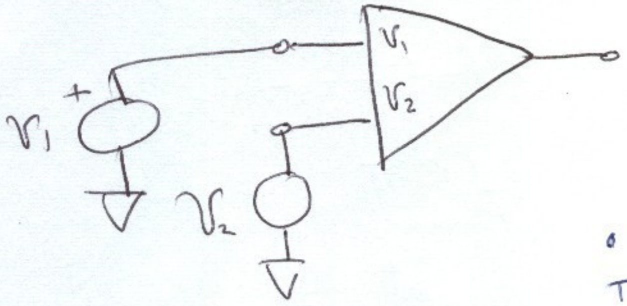
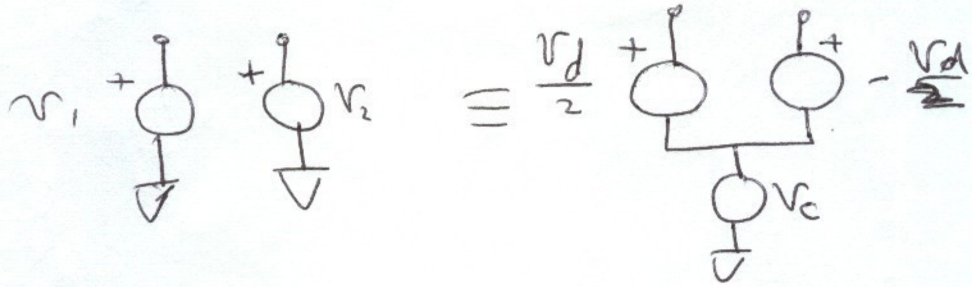
DIFFERENTIAL AMPLIFIERS



$v_o = A_{dm}(v_1 - v_2)$

↑ OUTPUT PROPORTIONAL TO DIFFERENCE.

- NO NEED OF CAPACITORS OR LEVEL SHIFTERS TO COUPLE DIFFERENTIAL AMPS.



$$\begin{cases} v_d = v_1 - v_2 \\ v_c = \frac{v_1 + v_2}{2} \end{cases}$$

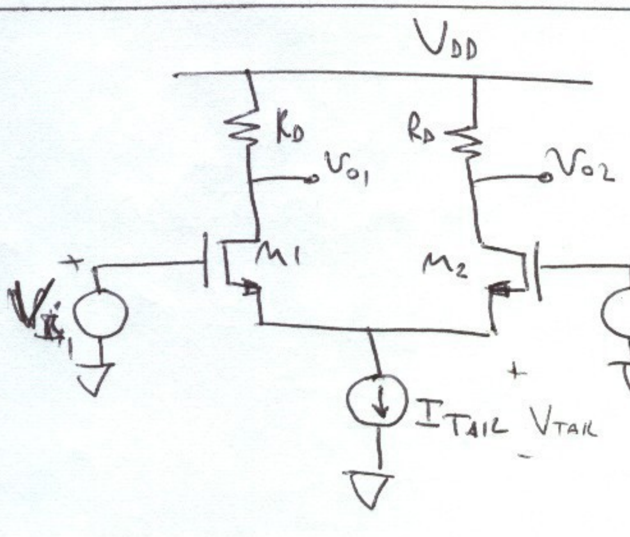
- IN PRACTICE, AMPLIFIERS RESPOND TO COMMON-MODE VOLTAGE IN ADDITION TO DIFFERENTIAL VOLTAGE.

$$A_{dm} = \frac{v_o}{v_d}$$

$$A_{cm} = \frac{v_o}{v_c}$$

$$CMRR = \frac{A_{dm}}{A_{cm}}$$, CMRR HIGH IS GOOD.

DC TRANSFER OF A SOURCE-COUPLED PAIR (§3.5.1)



- ASSUME $\lambda = 0$,
- NO BODY EFFECT.
- DISCUSS COMMON-MODE VOLTAGE RANGE

$$V_{I_1} - V_{gs_1} + V_{gs_2} - V_{I_2} = 0$$

$$V_{gs_1} = V_t + \sqrt{\frac{2 I_{d1}}{k'\left(\frac{W}{L}\right)}} \quad , \quad V_{gs_2} = V_t + \sqrt{\frac{2 I_{d2}}{k' \frac{W}{L}}}$$

$$V_{id} = V_{I_1} - V_{I_2} = V_{gs_1} - V_{gs_2} = \frac{\sqrt{I_{d1}} - \sqrt{I_{d2}}}{\sqrt{\frac{k'}{2} \frac{W}{L}}}$$

BUT $I_{d1} + I_{d2} = I_{TAIL}$

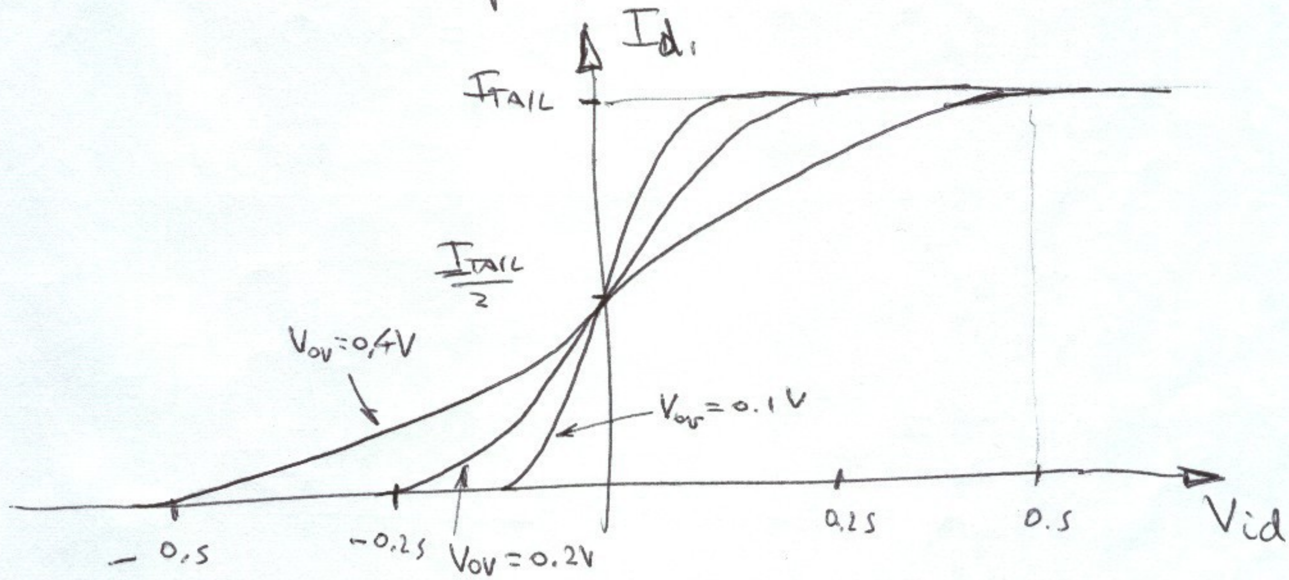
$$\therefore \quad I_{d1} = \frac{I_{TAIL}}{2} + \frac{k'}{4} \frac{W}{L} V_{id} \sqrt{\frac{4 I_{TAIL}}{k' \frac{W}{L}} - V_{id}^2}$$

VALID FOR $0 \leq I_{d1} \leq I_{TAIL}$

$$|V_{id}| \leq \sqrt{\frac{2 I_{TAIL}}{k' \frac{W}{L}}}$$

$$V_{id} = 0 \Rightarrow I_{d1} = I_{d2} = \frac{I_{TAIL}}{2} \Rightarrow I_{TAIL} = 2 I_{d1}\Big|_{V_{id}=0}$$

$$|V_{id}| \leq \sqrt{2} \sqrt{\frac{2 I_{d1}\big|_{V_{id}=0}}{k' \frac{W}{L}}} = \sqrt{2}\, V_{ov}\Big|_{V_{id}=0}$$



SMALL-SIGNAL ANALYSIS

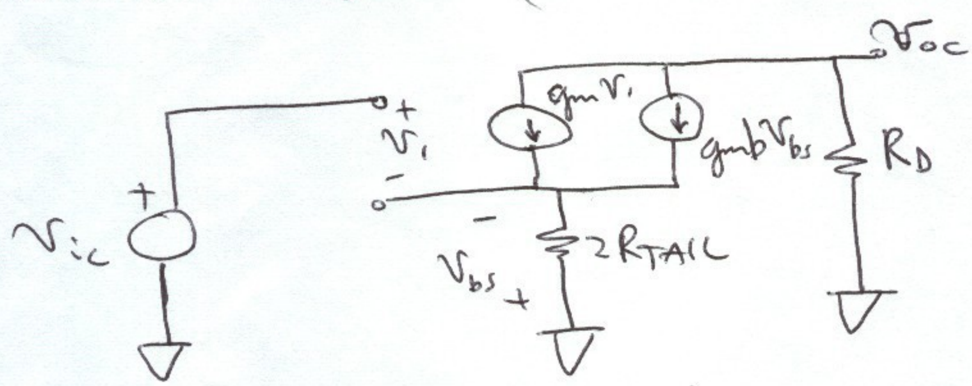
- DIFFERENTIAL MODE:

$$A_{dm} = -g_m (r_o // R_D)$$

$$A_{dm_{SE}} = \pm \frac{g_m (r_o // R_D)}{2}$$

(SINGLE OUTPUT, DEPENDING WHICH ONE)

- COMMON MODE: (FOR NOW NEGLECT EFFECT OF r_o)



$$v_{oc} = -(g_m v_1 + g_{mb} v_{bs}) R_D$$

$$v_1 = v_{ic} - v_{sb}, \quad v_{sb} = (g_m v_1 - g_{mb} v_{sb})\, 2R_{TAIL}$$

$$v_{sb} = [g_m (v_{ic} - v_{sb}) - g_{mb} v_{sb}]\, 2R_{TAIL}$$

$$v_{sb}\left(\frac{1}{2R_{TAIL}} + g_m + g_{mb}\right) = g_m v_{ic}$$

$$v_{sb} = \frac{g_m}{\frac{1}{2R_{TAIL}} + g_m + g_{mb}} v_{ic}$$

$$\frac{v_{oc}}{R_D} = -g_m (v_{ic} - v_{sb}) + g_{mb} v_{sb}$$

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

$$\frac{v_{oc}}{v_{ic}} = \left[-g_m + (g_m + g_{mb}) \frac{g_m}{\frac{1}{2R_{TAIL}} + g_m + g_{mb}}\right] R_D$$

$$\frac{v_{oc}}{v_{ic}} = \frac{-g_m\left(\frac{1}{2R_{TAIL}} + g_m + g_{mb}\right) + g_m(g_m + g_{mb})}{\frac{1}{2R_{TAIL}} + g_m + g_{mb}} R_D$$

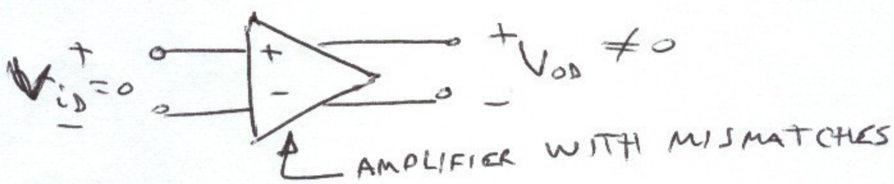
$$= -\frac{g_m R_D}{1 + (g_m + g_{mb})\, 2R_{TAIL}}$$

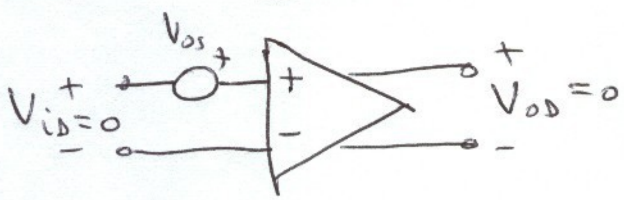
$$\boxed{A_{cm} = -\frac{g_m R_D}{1 + 2(g_m + g_{mb}) R_{TAIL}}}$$

$$\boxed{CMRR = \frac{A_{dm}}{A_{cm}} \cong 1 + 2(g_m + g_{mb}) R_{TAIL}}$$

(NEGLECTING r_o) (DIFF. OUTPUT).

INPUT OFFSET VOLTAGE (DUE TO MISMATCH)





EQUIVALENT INPUT OFFSET VOLTAGE

- OFFSET CURRENT IN CMOS AMPLIFIERS GENERALLY NEGLIGIBLE.

$$V_{OS} = \underbrace{\Delta V_t}_{\text{AROUND 2 mV}} + \overbrace{\frac{(V_{GS} - V_t)}{2}}^{V_{OV}}\left(-\frac{\Delta R_D}{R_D} - \frac{\Delta\left(\frac{W}{L}\right)}{\left(\frac{W}{L}\right)}\right)$$

$V_{OV} \uparrow \Longrightarrow$ MORE OFFSET DUE TO MISMATCH IN R_D AND $\frac{W}{L}$.