EE223 Analog Integrated Circuits
Fall 2018

Lecture 10: Folded –Cascode and Differential Pairs

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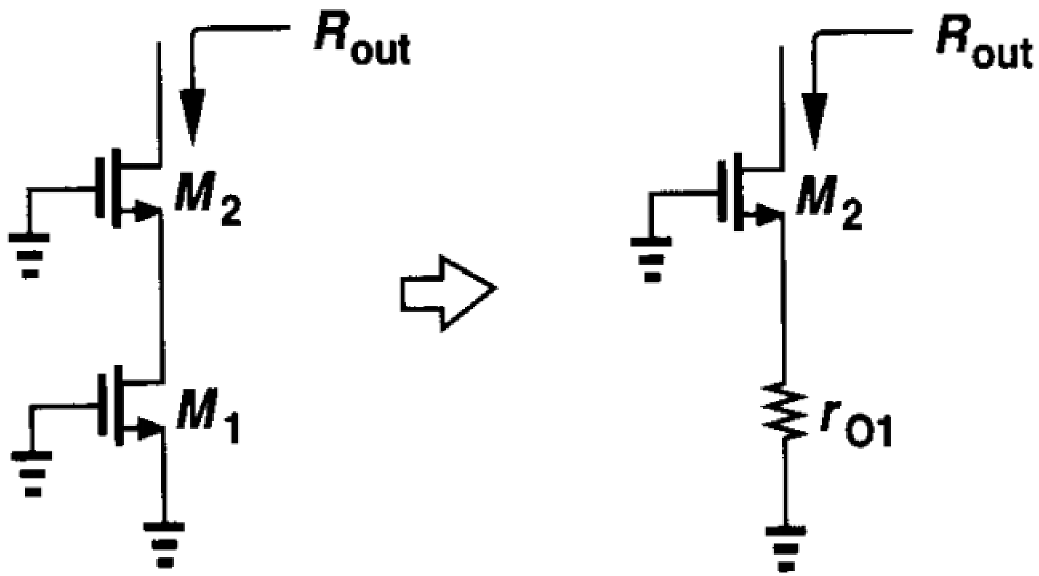
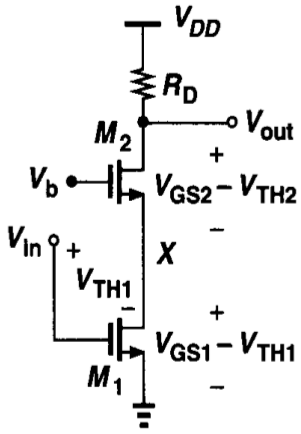
Output Impedance of Cascode Stage

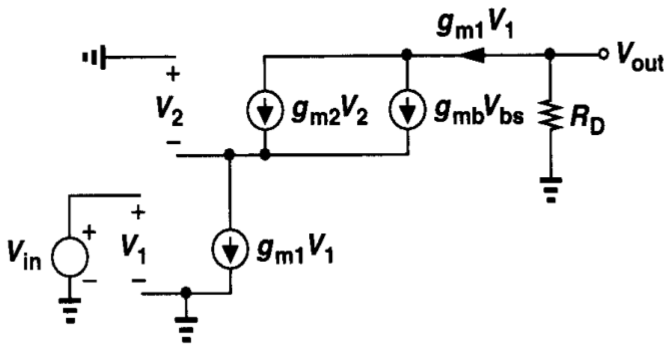


$$R_{out} = r_{o1} + r_{o2} + (g_{m2} r_{o2}) r_{o1}$$

$$R_{out} = r_{o1} + r_{o2} + (g_{m2} + g_{mb2}) r_{o2} r_{o1}$$ if $g_{mb} \neq 0$

Gain of Cascode Stage





$$A_v = \frac{V_{out}}{V_{in}} = -g_{m1}R_{out}$$

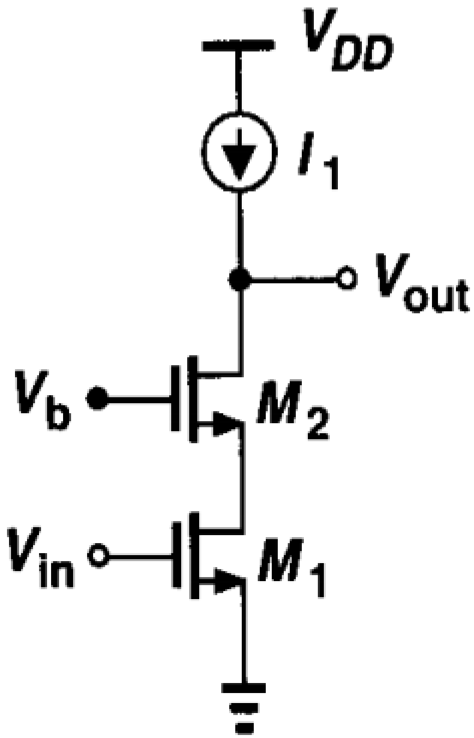
$$R_{out} = \{r_{o1} + r_{o2} + (g_{m2} + g_{mb2})r_{o2}r_{o1}\} // R_D$$

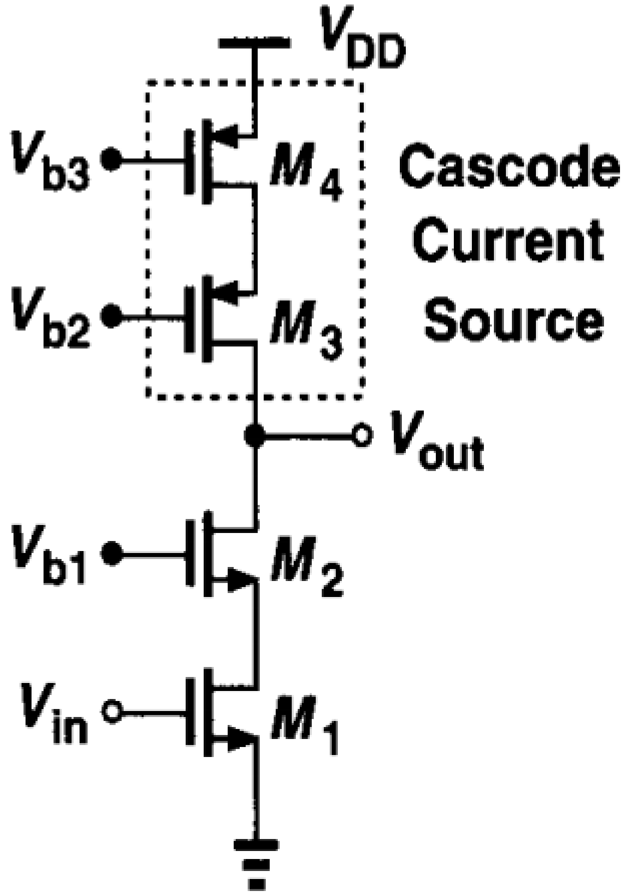
$$\approx (g_{m2}r_{o2})\, r_{o1} \,//\, R_D$$

$$A_v \approx -g_{m1}(g_{m2}r_{o2})\, r_{o1} = -(g_m\, r_o)^2$$

if R_D is neglected

Cascode Amp with Cascode Current Source

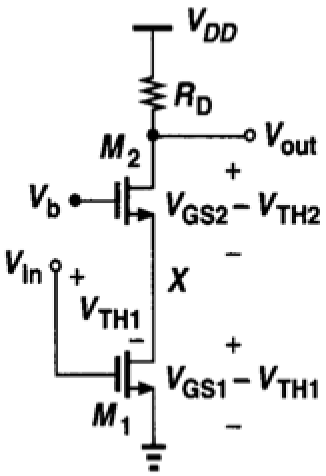


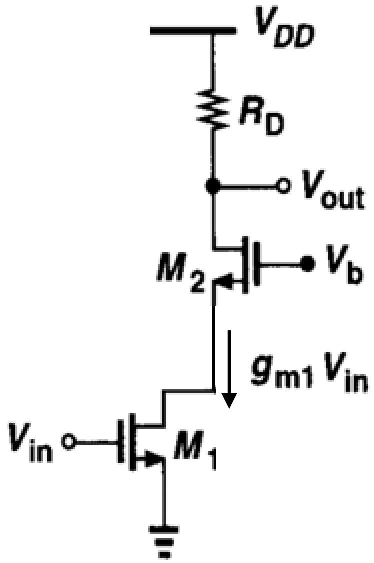


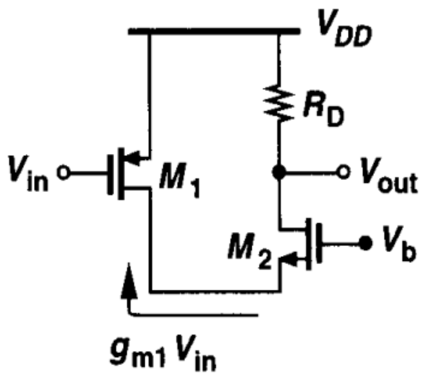
$$A_v \approx -g_{m1}[\{(g_{m2}r_{o2})\, r_{o1}\}||\{(g_{m3}r_{o3})\, r_{o4}\}] \approx -\frac{(g_m r_o)^2}{2}$$

Folded Cascode Structures

Folded Cascode Topology : Cascade of CS stage and CG stage with different transistor types for CS and CG

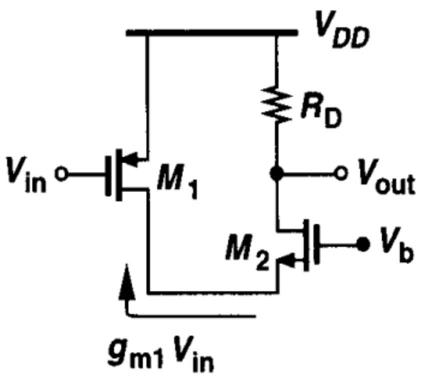


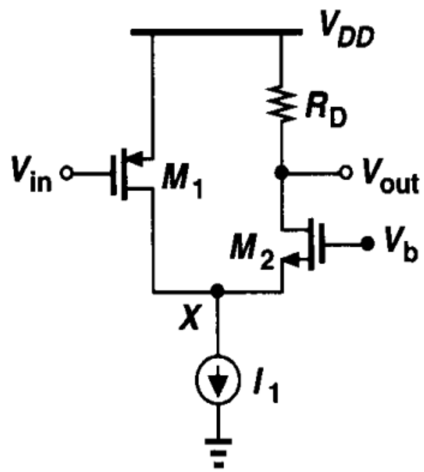




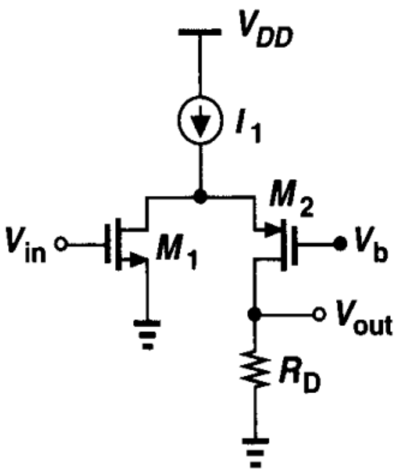
Folded Cascode Structures

Folded Cascode Topology : Cascade of CS stage and CG stage with different transistor types for CS and CG



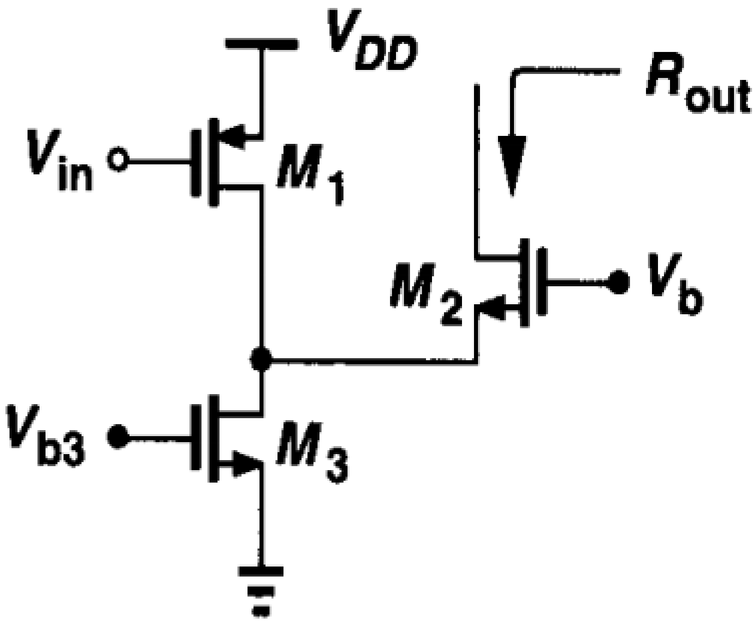


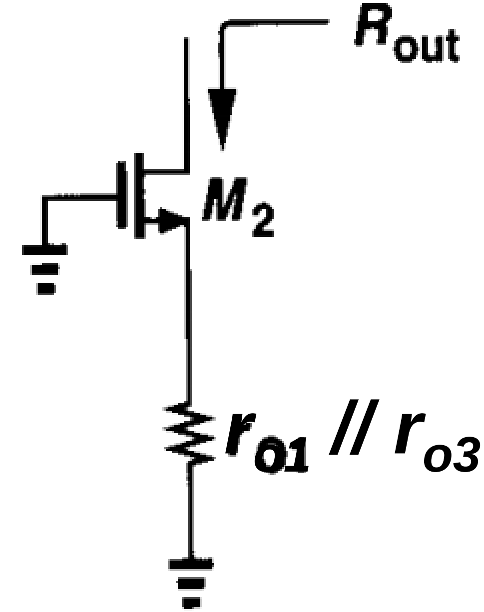
PMOS CS
NMOS CG



NMOS CS
PMOS CG

Output Impedance of Folded Cascode



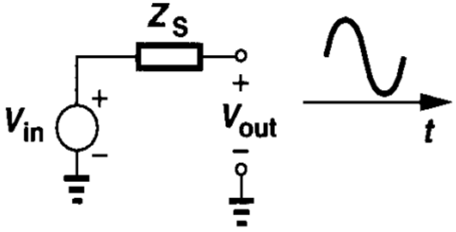


$$R_{out} = R_S + r_{o2} + (g_{m2} + g_{mb2}) r_{o2} R_S$$

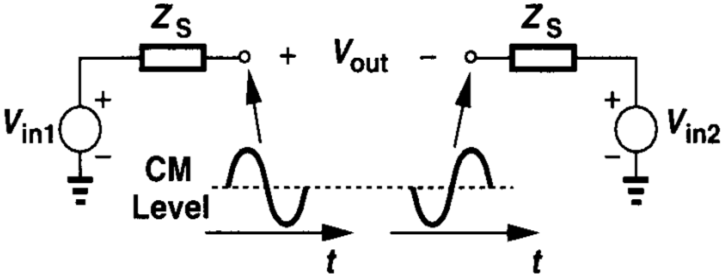
$$R_S = r_{o1} // r_{o3}$$

Single-Ended vs. Differential Operation

Single-ended



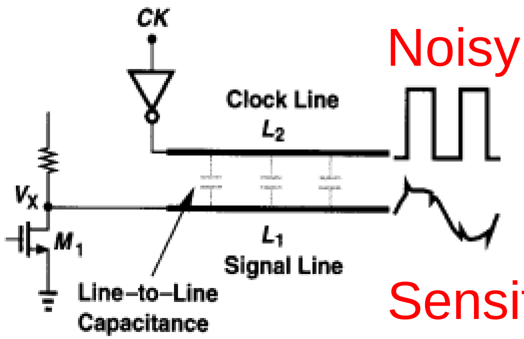
Differential

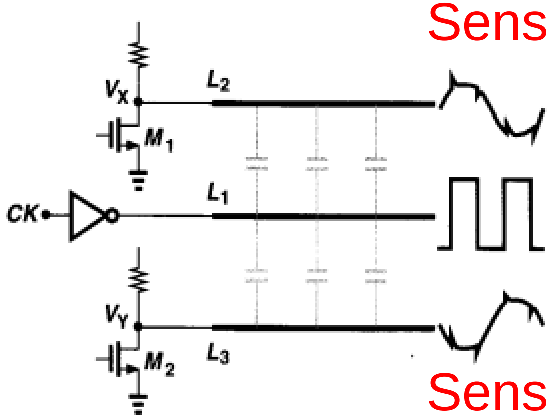


Advantages of Differential Operation

Single-ended

Differential

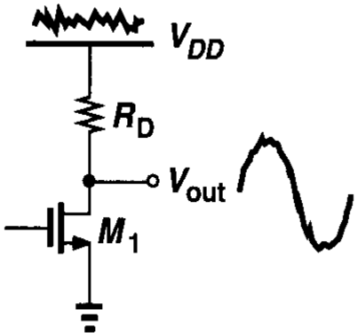




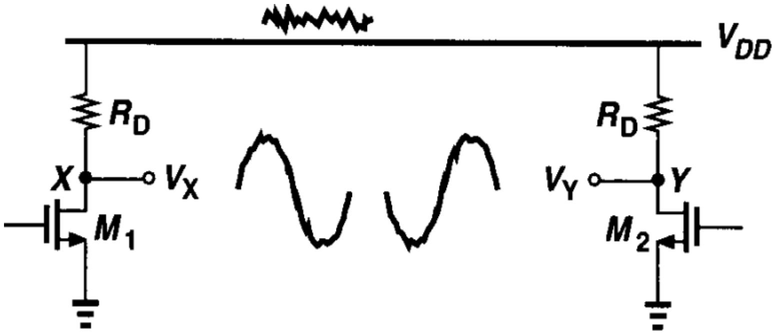
Immunity to environmental noise
→ Reject common-mode noise

Advantages of Differential Operation

Single-ended



Differential



Immunity to environmental noise
→ Robust to supply noise

Other Advantages of Differential Operation

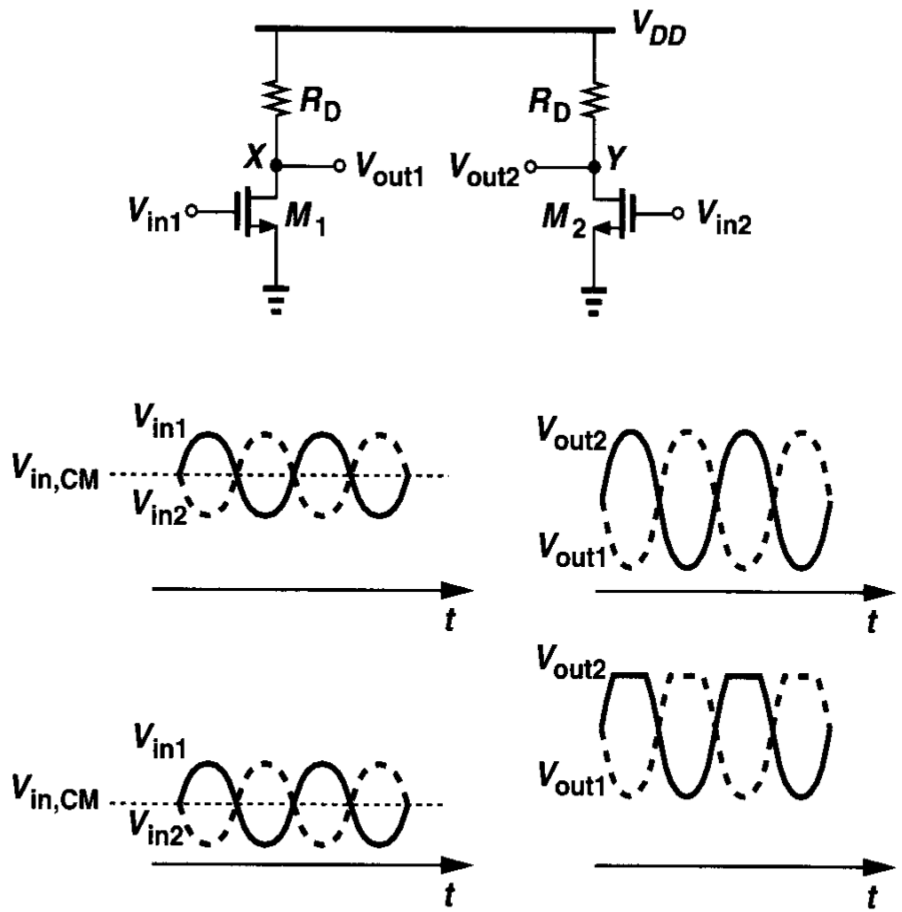
- Increased Swing
- Simpler Biasing
- Higher Linearity

- Disadvantage

  → Area Increase

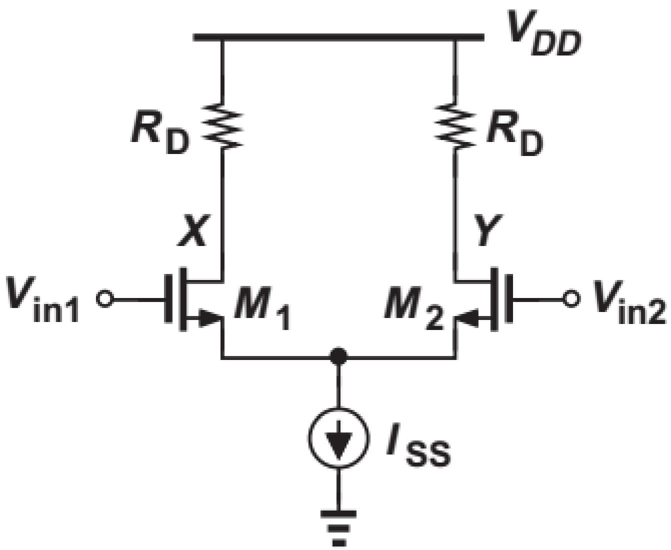
  → Common-mode stabilization circuit necessary

Simple Differential Circuit

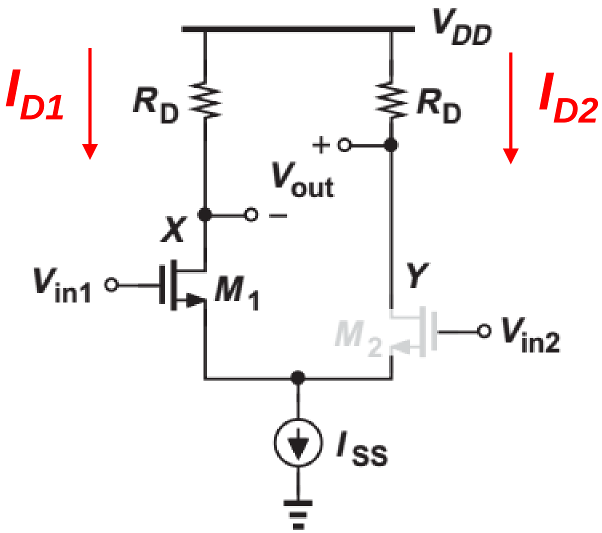


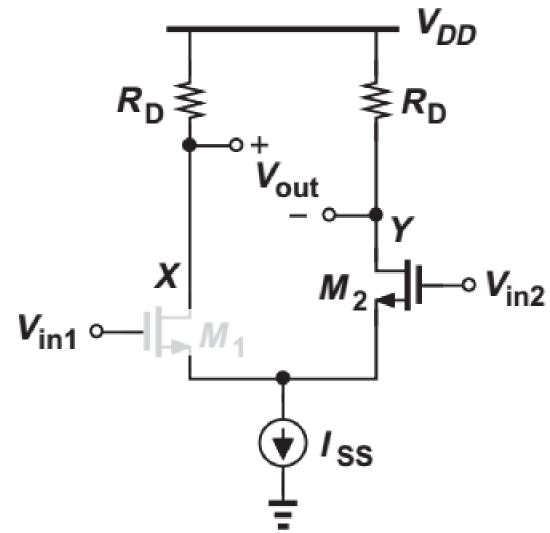
Sensitive to input common-mode level

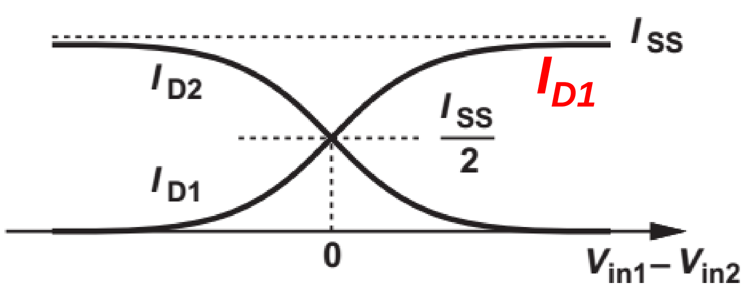
MOS Differential Pair

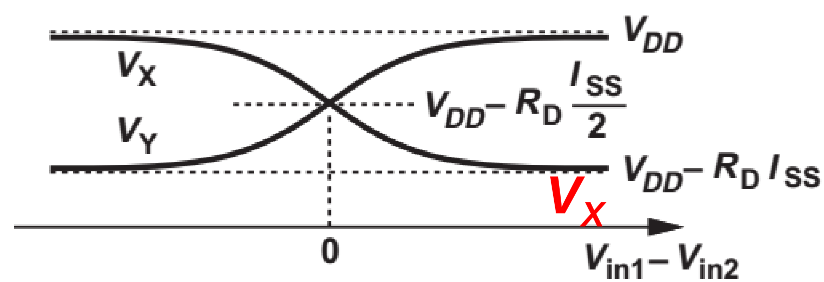


Input-Output Characteristics of Differential Pair

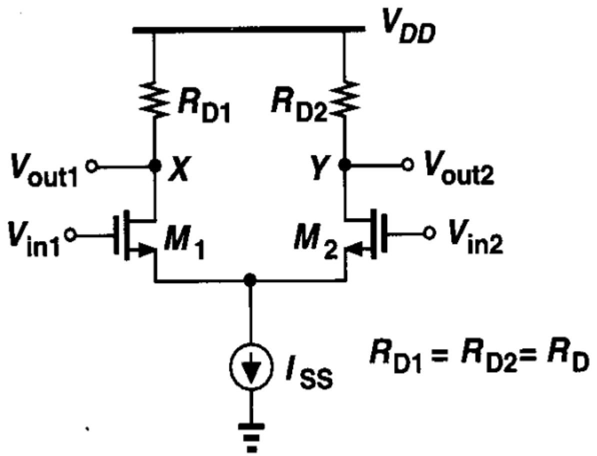




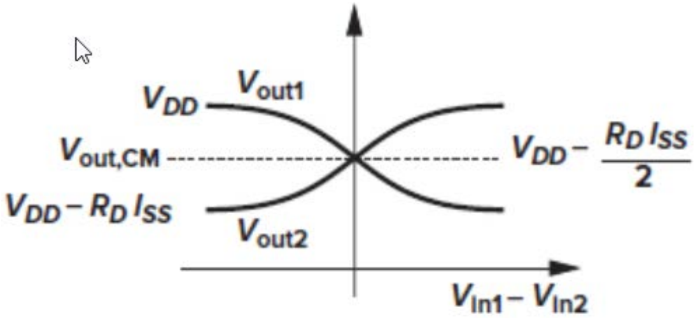


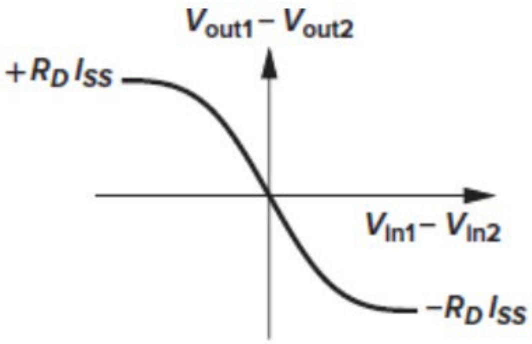


Input-Output Characteristics of Differential Pair

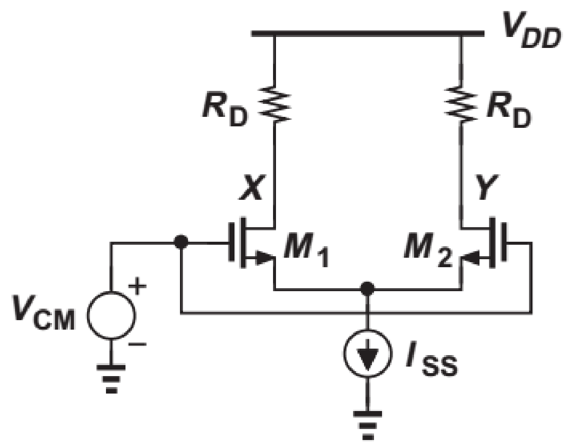


- Output signal levels are well defined and independent of input CM level
- Circuit becomes nonlinear as input swing increases





CM Response of MOS Differential Amplifier



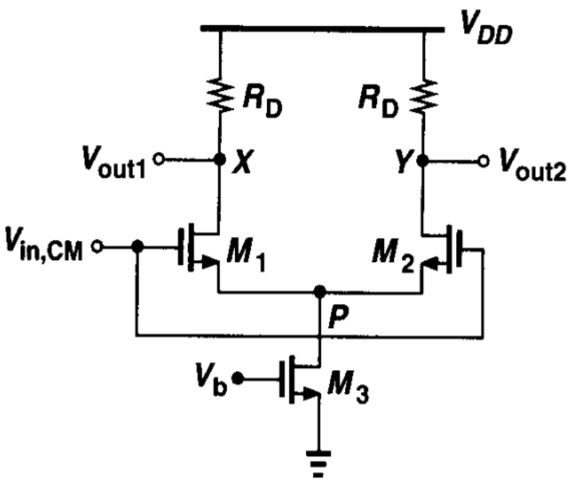
$$I_{D1} = I_{D2} = \frac{I_{SS}}{2}$$

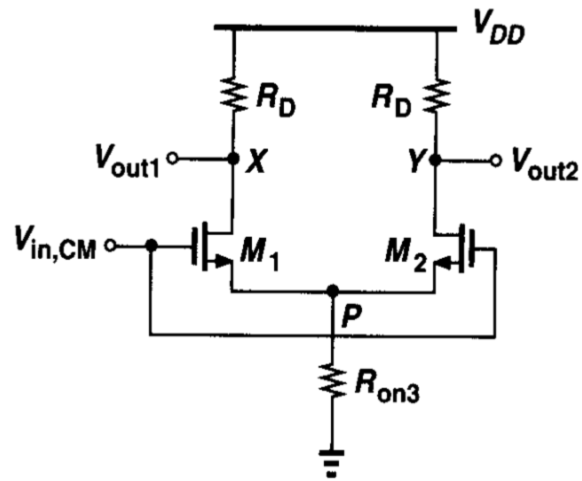
$$V_X = V_Y = V_{DD} - R_D \frac{I_{SS}}{2}$$

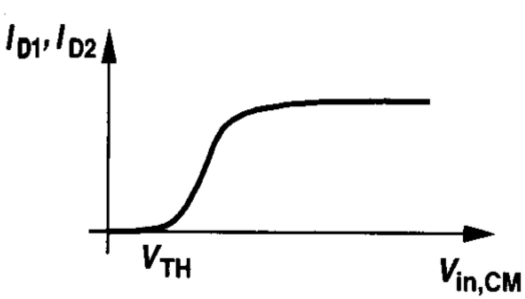
$$(V_{GS} - V_{TH})_{equil.} = \sqrt{\frac{I_{SS}}{\mu_n C_{ox} \frac{W}{L}}}$$

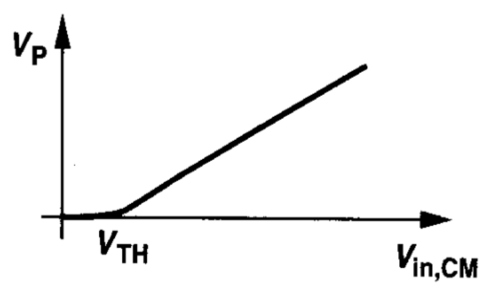
$$V_{DD} - R_D \frac{I_{SS}}{2} > V_{CM} - V_{TH}$$

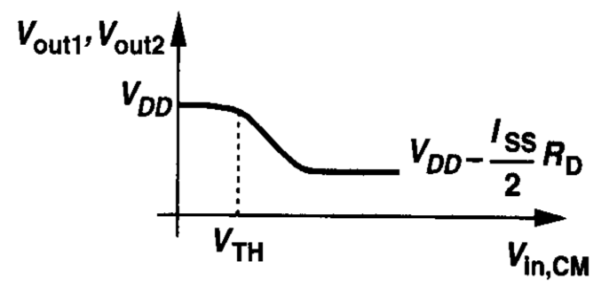
Common-Mode Characteristics of Differential Pair





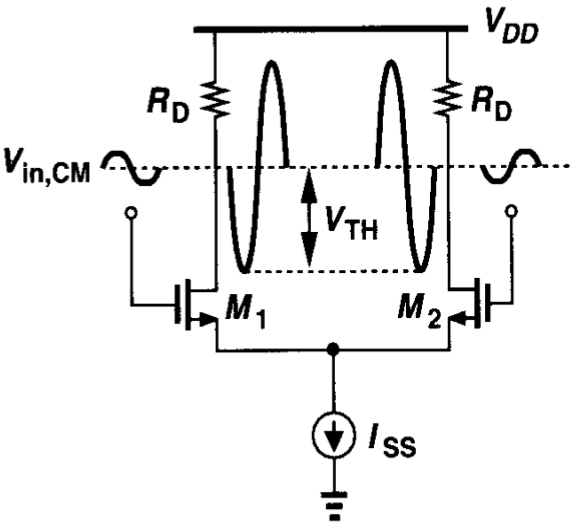






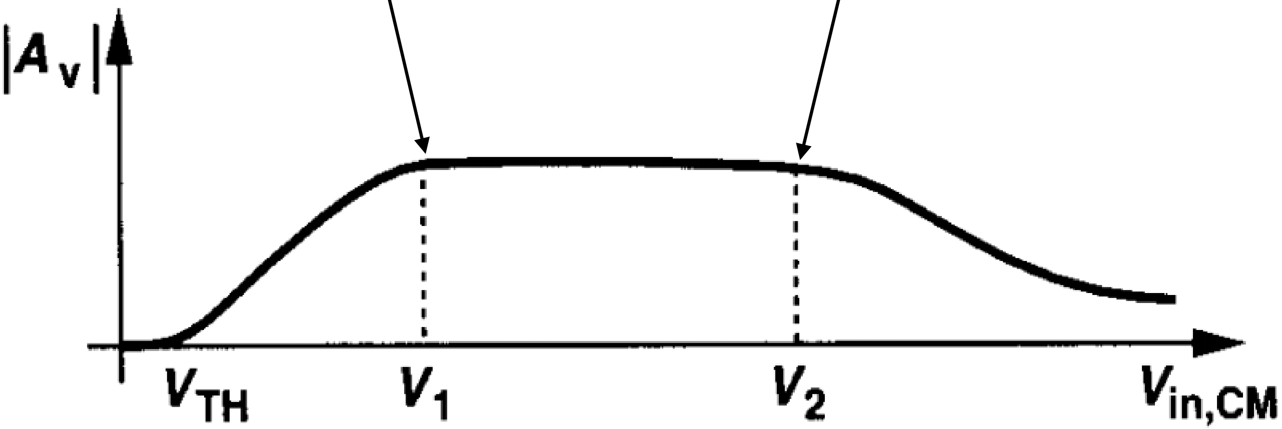
$$V_{GS1} + (V_{GS3} - V_{TH3}) \leq V_{in,CM} \leq \min\left[V_{DD} - R_D\frac{I_{SS}}{2} + V_{TH},\ V_{DD}\right]$$

Differential Gain vs. $V_{in,CM}$

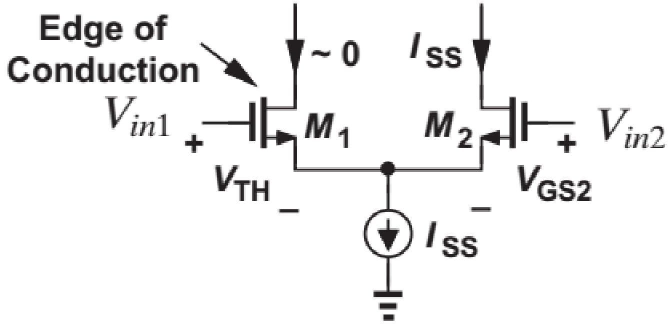


Tail current source enters Saturation

Input transistors enter the Triode region



Large Signal Analysis of Differential Pair



$$I_D = (1/2)\mu_n C_{ox}(W/L)(V_{GS} - V_{TH})^2$$

$$V_{GS} = V_{TH} + \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}}$$

$$(V_{GS} - V_{TH})_{equil.} = \sqrt{\frac{2I_{D1}}{KP\left(\frac{W}{L}\right)}} = \sqrt{\frac{2\left(\frac{I_{SS}}{2}\right)}{KP\left(\frac{W}{L}\right)}}$$

$$V_{in1} - V_{GS1} = V_{in2} - V_{GS2}$$

$$I_{D1} + I_{D2} = I_{SS}$$

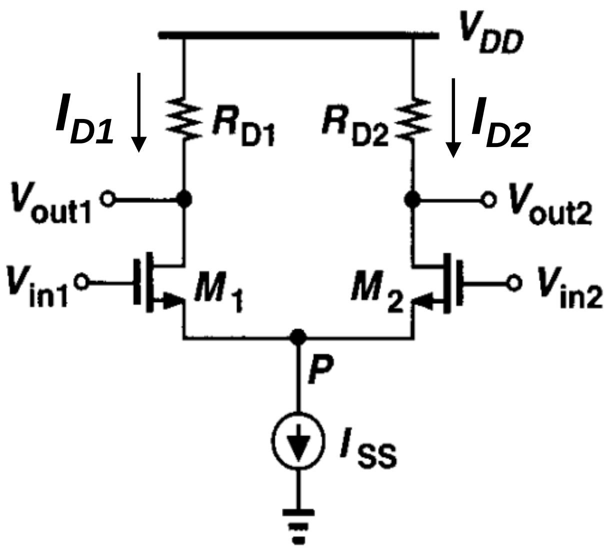
$$V_{GS1} = V_{TH}$$

$$V_{GS2} = V_{TH} + \sqrt{\frac{2I_{SS}}{\mu_n C_{ox}\frac{W}{L}}}$$

$$|V_{in1} - V_{in2}|_{max} = \sqrt{\frac{2I_{SS}}{\mu_n C_{ox}\frac{W}{L}}}$$

$$\boxed{|V_{in1} - V_{in2}|_{max} = \sqrt{2}(V_{GS} - V_{TH})_{equil.}}$$

Large Signal Analysis of Differential Pair



$\sqrt{2}\, V_{dsat}$ *of M_1 & M_2 in equilibrium*