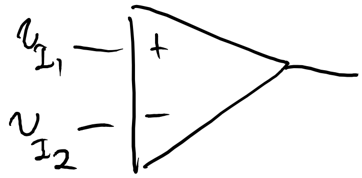
Lecture 15 - Diff pairs

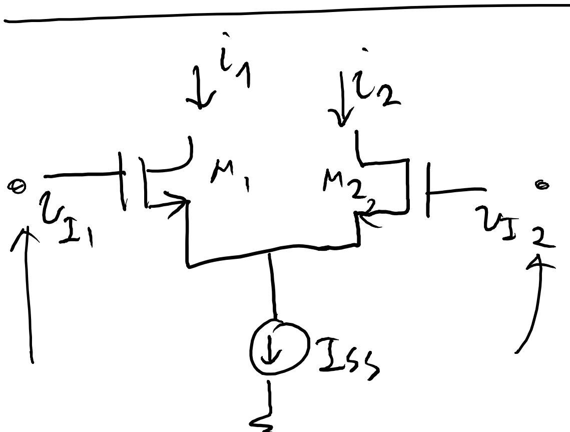
Differential Amplifier



$$v_O = A_{dm} \cdot (v_{I1} - v_{I2}) + A_{cm}\left(\frac{v_{I1}+v_{I2}}{2}\right)$$

Defs: $v_{Id} = v_{I1} - v_{I2}$, $v_{ic} = \frac{v_{I1}+v_{I2}}{2}$

want: large A_{dm} , small A_{cm} , $CMRR = \left|\frac{A_{dm}}{A_{cm}}\right|$



$$\Delta i = i_1 - i_2$$

$$v_{Id} = v_{I_1} - v_{I2}$$

$$i_1 = \frac{k'}{2}\frac{W}{L}(v_{GS1} - V_{th})^2$$

$$i_2 = \frac{k'}{2}\frac{W}{L}(v_{GS2} - V_{th})^2$$

Assumptions:

1. $M_1\ M_2$ in SAT
2. $M_{1,2}$ identical
3. Neglect the B.E
4. Neglect r_o

KVL: $v_{I1} - v_{I2} = v_{GS1} - v_{GS2} = v_{Id}$

$$v_{Id} = v_{ov1} - v_{ov2} = \frac{\sqrt{i_{D1}} - \sqrt{i_{D2}}}{\sqrt{\frac{k'}{2}\frac{W}{L}}}$$

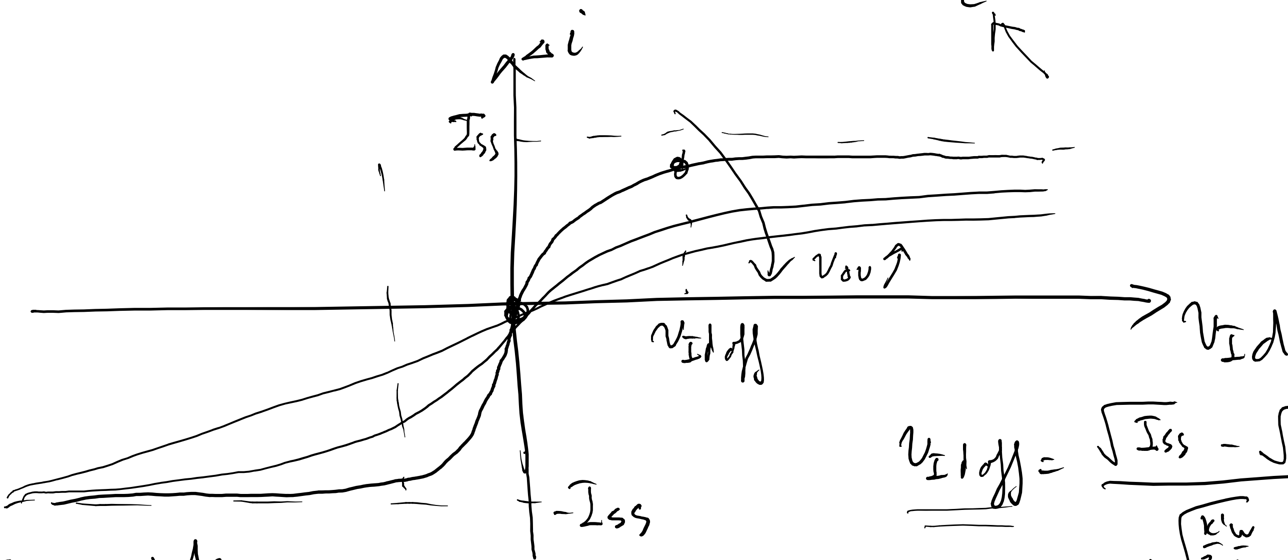
KCL: $I_{ss} = i_1 + i_2$

Solve by i_1 $\Rightarrow$

$$i_1 = \frac{I_{ss}}{2} + \frac{k'}{4}\frac{W}{2} v_{Id} \sqrt{\frac{4 I_{ss}}{k' \frac{W}{L}} - v_{Id}^2}$$

$$i_2 = \frac{I_{ss}}{2} - \frac{k'}{4}\frac{W}{2} v_{Id} \sqrt{\frac{4 I_{ss}}{k' \frac{W}{L}} - v_{Id}^2}$$

$$\Delta i = i_1 - i_2 = \frac{k'}{2}\frac{W}{L} v_{Id} \sqrt{\frac{4 I_{ss}}{k' \frac{W}{L}} - v_{Id}^2}$$

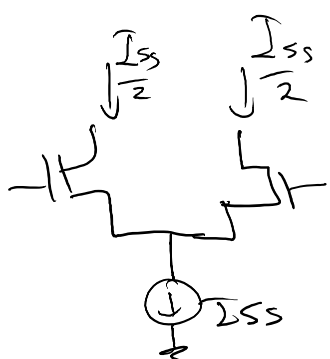


$$\underline{v_{Idoff}} = \frac{\sqrt{I_{ss}} - \sqrt{0}}{\sqrt{\frac{k'}{2}\frac{W}{L}}} = \underline{V_{ov}}\sqrt{2}$$

$V_{GS} - V_{th} \Big|_{v_{Id}=0}$

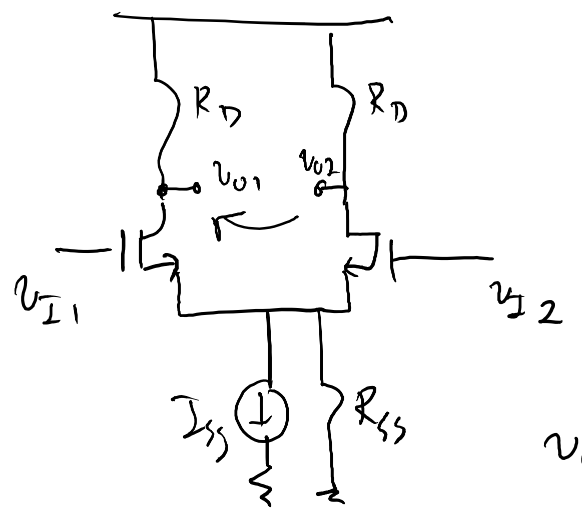
Key points:

1. If v_{Id} small
   $\Delta i \approx v_{Id} \sqrt{I_{ss}}$
2. $-I_{ss} < \Delta i < I_{ss}$
3. $v_{Idoff} = f\left(\frac{W}{L}, I_{ss}\right)$



(4) Input range $= \sqrt{2} \cdot V_{ov} \Big|_{v_{Id}=0} > 6 V_T$ (BJT)

(5) Similar to BJT with E-degeneration



$$v_{o1} = A_{11} \cdot v_{I1} + A_{12} \cdot v_{I2}$$

$$v_{o2} = A_{21} \cdot v_{I1} + A_{22} \cdot v_{I2}$$

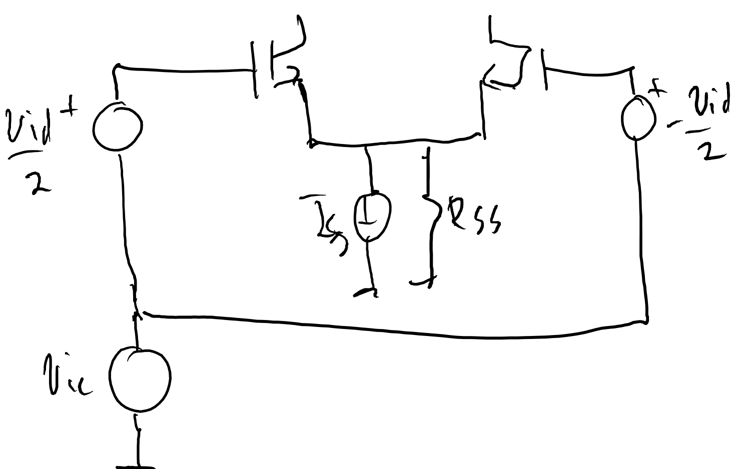
Change the variables:

$$v_{id} = v_{i1} - v_{i2} \qquad v_{od} = v_{o1} - v_{o2}$$

$$v_{ic} = \frac{v_{i1} + v_{i2}}{2} \qquad v_{oc} = \frac{v_{o1} + v_{o2}}{2}$$

$$v_{od} = A_{dm} \cdot v_{id} + A_{cm-dm} \cdot v_{ic}$$

$$v_{oc} = A_{dm-cm} \cdot v_{id} + A_{cm} \cdot v_{ic}$$



$A_{dm} = ?$

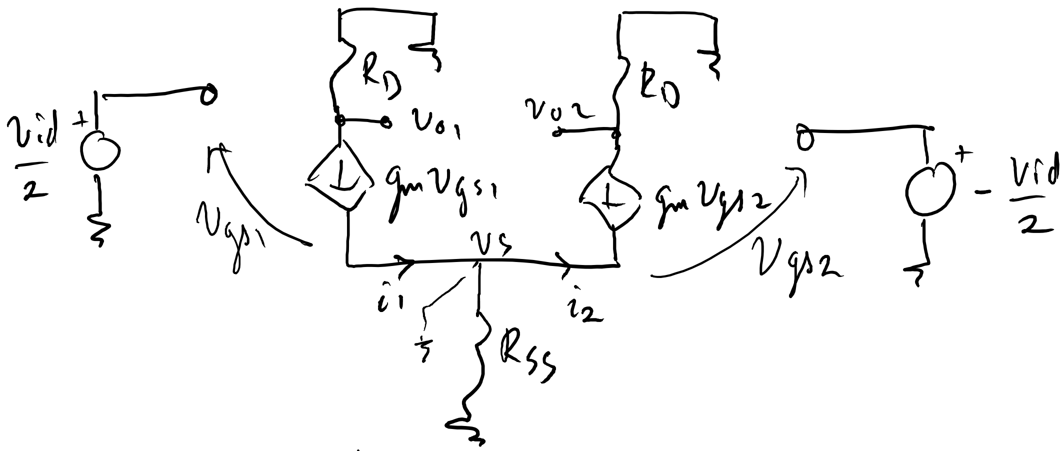
$A_{cm} = ?$

In balanced case:

$$A_{dm-cm} = A_{cm-dm} = 0$$

Superposition:

a) $v_{ic} = 0$ (Differential mode) $A_{dm} = ?$



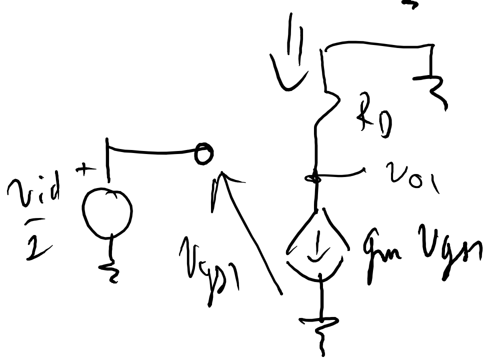
Assume:

$v_s = 0$

$\frac{v_{id}}{2} = v_{gs1} = -v_{gs2}$

$i_1 = i_2$

$i_{R_{SS}} = 0 \Rightarrow v_s = 0$



$$A_{dm} = \frac{v_{od}}{v_{id}} = -g_m R_D$$

$$\frac{v_{o1}}{\frac{v_{id}}{2}} = -g_m R_D$$

$$v_{od} = v_{o1} - v_{o2}$$

$$\frac{v_{o2}}{-\frac{v_{id}}{2}} = -g_m R_D$$

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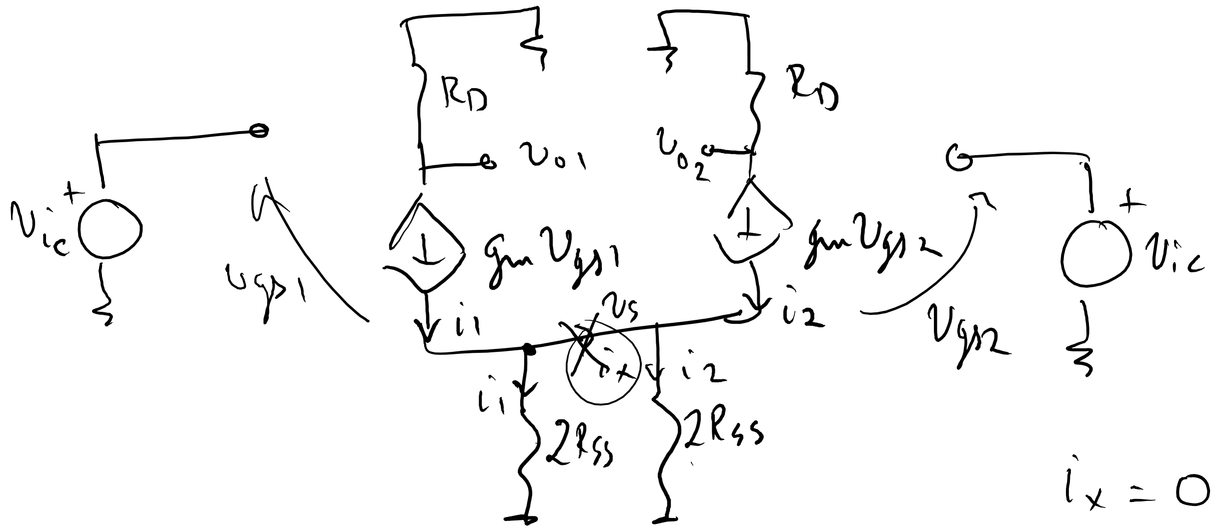
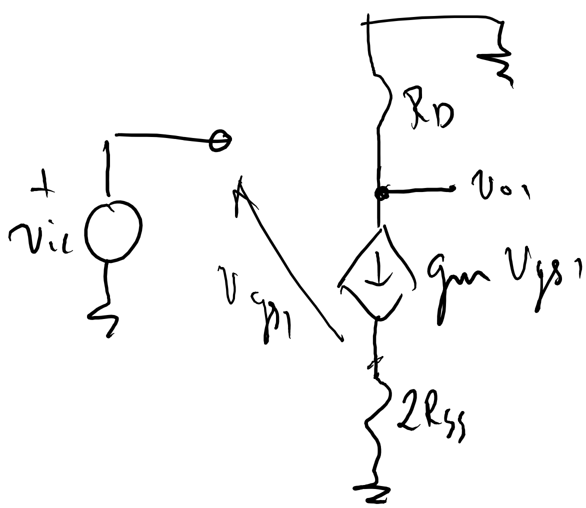
b) Common-mode ($v_{id} = 0$) $A_{cm} = ?$



$i_x = 0$

$i_1 = i_2$



$$A_{cm} = -\frac{g_m R_D}{1 + (g_m + g_{mb}) \cdot (2R_{SS})} = \frac{v_{oc}}{v_{ic}}$$

$$v_{oc} = \frac{v_{o1} + v_{o2}}{2} = v_{o1} = v_{o2}$$

Small-signal half-circuit (bisection) analysis of balanced circuits

(1) Draw schematic of the ckt - see balance

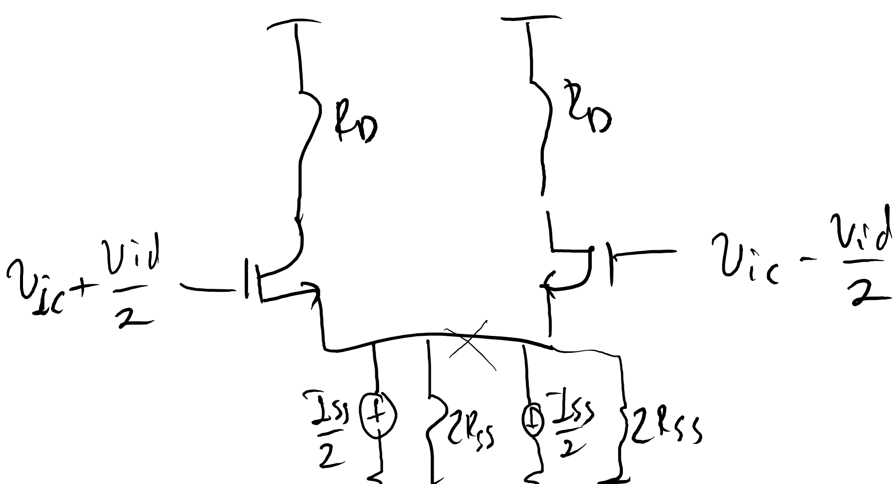
(2) Use superposition

a) Apply DM input and simplify schematic

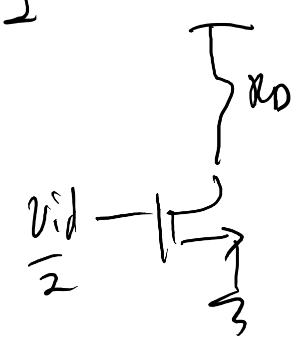
b) Apply CM input and simplify sch.

c) Add the two

(1)



(2a) Apply DM ⇒ $v_{ic}=0$



$A_{dm} = -g_m R_D$

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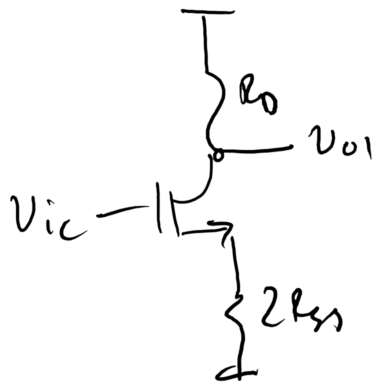
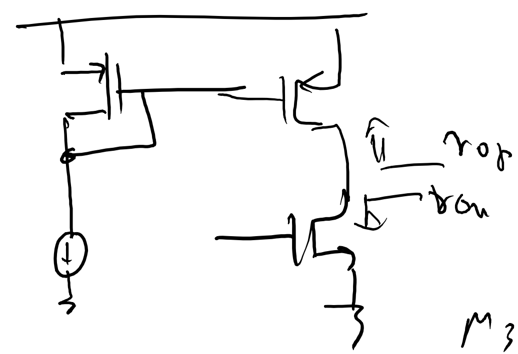
2b

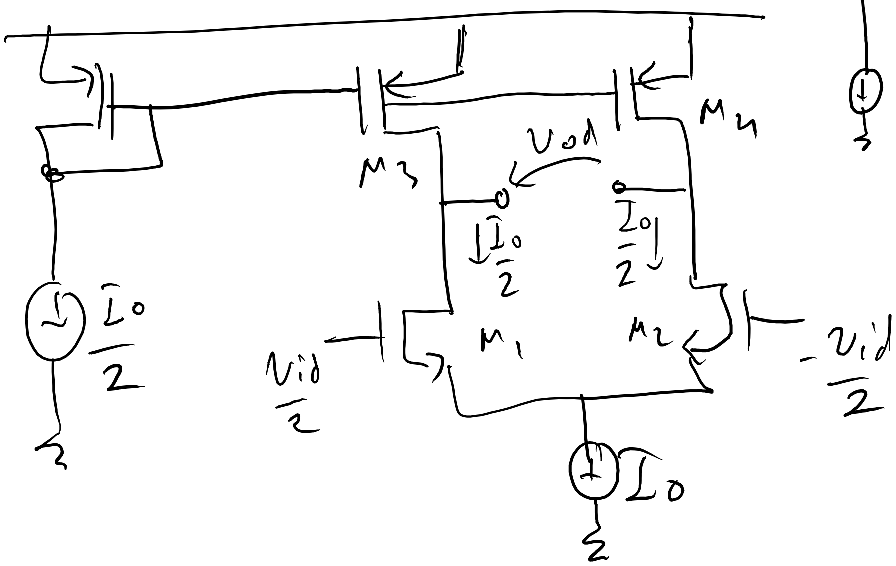


$$A_{cm} = -\frac{g_m R_D}{1 + (g_m + g_{mb})(2R_{SS})}$$

$$CMRR = 1 + (g_m + g_{mb})\,2R_{SS}$$

Active 1:





M_3, M_4 identical

$$A_{dm} = \frac{v_{od}}{v_{id}} = -g_m(r_{op} \| r_{on})$$

$$= -g_{m1}(r_{o1} \| r_{o3})$$

b) Diff pair with current mirror load