Lecture 17

VE 311 Analog Circuits

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Recap of Last Lecture

- Source Follower
- Emitter Follower
- Common Gate

Topics to be Covered

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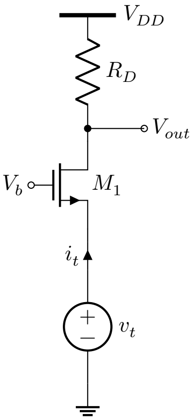
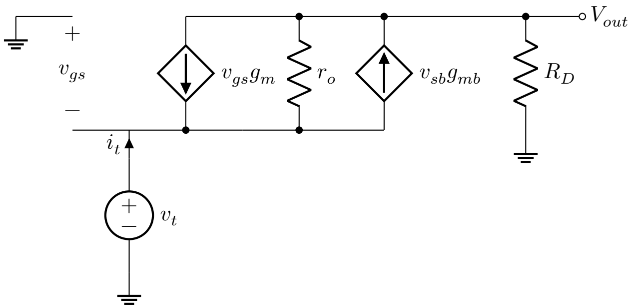
- Common Gate
- Cascode
- Differential amplifier

CG Input Impedance Small-signal Analysis ($\lambda \neq 0$, $\gamma \neq 0$)





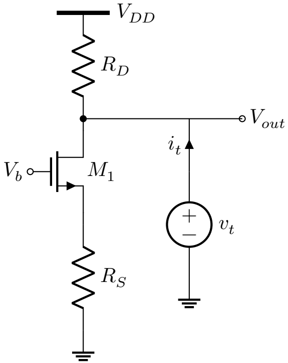
CG Input Impedance ($\lambda \neq 0$, $\gamma \neq 0$)

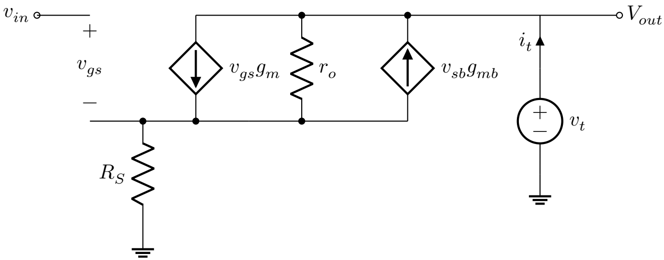
$$i_t = v_t(g_m + g_{mb}) + \frac{v_t - v_{out}}{r_O} \tag{1}$$

$$V_{out} = R_D i_t \tag{2}$$

$$R_{in} = \frac{R_D + r_o}{1 + (g_m + g_{mb})r_o} \begin{cases} \text{If } R_D = 0 & R_{in} = r_o \parallel \frac{1}{g_m} \parallel \frac{1}{g_{mb}} \\ \text{If } R_D = \infty & R_{in} = \infty \end{cases} \tag{3}$$

CG Output Impedance ($\lambda \neq 0$, $\gamma \neq 0$)



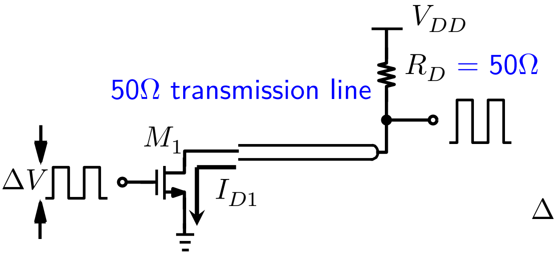


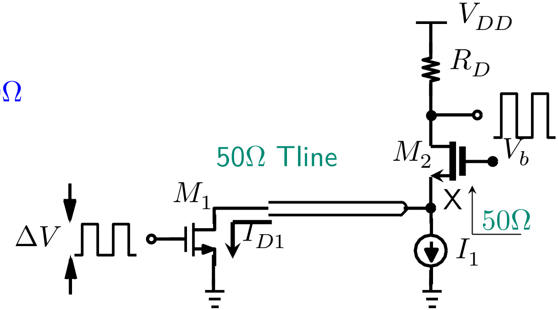
Same as CS with source degradation

$$R_{out} = [R_S + r_{o1} + (g_{m1} + g_{mb1})r_{o1}R_S] \parallel R_D \tag{4}$$

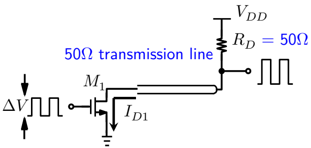
Applications of CG

Calculate the small-signal voltage gain at low frequencies of the circuits below. To minimize wave reflection at point X, the input impedance must be equal to 50Ω.

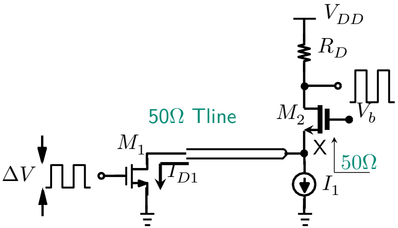




Applications of CG



$$A_v = -g_{m1} R_D \tag{5}$$



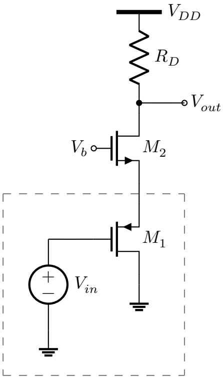
$$A_v = -g_{m1} R_D \tag{6}$$

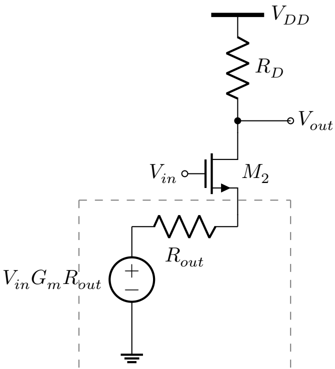
R_D can be much larger than 50Ω, so as to achieve a much higher gain.

$$R_{in} = \frac{R_D + r_{o2}}{1 + (g_{m2} + g_{mb2}) r_{o2}} = 50\Omega \tag{7}$$

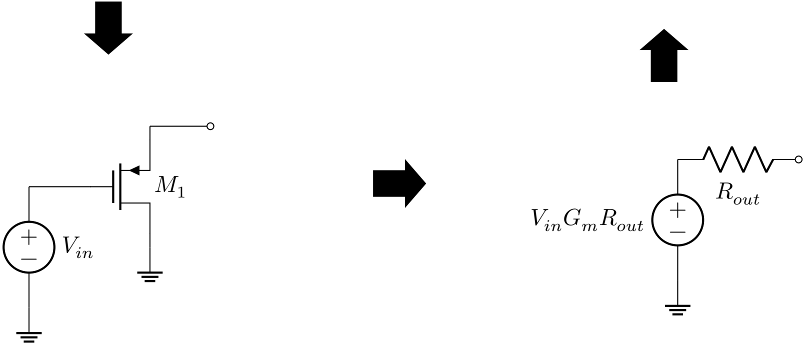
CG Example

Calculate the small-signal voltage gain of the circuit below. $(\lambda \neq 0, \gamma \neq 0)$





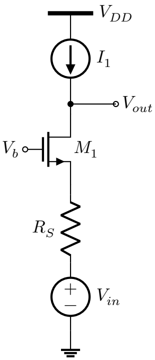
CG Example

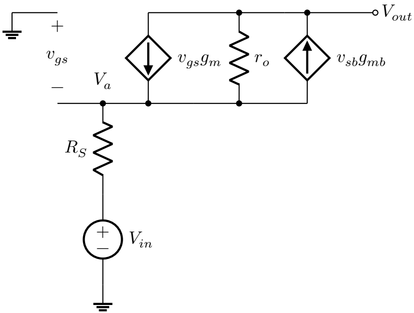


$$\begin{cases} G_m = & g_{m1} \\ R_{out} = & r_{o1} \parallel \frac{1}{g_{m1}} \parallel \frac{1}{g_{mb1}} \end{cases} \tag{8}$$

Example

Calculate the small-signal voltage gain of the circuit below. $(\lambda \neq 0, \gamma \neq 0)$





Since no current flowing in R_S, $V_a = V_{in}$

Example

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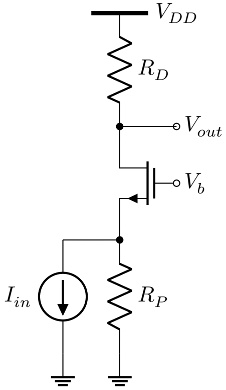
$$V_{out} - V_{in}(g_m + g_{mb})r_o = V_{in} \tag{9}$$

$$A_v = \frac{V_{out}}{V_{in}} = 1 + (g_m + g_{mb})r_o \tag{10}$$

Example

Calculate the small-signal trans-impedance gain of the circuit below. $(\lambda \neq 0, \gamma \neq 0)$



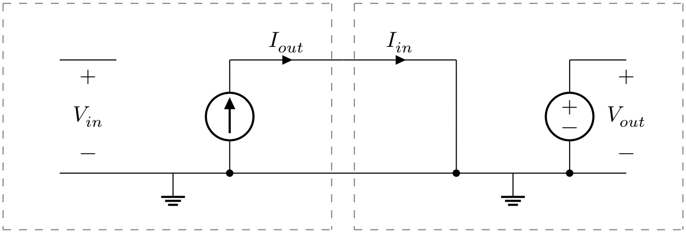
$$R_{in} = \frac{R_D + r_o}{1 + (g_m + g_{mb})r_o} \tag{11}$$

$$-i_{in}\frac{R_P}{R_{in} + R_P}R_D = V_{out} \tag{12}$$

$$\frac{V_{out}}{i_{in}} = -\frac{R_P}{R_{in} + R_P}R_D \tag{13}$$

$$= \frac{-R_P R_D[1 + (g_m + g_{mb})r_o]}{R_D + r_o + R_P + (g_m + g_{mb})r_o R_P} \tag{14}$$

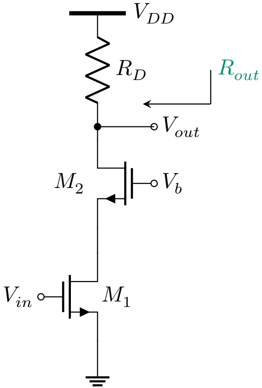
Cascode



Common-Source   Common-Gate + Source Follower

Cascode is a common gate on top of a common source.

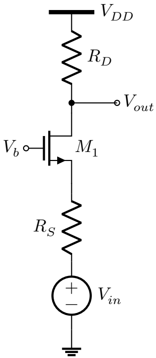
CS + CG with Resistive Load ($\lambda \neq 0$, $\gamma \neq 0$)



$$G_m = -g_{m1} \frac{r_{o1}}{r_{o1} + \left(r_{o2} \parallel \frac{1}{g_{m2}+g_{mb2}}\right)} \tag{15}$$

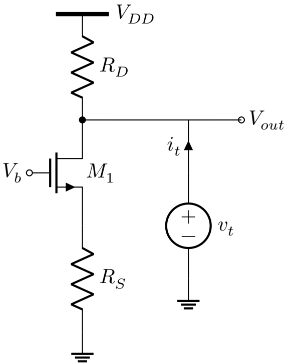
$$R_{out} = [r_{o1} + r_{o2} + (g_{m2} + g_{mb2}) r_{o2} r_{o1}] \parallel R_D \tag{16}$$

CS + CG with Resistive Load ($\lambda \neq 0$, $\gamma \neq 0$)



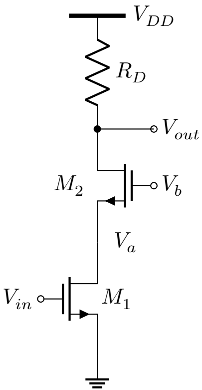
$$G_m = \frac{(g_m + g_{mb})r_{o1} + 1}{r_{o1} + R_S + (g_m + g_{mb})r_{o1}R_S} \tag{17}$$

CS + CG with Resistive Load ($\lambda \neq 0$, $\gamma \neq 0$)



$$R_{out} = [R_S + r_{o1} + (g_{m1} + g_{mb1})r_{o1}R_S] \parallel R_D \tag{18}$$

CS + CG with Resistive Load ($\lambda \neq 0$, $\gamma \neq 0$)



$$A_v = G_m R_{out} \tag{19}$$

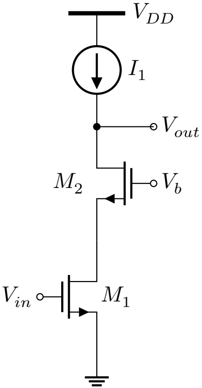
$$V_a \geqq V_{in} - V_{TH1} \tag{20}$$

$$V_b - V_{GS2} \geqq V_{in} - V_{TH1} \tag{21}$$

$$V_b \geqq V_{in} - V_{TH1} + V_{GS2} \tag{22}$$

$$V_{out} \geqq V_b - V_{TH2} \geqq (V_{in} - V_{TH1}) + (V_{GS2} - V_{TH2}) \tag{23}$$

CS + CG with Ideal Current Source ($\lambda \neq 0$, $\gamma \neq 0$)



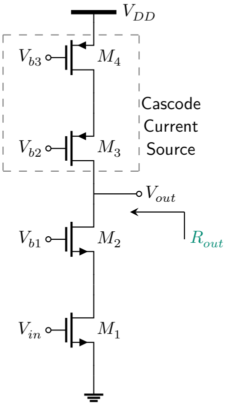
$$V_{DD} \geqq V_{out} \geqq V_{ov1} + V_{ov2} \tag{24}$$

$$G_m = -g_{m1} \frac{r_{o1}}{r_{o1} + \left(r_{o2} \parallel \frac{1}{g_{m2}+g_{mb2}}\right)} \tag{25}$$

$$R_{out} = r_{o1} + r_{o2} + (g_{m2} + g_{mb2}) r_{o2} r_{o1} \tag{26}$$

$$A_v = G_m R_{out} \tag{27}$$

CS + CG with Ideal Current Source ($\lambda \neq 0$, $\gamma \neq 0$)



$$G_m = -g_{m1} \frac{r_{o1}}{r_{o1} + \left(r_{o2} \parallel \frac{1}{g_{m2} g_{mb2}}\right)} \tag{28}$$

$$R_{out} = [r_{o1} + r_{o2} + (g_{m2} + g_{mb2}) r_{o2} r_{o1}] \parallel [r_{o3} + r_{o4} + (g_{m3} + g_{mb3}) r_{o3} r_{o4}] \tag{29}$$

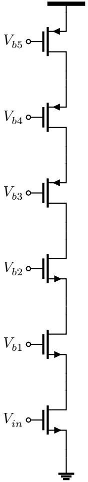
$$A_v = G_m R_{out} \tag{30}$$

$$V_{DD} - V_{ov3} - V_{ov4} \geqq V_{out} \geqq V_{ov1} + V_{ov2} \tag{31}$$

CS + CG with Ideal Current Source

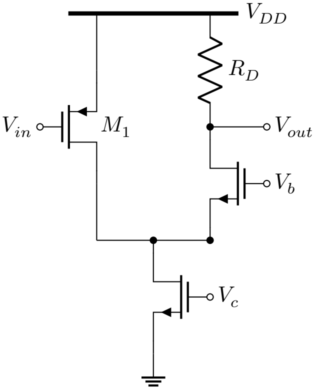
Can we cascode more to get higher gain?
Problems:

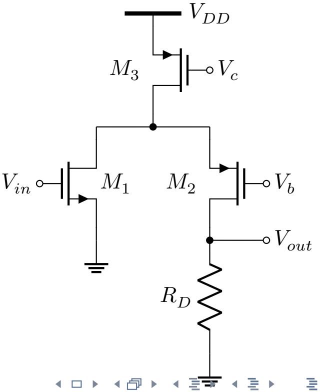
1. Headroom
2. nA of current makes it sensitive towards leakage, PVT, noise
3. Because how output impedance scales, you will only see triple cascode in MOSFET but not in BJT.



Folded Cascode ($\lambda \neq 0$, $\gamma \neq 0$)

We don't care about M_3's non-ideality.





Folded Cascode ($\lambda \neq 0$, $\gamma \neq 0$)

$$G_m = -g_{m1} \frac{(r_{o1} \parallel r_{o3})}{(r_{o1} \parallel r_{o3}) + \left(r_{o2} \parallel \frac{1}{g_{m2}+g_{mb2}}\right)} \tag{32}$$

$$R_{out} = [(r_{o1} \parallel r_{o3}) + r_{o2} + (g_{m2} + g_{mb2})r_{o2}(r_{o1} \parallel r_{o3})] \parallel R_D \tag{33}$$

$$A_v = G_m R_{out} \tag{34}$$

Single-Ended vs Differential Signals

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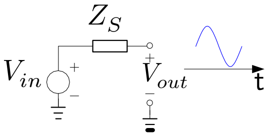
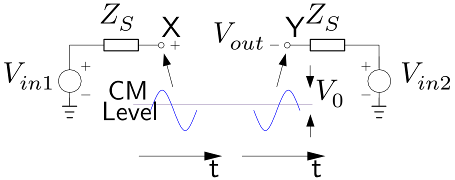
Single-ended

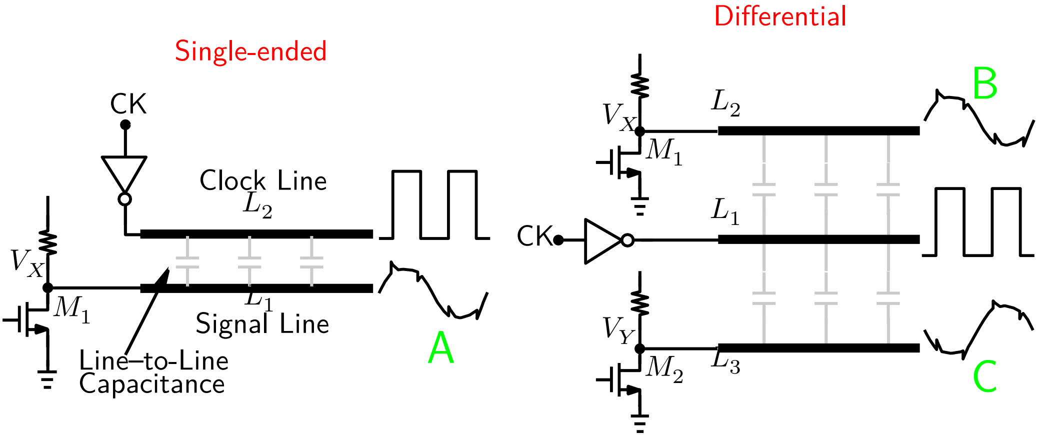


Differential



- $B - C = A$ (matters)
- $(B + C)/2 =$ common-mode level (doesn't matter)
- Single-ended signal: a voltage signal measured with respect to ground
- Differential signal: a voltage signal measured between two nodes, each having equal amplitude and opposite phase around a common-mode (CM) level

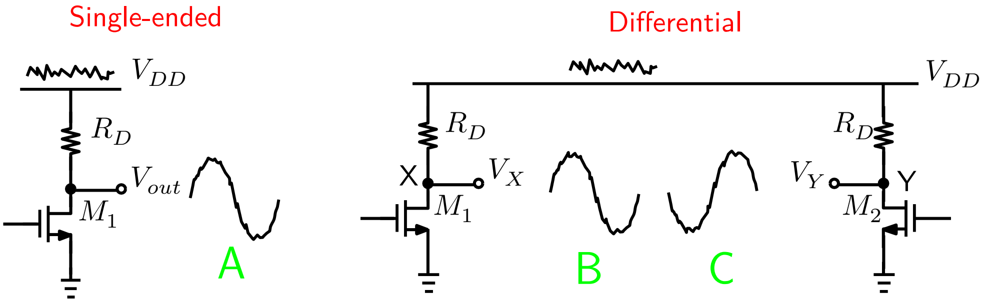
Common-Mode Noise Rejection



Common-Mode Noise Rejection

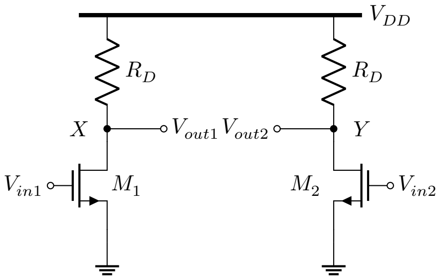
- A corrupted; B corrupted; C corrupted
- $(B + C)/2 =$ CM corrupted
- $(B - C)$ not corrupted

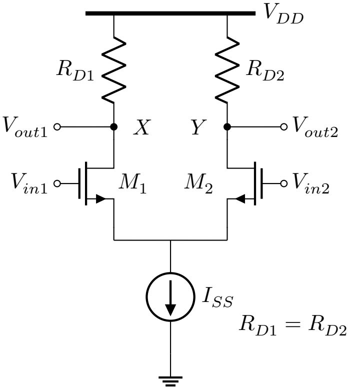
Increased Output Swing



- $(V_{GS1} - V_{TH1}) \leq A \leq V_{DD}$
- $(V_{GS1,2} - V_{TH1,2}) - V_{DD} \leq (B - C) \leq V_{DD} - (V_{GS1,2} - V_{TH1,2})$

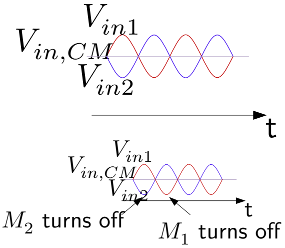
$V_{in,CM}$ and $V_{out,CM}$

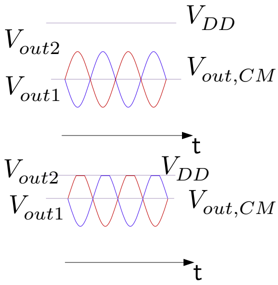




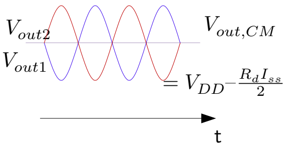
$R_{D1} = R_{D2} = R_D$

$V_{in,CM}$ and $V_{out,CM}$



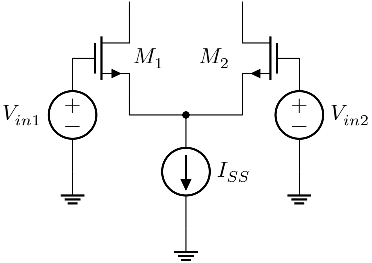


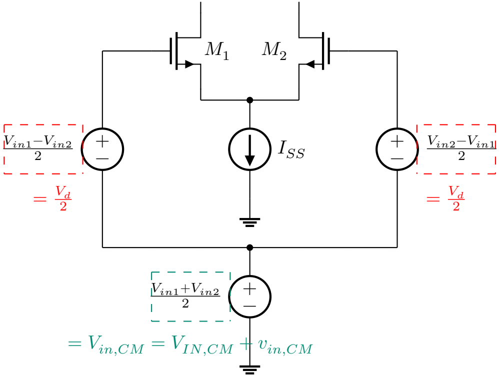
- $V_{out,CM}$ dependent on $V_{in,CM}$



- $V_{out,CM}$ independent from $V_{in,CM}$
- Better design

Common-Mode + Differential-Mode





Not necessarily fully differential

Common-Mode + Differential-Mode

$$A_{DM} = \frac{V_{out1} - V_{out2}}{V_d} \quad (35)$$

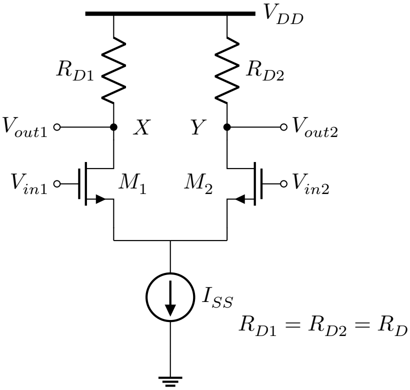
$$A_{CM} = \frac{V_{out,CM}}{V_{in,CM}} \quad (36)$$

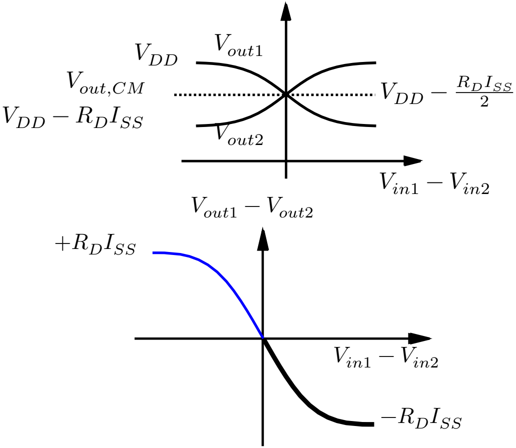
$$\Rightarrow$$

$$A_{CM-DM} = \frac{V_{out1} - V_{out2}}{V_{in,CM}} \quad (37)$$

$$CMRR = \left| \frac{A_{DM}}{A_{CM-DM}} \right| \quad (38)$$

Differential-Mode (Qualitative Analysis)





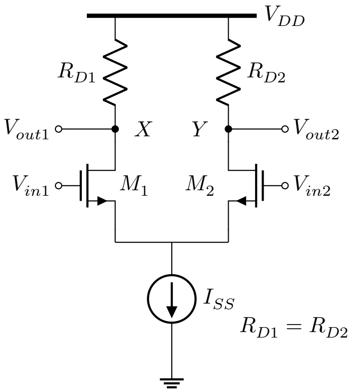
Differential-Mode (DC Analysis) ($\lambda = 0$, $\gamma = 0$)

$$V_{in1} - V_{GS1} = V_{in2} - V_{GS2} \quad (39)$$

$$V_{in1} - V_{in2} = V_{GS1} - V_{GS2} \quad (40)$$

$$= (V_{GS1} - V_{TH}) - (V_{GS2} - V_{TH}) \quad (41)$$

$$= \sqrt{\frac{2I_{D1}}{\mu_n C_{ox} \frac{W}{L}}} - \sqrt{\frac{2I_{D2}}{\mu_n C_{ox} \frac{W}{L}}} \quad (42)$$



$R_{D1} = R_{D2} = R_D$

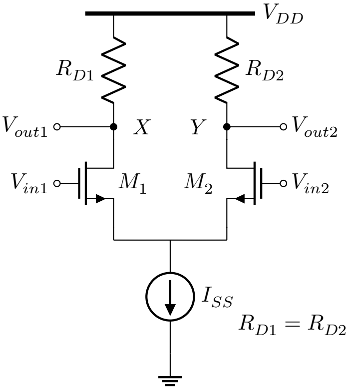
Differential-Mode (DC Analysis)

$$(V_{in1} - V_{in2})^2 \tag{43}$$

$$= \frac{2I_{D1}}{\mu_n C_{ox}\frac{W}{L}} + \frac{2I_{D2}}{\mu_n C_{ox}\frac{W}{L}} - 2\frac{\sqrt{4I_{D1}I_{D2}}}{\mu_n C_{ox}\frac{W}{L}} \tag{44}$$

$$\frac{2}{\mu_n C_{ox}\frac{W}{L}}\left(I_{SS} - 2\sqrt{I_{D1}I_{D2}}\right) \tag{45}$$

$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{in2})^2 = I_{SS} - 2\sqrt{I_{D1}I_{D2}} \tag{46}$$



$R_{D1} = R_{D2} = R_D$

Differential-Mode (DC Analysis)

$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1}-V_{in2})^2 - I_{SS} = -2\sqrt{I_{D1}I_{D2}} \tag{47}$$

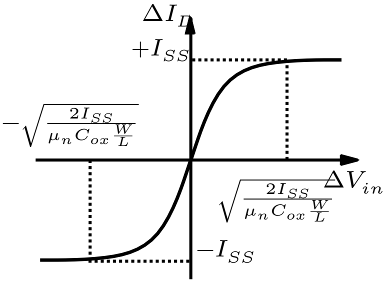
$$\frac{1}{4}(\mu_n C_{ox}\frac{W}{L})^2(V_{in1}-V_{in2})^4 + {I_{SS}}^2 - \mu_n C_{ox}\frac{W}{L}(V_{in1}-V_{in2})^2 I_{SS} = 4I_{D1}I_{D2} \tag{48}$$

$$\frac{1}{4}(\mu_n C_{ox}\frac{W}{L})^2(V_{in1}-V_{in2})^4 + I_{SS}^2 - \mu_n C_{ox}\frac{W}{L}(V_{in1}-V_{in2})^2 I_{SS} = I_{SS}^2 - (I_{D1}-I_{D2})^2 \tag{49}$$

$$\Delta I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\Delta V_{in}\sqrt{\frac{4I_{SS}}{\mu_n C_{ox}\frac{W}{L}} - {\Delta V_{in}}^2} \tag{50}$$

Differential-Mode (DC Analysis)

$$\Delta I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\Delta V_{in}\sqrt{\frac{4I_{SS}}{\mu_n C_{ox}\frac{W}{L}} - \Delta V_{in}{}^2} \tag{51}$$



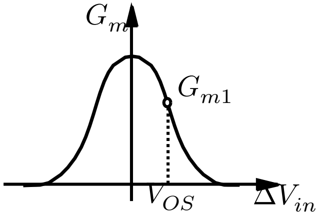
Differential-Mode (DC Analysis)

$$G_m = \frac{\partial \Delta I_D}{\partial \Delta V_{in}} \tag{52}$$

$$= \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\frac{\frac{4I_{ss}}{\mu_n C_{ox}\frac{W}{L}} - 2\Delta V_{in}^2}{\sqrt{\frac{4I_{ss}}{\mu_n C_{ox}\frac{W}{L}} - \Delta V_{in}^2}} \tag{53}$$

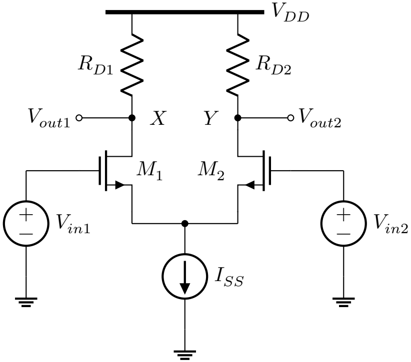
At $\Delta V_{in} = 0$,

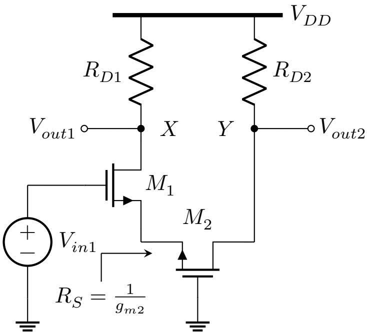
$$A_{DM} = \frac{V_{out1} - V_{out2}}{\Delta V_{in}} = -g_{m1,2}R_D \tag{54}$$



- Larger I_{SS} leads to higher G_m and wider input range.
- Smaller W/L leads to lower G_m but wider input range.

Differential-Mode (Superposition)



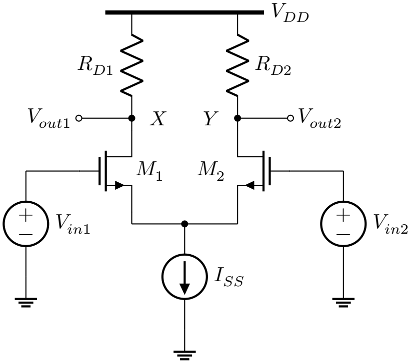


$$V_{out1} = -\frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}} V_{in1} \tag{55}$$

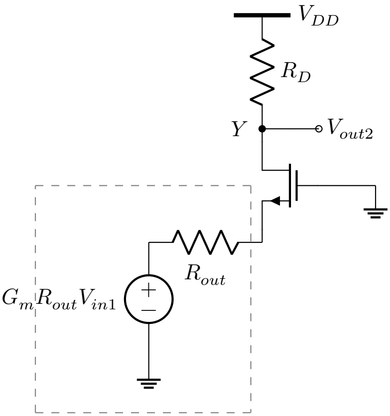
Differential-Mode (Superposition)

Small-signal Analysis

$\lambda \neq 0$
$\gamma \neq 0$



Differential-Mode (Superposition)

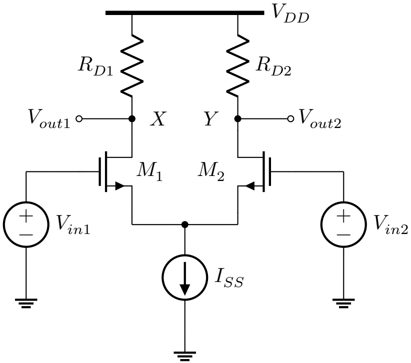


$$G_m = g_{m1} \tag{56}$$

$$R_{out} = \frac{1}{g_{m1}} \tag{57}$$

$$V_{out2} = -\frac{R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}} V_{in1} \tag{58}$$

Differential-Mode (Superposition)



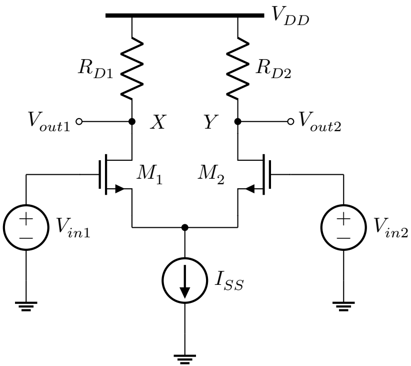
$$V_{out1} - V_{out2} = -\frac{2R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}} V_{in1} \tag{59}$$

$$= -g_m R_D V_{in1} \tag{60}$$

$$V_{out1} - V_{out2} = -\frac{2R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}} V_{in2} \tag{61}$$

$$= -g_m R_D V_{in2} \tag{62}$$

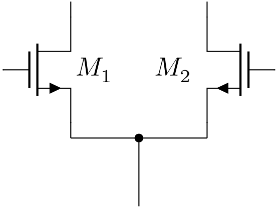
Differential-Mode (Superposition)

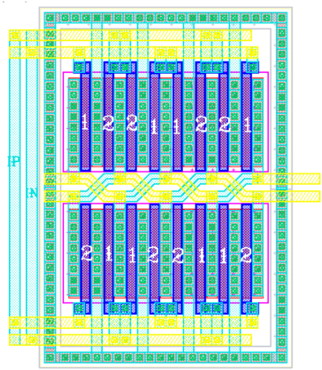


$$A_{DM} = \frac{V_{out1} - V_{out2}}{V_{in1} - V_{in2}} \tag{63}$$

$$= -g_m R_D \tag{64}$$

Differential pair





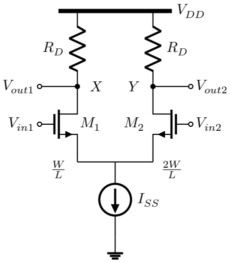
Example

Calculate the A_{DM} of the differential pair below if the biasing conditions of M_1 and M_2 are the same.

$$V_{out1} - V_{out2} = -\frac{2R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}} V_{in1} = -\frac{4}{3} g_m R_D V_{in1} \quad (65)$$

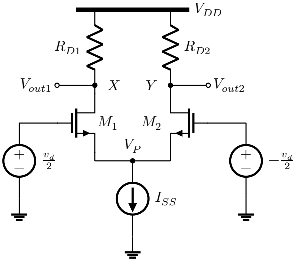
$$V_{out1} - V_{out2} = -\frac{2R_D}{\frac{1}{g_{m1}} + \frac{1}{g_{m2}}} V_{in2} = -\frac{4}{3} g_m R_D V_{in2} \quad (66)$$

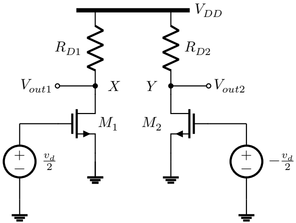
$$A_{DM} = \frac{V_{out1} - V_{out2}}{V_{in1} - V_{in2}} = -\frac{4}{3} g_m R_D \quad (67)$$



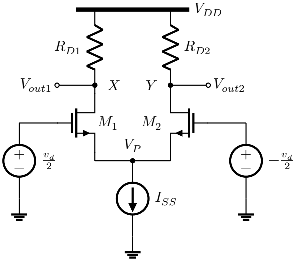
Small-Signal, Half-circuit ($\lambda \neq 0$, $\gamma \neq 0$)

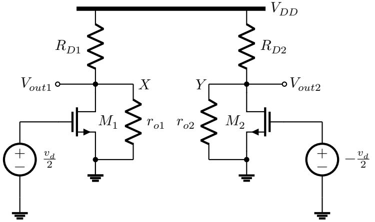
- Assume the circuit is fully symmetric.
- For $i_{d1} + i_{d2} = 0$ and $g_{m1}\frac{v_d}{2} + g_{m2}(-\frac{v_d}{2}) = 0$, V_P must be a constant voltage in DC analysis and a virtual ground in small-signal analysis.





Small-Signal, Half-circuit ($\lambda \neq 0$, $\gamma \neq 0$)





$$V_{out1} = -g_m(R_D \parallel r_o)\frac{v_d}{2} \tag{68}$$

$$V_{out2} = -g_m(R_D \parallel r_o)(-\frac{v_d}{2}) \tag{69}$$

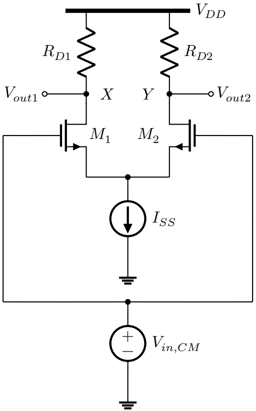
$$A_{DM} = \frac{V_{out1} - V_{out2}}{v_d} = -g_m(R_D \parallel r_o) \tag{70}$$

Common-Mode Response ($\lambda \neq 0$, $\gamma \neq 0$)

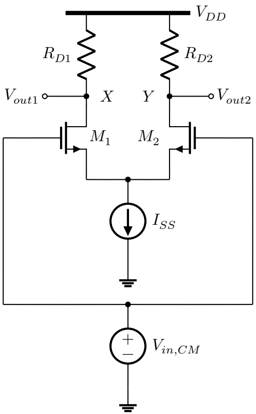
If the circuit is fully symmetric,

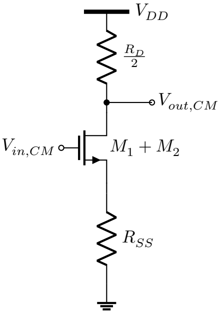
$$A_{CM-DM} = \frac{V_{out1} - V_{out2}}{v_{in,CM}} = 0 \qquad (71)$$

$$CMRR = \left| \frac{A_{DM}}{A_{CM-DM}} \right| = \infty \qquad (72)$$



Common-Mode Response ($\lambda \neq 0$, $\gamma \neq 0$)





Perturbing biasing condition $\rightarrow$ Altering transconductance (g_m)

Common-Mode Response ($\lambda \neq 0$, $\gamma \neq 0$)

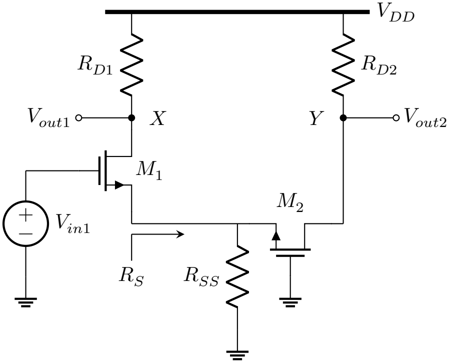
If the circuit is fully symmetric,

$$A_{CM} = \frac{V_{out,CM}}{V_{in,CM}} \tag{73}$$

$$= \frac{-2g_m \frac{r_o}{2}}{R_{SS} + \frac{r_o}{2} + (2g_m + 2g_{mb2})\frac{r_o}{2}R_{SS}} \cdot \frac{\left[R_{SS} + \frac{r_o}{2} + (2g_m + 2g_{mb})\frac{r_o}{2}R_{SS}\right]\frac{R_D}{2}}{\left[R_{SS} + \frac{r_o}{2} + (2g_m + 2g_{mb})\frac{r_o}{2}R_{SS}\right] + \frac{R_D}{2}} \tag{74}$$

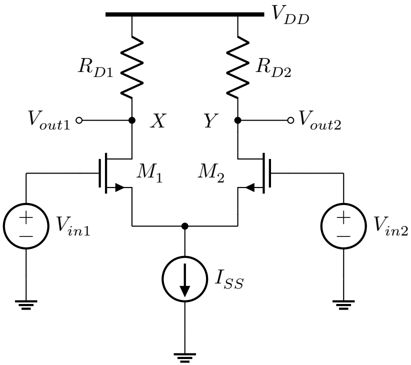
$$= 0 \quad \text{if } R_{SS} = \infty \tag{75}$$

Nonzero R_{SS} ($\lambda = 0$, $\gamma = 0$)



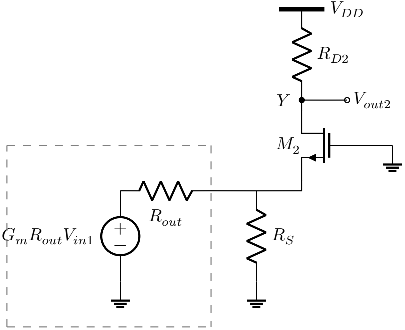
$$R_S = \frac{1}{g_{m2}} \parallel R_{SS} \tag{76}$$

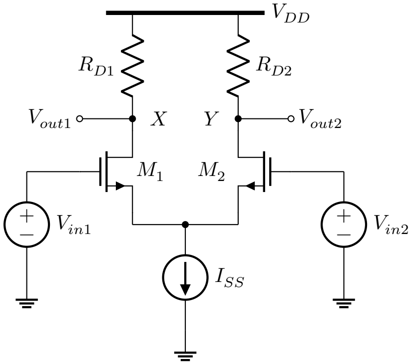
Nonzero R_{SS} ($\lambda = 0$, $\gamma = 0$)



$$V_{out1} = -\frac{R_D}{\frac{1}{g_{m1}} + \left(\frac{1}{g_{m2}} \parallel R_{SS}\right)} V_{in1} \quad (77)$$

Nonzero R_{SS} ($\lambda = 0$, $\gamma = 0$)



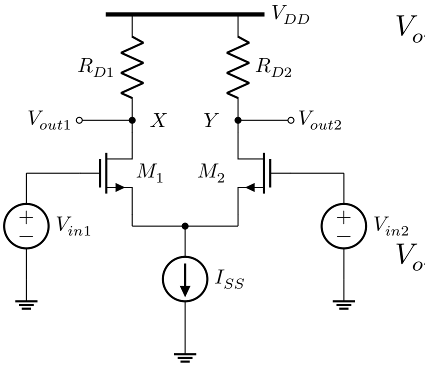


$$G_m = g_{m1} \tag{78}$$

$$R_{out} = \frac{1}{g_{m1}} \tag{79}$$

$$V_{out2} = -\frac{\frac{R_{SS}}{R_{SS}+\frac{1}{g_{m2}}} R_D}{\frac{1}{g_{m1}} + \left(\frac{1}{g_{m2}} \parallel R_{SS}\right)} V_{in1} \tag{80}$$

Nonzero R_{ss}



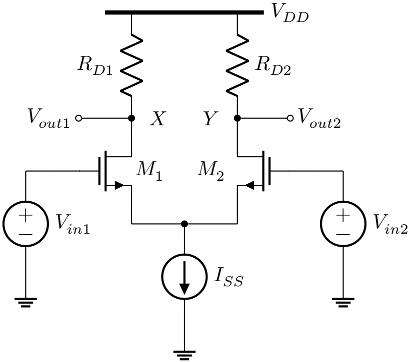
$$V_{out1} - V_{out2} = -\frac{(g_{m1} + 2R_{SS}g_{m1}g_{m2})R_D}{1 + (g_{m1} + g_{m2})R_{SS}} V_{in1} \quad (81)$$

$$= -g_m R_D V_{in1} \quad (82)$$

$$V_{out1} - V_{out2} = -\frac{(g_{m1} + 2R_{SS}g_{m1}g_{m2})R_D}{1 + (g_{m1} + g_{m2})R_{SS}} V_{in1} \quad (83)$$

$$= -g_m R_D V_{in2} \quad (84)$$

Nonzero R_{ss}



$$A_{DM} = \frac{V_{out1} - V_{out2}}{V_{in1} - V_{in2}} = -g_m R_D \qquad (85)$$

A_{DM} with MOS Loads ($\lambda \neq 0$, $\gamma \neq 0$)

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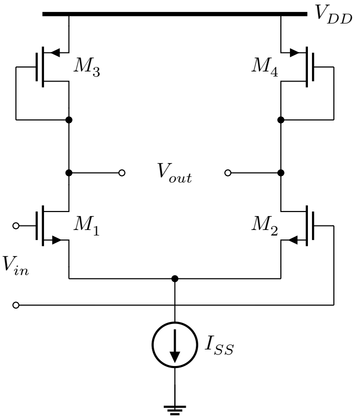
Higher A_{DM}

- $\rightarrow$ Smaller $(W/L)_P$
- $\rightarrow$ Larger $(V_{SGP}-V_{THP})$
- $\rightarrow$ Smaller $V_{in,CM}$ headroom



A_{DM} with MOS Loads ($\lambda \neq 0$, $\gamma \neq 0$)

$$V_{out1} = -g_{mN}(r_{oN} \parallel r_{oP} \parallel \frac{1}{g_{mP}})\frac{v_d}{2} \tag{86}$$

$$V_{out2} = -g_{mN}(r_{oN} \parallel r_{oP} \parallel \frac{1}{g_{mP}})(-\frac{v_d}{2}) \tag{87}$$

$$A_{DM} = \frac{V_{out1} - V_{out2}}{v_d} = -g_{mN}\left(r_{oN} \parallel r_{oP} \parallel \frac{1}{g_{mP}}\right) \tag{88}$$

$$\approx -\frac{g_{mN}}{g_{mP}} \approx -\sqrt{\frac{\mu_n (W/L)_N}{\mu_p (W/L)_P}} \tag{89}$$

A_{DM} with MOS Loads ($\lambda \neq 0$, $\gamma \neq 0$)

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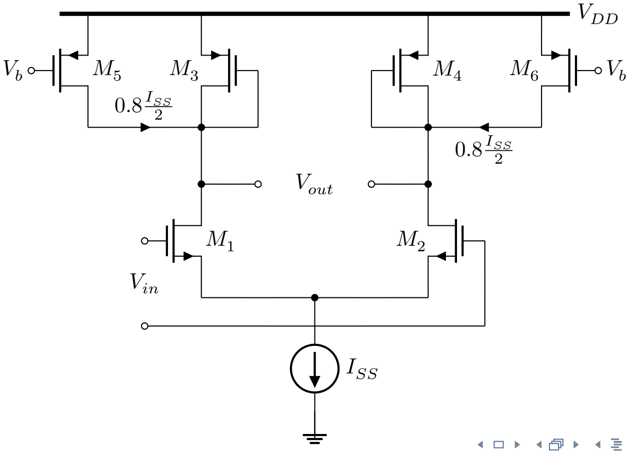


A_{DM} with MOS Loads

$$V_{out1} = -g_{m1,2}\left(r_{o1,2} \parallel r_{o3,4} \parallel \frac{1}{g_{m3,4}} \parallel r_{o5,6}\right)\frac{v_d}{2} \tag{90}$$

$$V_{out2} = -g_{m1,2}\left(r_{o1,2} \parallel r_{o3,4} \parallel \frac{1}{g_{m3,4}} \parallel r_{o5,6}\right)(-\frac{v_d}{2}) \tag{91}$$

$$A_{DM} = \frac{V_{out1} - V_{out2}}{v_d} \approx -\frac{g_{m1,2}}{g_{m3,4}} \approx -\sqrt{\frac{5\mu_n(W/L)_{1,2}}{\mu_p(W/L)_{3,4}}} \tag{92}$$

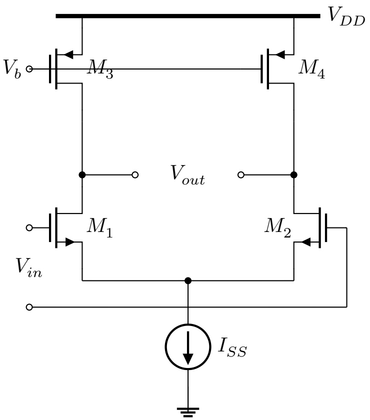
A_{DM} with MOS Loads ($\lambda \neq 0$, $\gamma \neq 0$)

$$V_{out1} = -g_{m1,2}(r_{o1,2} \parallel r_{o3,4})\frac{v_d}{2} \quad (93)$$

$$V_{out2} = -g_{m1,2}(r_{o1,2} \parallel r_{o3,4})(-\frac{v_d}{2}) \quad (94)$$

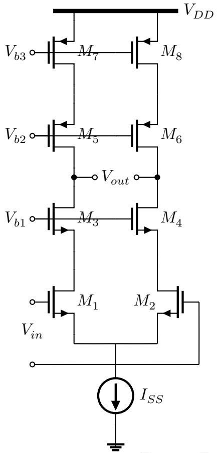
$$A_{DM} = \frac{V_{out1} - V_{out2}}{v_d} \quad (95)$$

$$= -g_{m1,2}(r_{o1,2} \parallel r_{o3,4}) \quad (96)$$



A_{DM} with MOS Loads ($\lambda \neq 0$, $\gamma \neq 0$)

Higher R_{out}
$\rightarrow$ High A_{DM}
$\rightarrow$ Small $V_{in,CM}$ headroom
Telescopic cascode



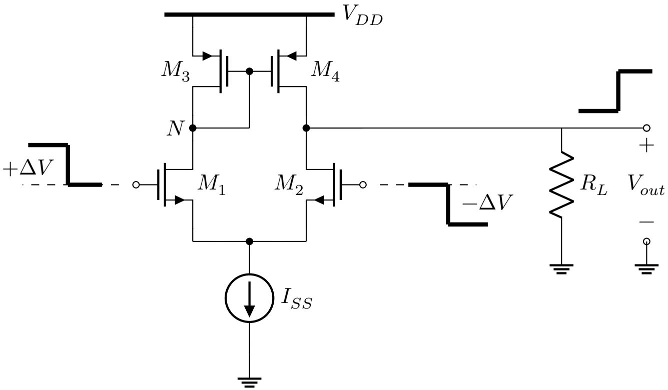
A_{DM} with MOS Loads ($\lambda \neq 0$, $\gamma \neq 0$)

$$V_{out1} \cong -g_{m1,2}\left\{[r_{o1,2} + r_{o3,4} + (g_{m3,4} + g_{mb3,4})r_{o3,4}r_{o1,2}] \parallel [r_{o7,8} + r_{o5,6} + (g_{m5,6} + g_{mb5,6})r_{o5,6}r_{o7,8}]\right\}\frac{v_d}{2} \quad (97)$$

$$V_{out2} \cong -g_{m1,2}\left\{[r_{o1,2} + r_{o3,4} + (g_{m3,4} + g_{mb3,4})r_{o3,4}r_{o1,2}] \parallel [r_{o7,8} + r_{o5,6} + (g_{m5,6} + g_{mb5,6})r_{o5,6}r_{o7,8}]\right\}(-\frac{v_d}{2}) \quad (98)$$

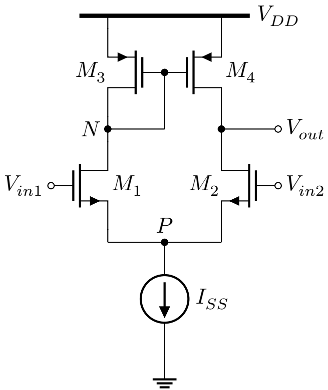
$$A_{DM} = \frac{V_{out1} - V_{out2}}{v_d} \cong -g_{m1,2}[(g_{m3,4} + gmb_{3,4})r_{o3,4}r_{o1,2} \parallel (g_{m5,6} + g_{mb5,6})r_{o5,6}r_{o7,8}] \quad (99)$$

Differential Pair with Active Load

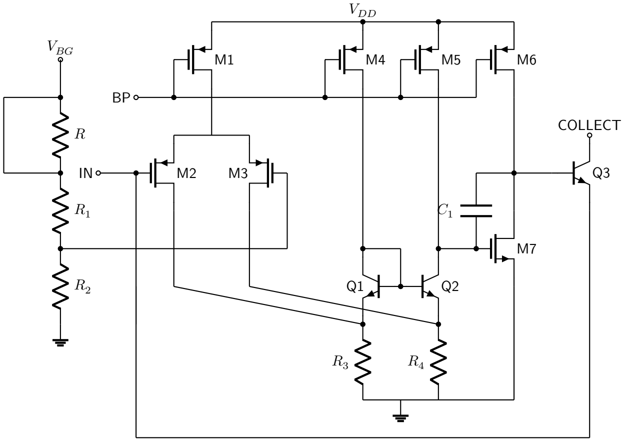


Asymmetric Differential Pair

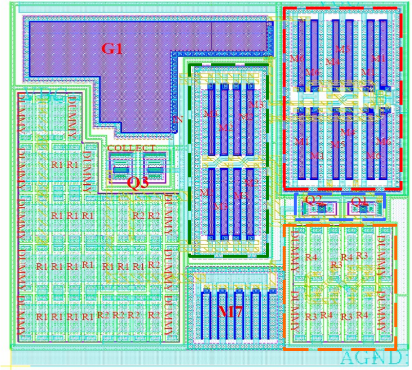
Why N is not on the right branch?
Caveat: Because of the vastly different resistance magnitude at the drains of M_1 and M_2, the voltage swings at these two nodes are different and therefore node P cannot be viewed as a virtual ground when $V_{in2} = -V_{in1}$.



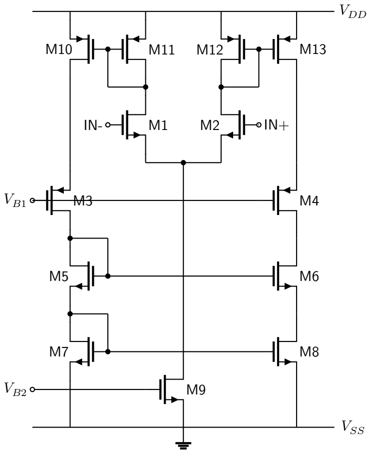
OPA Layout

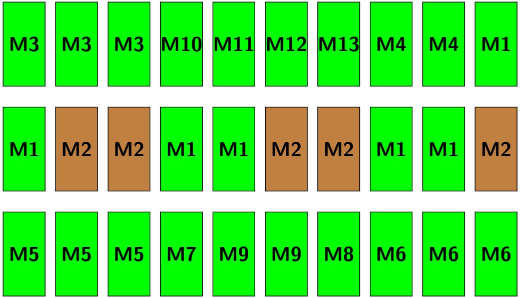


OPA Layout


G1
COLLECT
Q3
R1 R1
R1 R1 R1
R2 R2
R1 R1 R1 R1 R1 R1 R1 R2
R1 R1 R1 R1 R2 R2 R2 R2
DUMMY
M17
Q2
Q1
R4
R4 R3
R3
R3 R4 R3 R4
AGND

OPA Layout





Floor Plan