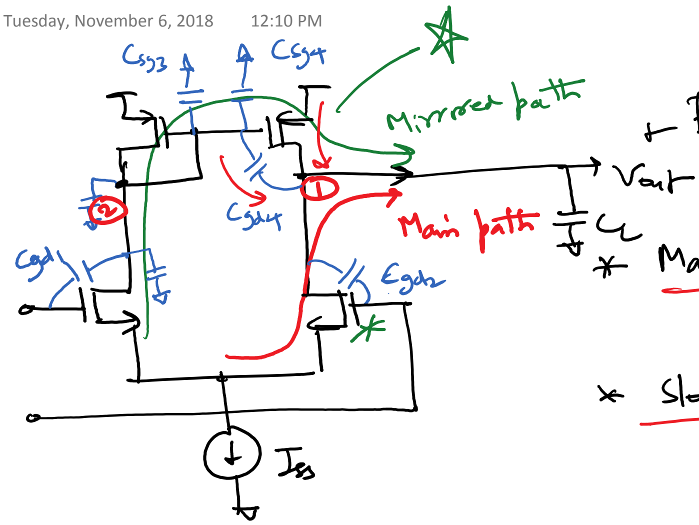

→ Both paths have different transfer functions

* Main path (fast path) contains a pole at node ①

* Slow path contains two poles
↳ one at node ① and a "Mirror pole" at node ②

* Two zeros as well due to C_{gd2} & C_{gd4}

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

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

* $\omega_{z_2} = + \dfrac{g_{mn}}{C_{gd,n}}$ (RHP zero)

* $\omega_{z_1} = -2\dfrac{g_{mp}}{C_E}$ (LHP zero)
↳ Interesting!