EEE 51: Second Semester 2017 - 2018

Lecture 11

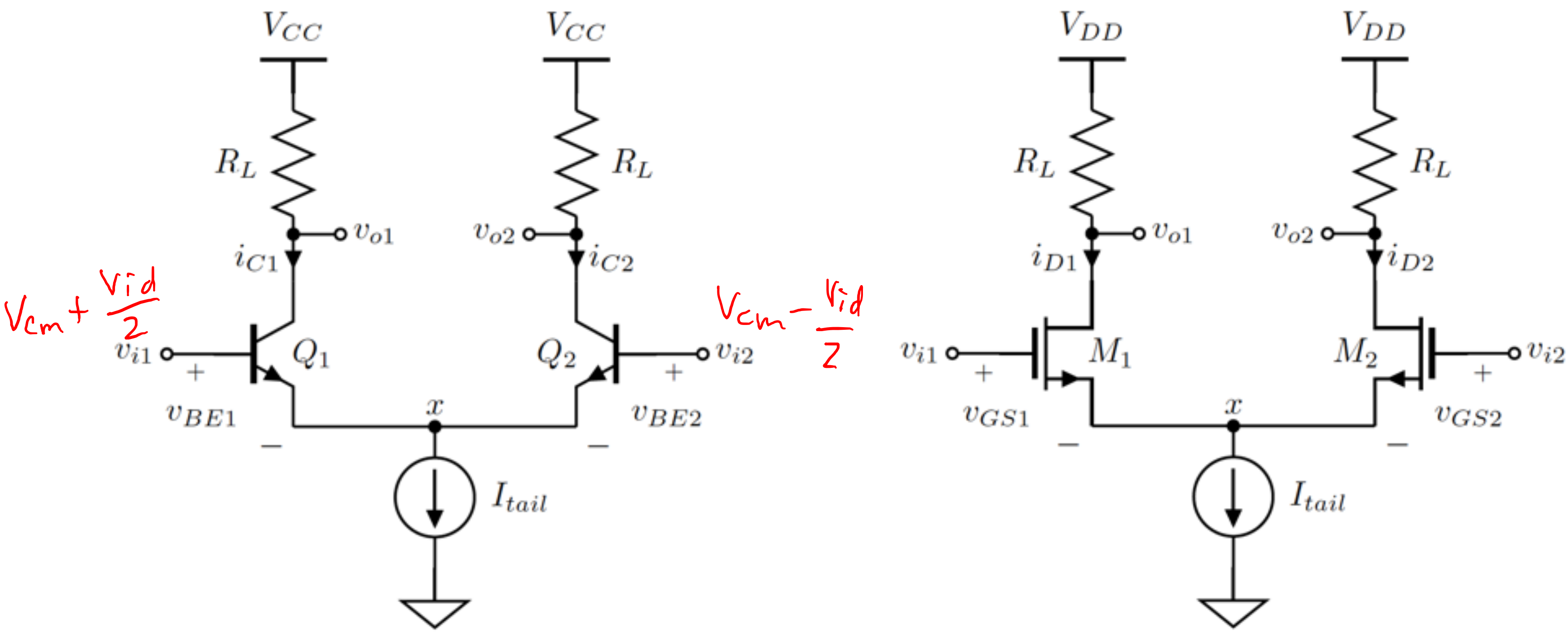
Differential Circuits

Today

- Small signal analysis of differential circuits

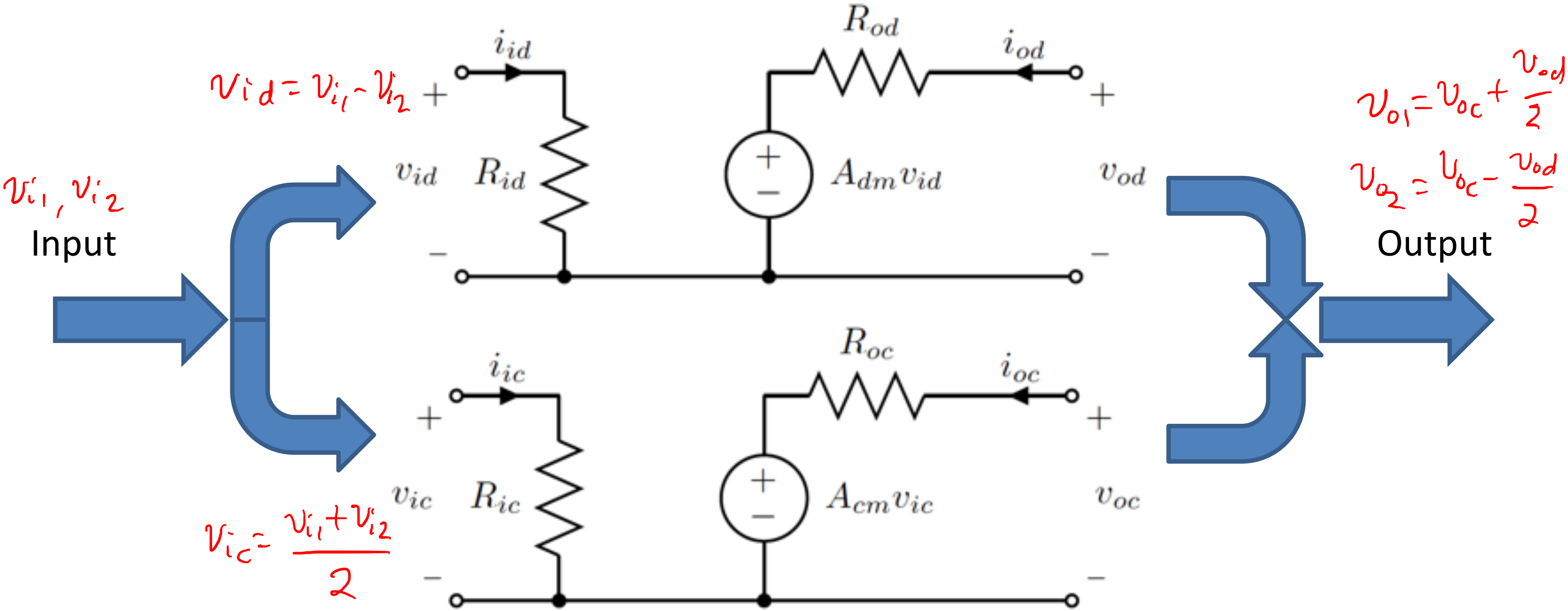
Differential Amplifiers

- After DC analysis → same small signal model

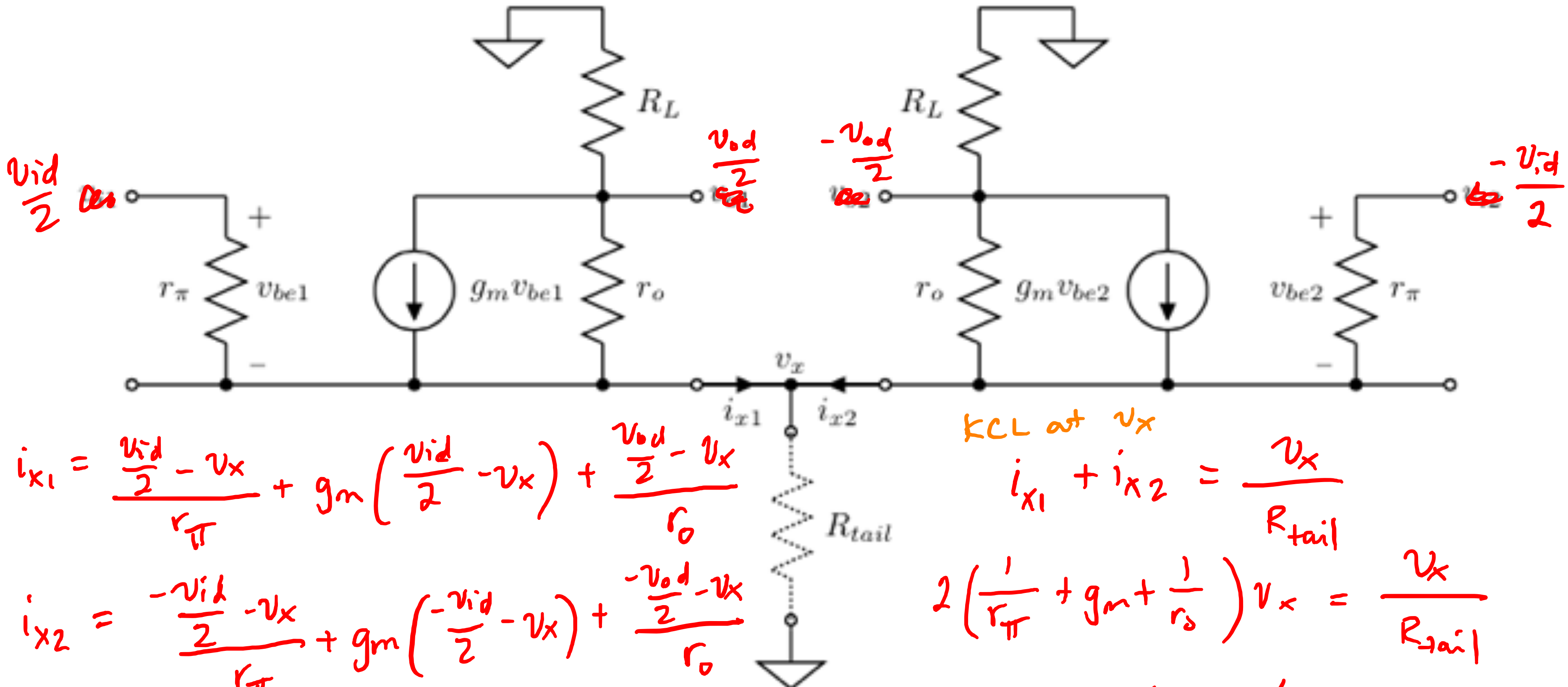


Differential vs. Common-Mode

- The amplifier processes the two signals differently!



Small-signal equivalent circuit



$$i_{x1} = \frac{\frac{v_{id}}{2} - v_x}{r_\pi} + g_m\left(\frac{v_{id}}{2} - v_x\right) + \frac{\frac{v_{od}}{2} - v_x}{r_o}$$

$$i_{x2} = \frac{-\frac{v_{id}}{2} - v_x}{r_\pi} + g_m\left(-\frac{v_{id}}{2} - v_x\right) + \frac{-\frac{v_{od}}{2} - v_x}{r_o}$$

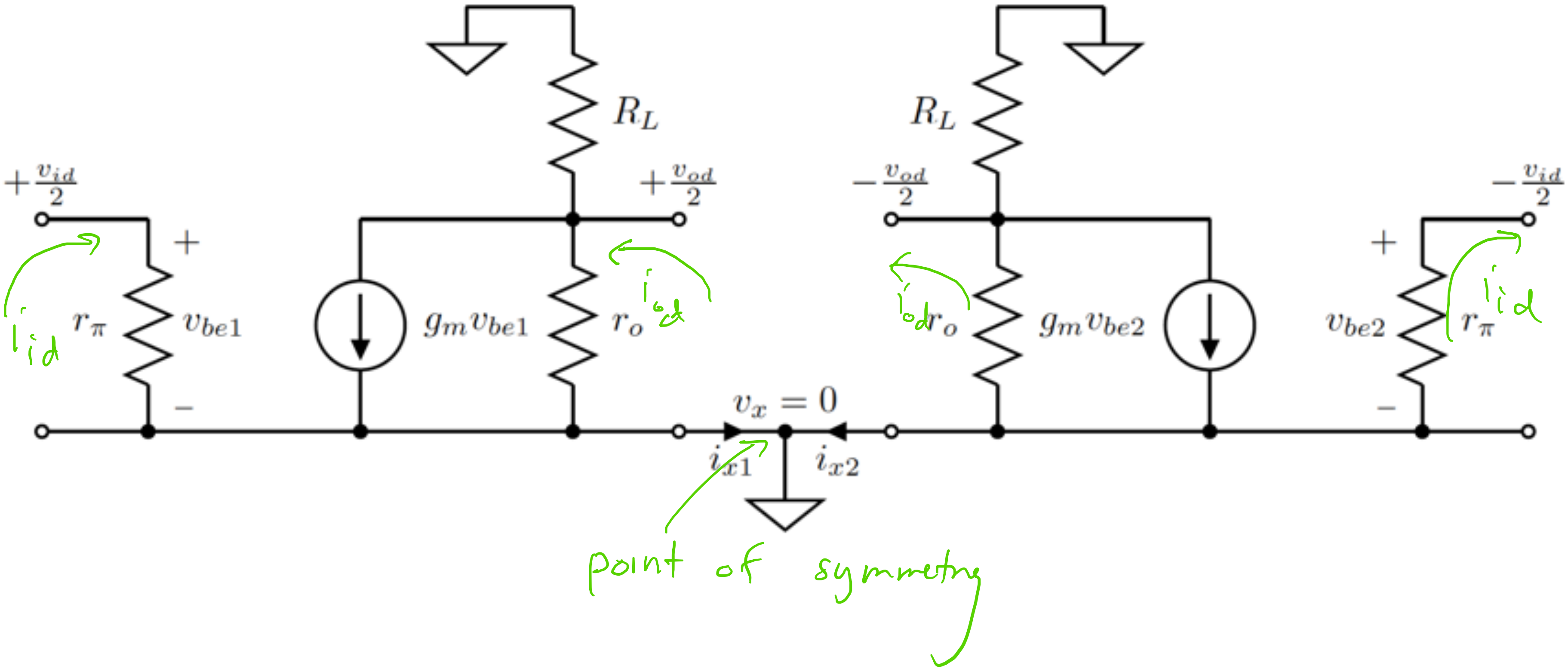
KCL at v_x

$$i_{x1} + i_{x2} = \frac{v_x}{R_{tail}}$$

$$2\left(\frac{1}{r_\pi} + g_m + \frac{1}{r_o}\right) v_x = \frac{v_x}{R_{tail}}$$

$$v_x = 0$$

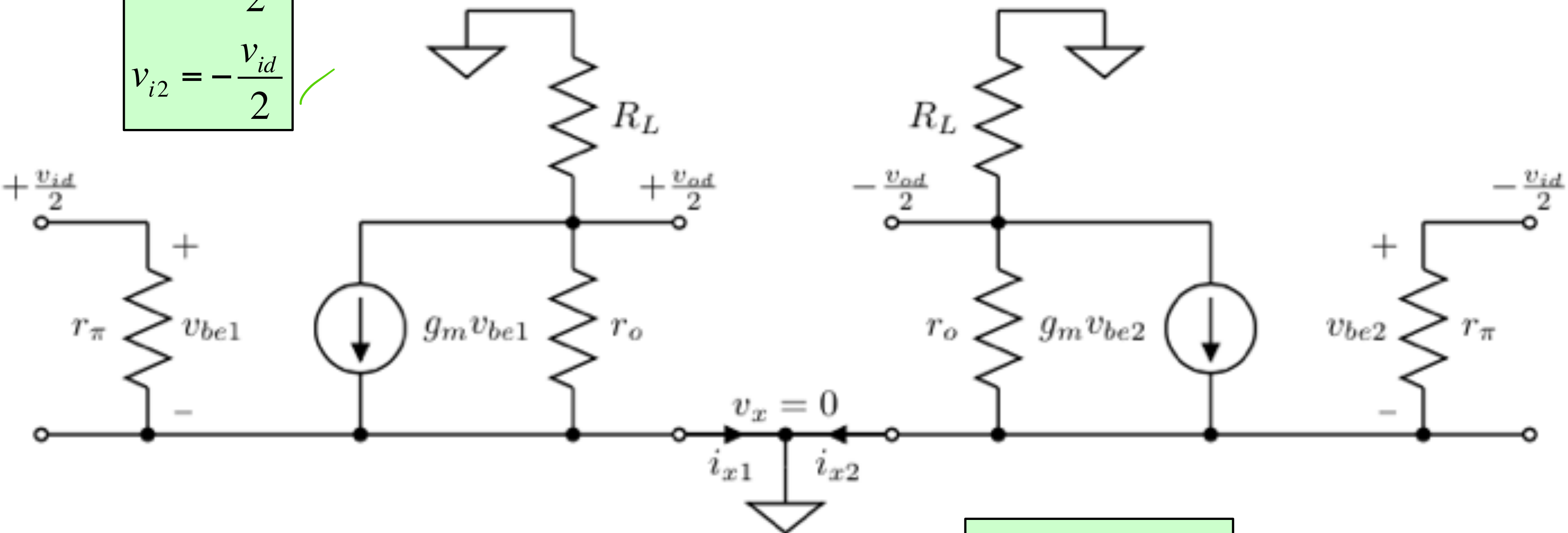
The Differential Mode Half Circuit



Half-circuit analysis (DM)

$$v_{i1} = +\frac{v_{id}}{2}$$

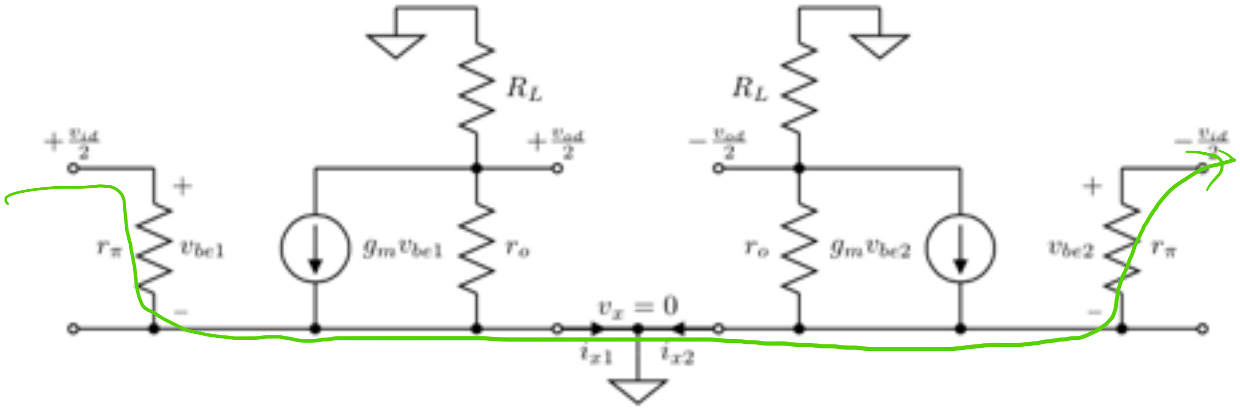
$$v_{i2} = -\frac{v_{id}}{2}$$



$$v_{id} = v_{i1} - v_{i2}$$

$$v_{ic} = \frac{v_{i1} + v_{i2}}{2} = 0$$

Half-circuit analysis (DM)

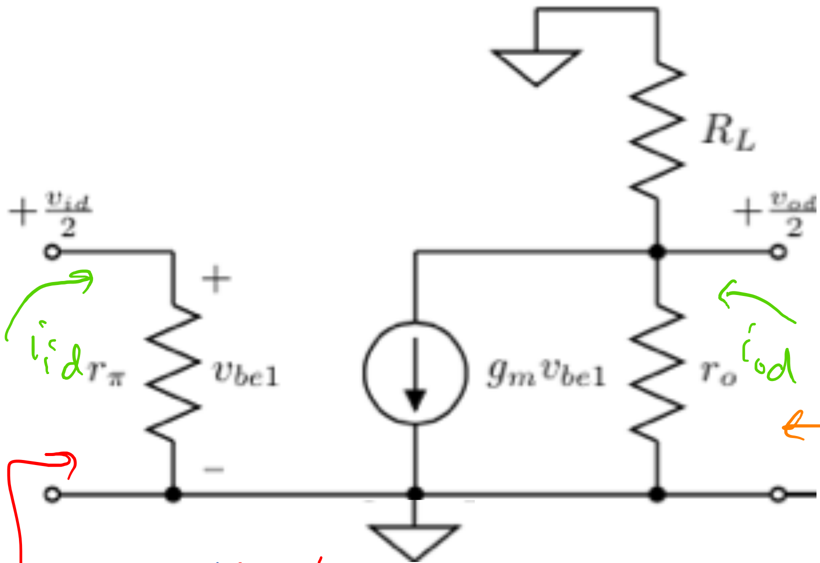


$$v_{i1} - v_{be1} + v_{be2} - v_{i2} = \left(+\frac{v_{id}}{2}\right) - v_{be1} + v_{be2} - \left(-\frac{v_{id}}{2}\right) = 0$$

$$v_{id} = v_{i1} - v_{i2} = v_{be1} - v_{be2}$$

$$i_{x1} = -i_{x2}$$ $\rightarrow$ $i_{x1} = i_{x2} = 0$

Half-circuit analysis (DM)



$$A_{dm} = \frac{+\frac{v_{od}}{2}}{+\frac{v_{id}}{2}} = \frac{v_{od}}{v_{id}} = -g_m \cdot (r_o \parallel R_L)$$

$$R_{id} = \frac{v_{id}}{i_{id}} = 2 \cdot r_\pi$$

$$R_{od} = \frac{v_{od}}{i_{od}} = 2 \cdot (r_o \parallel R_L)$$

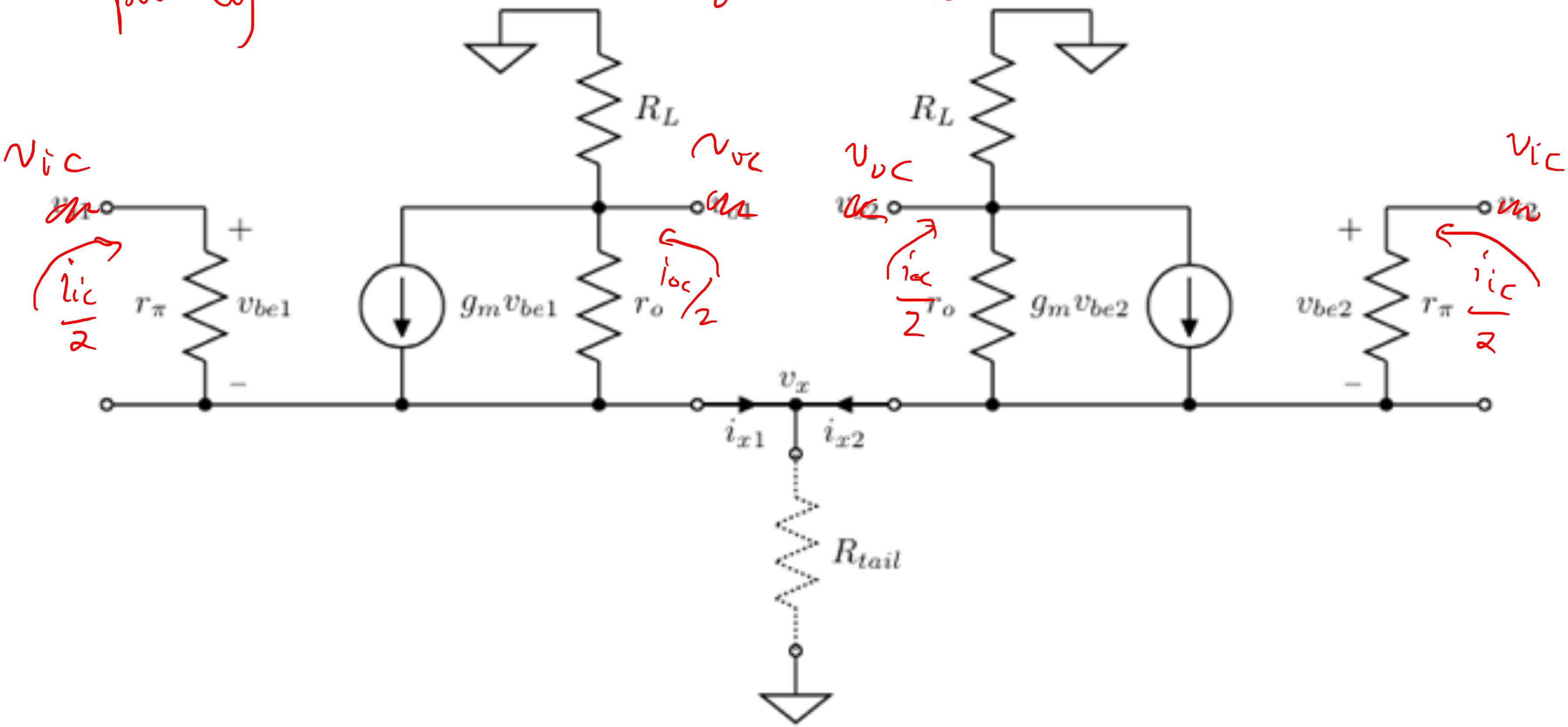
$$G_{md} = \frac{-A_{dm}}{R_{od}} = \frac{g_m}{2}$$

$$R_{in} = \left(\frac{v_{id}/2}{i_{id}} = r_\pi\right) 2$$

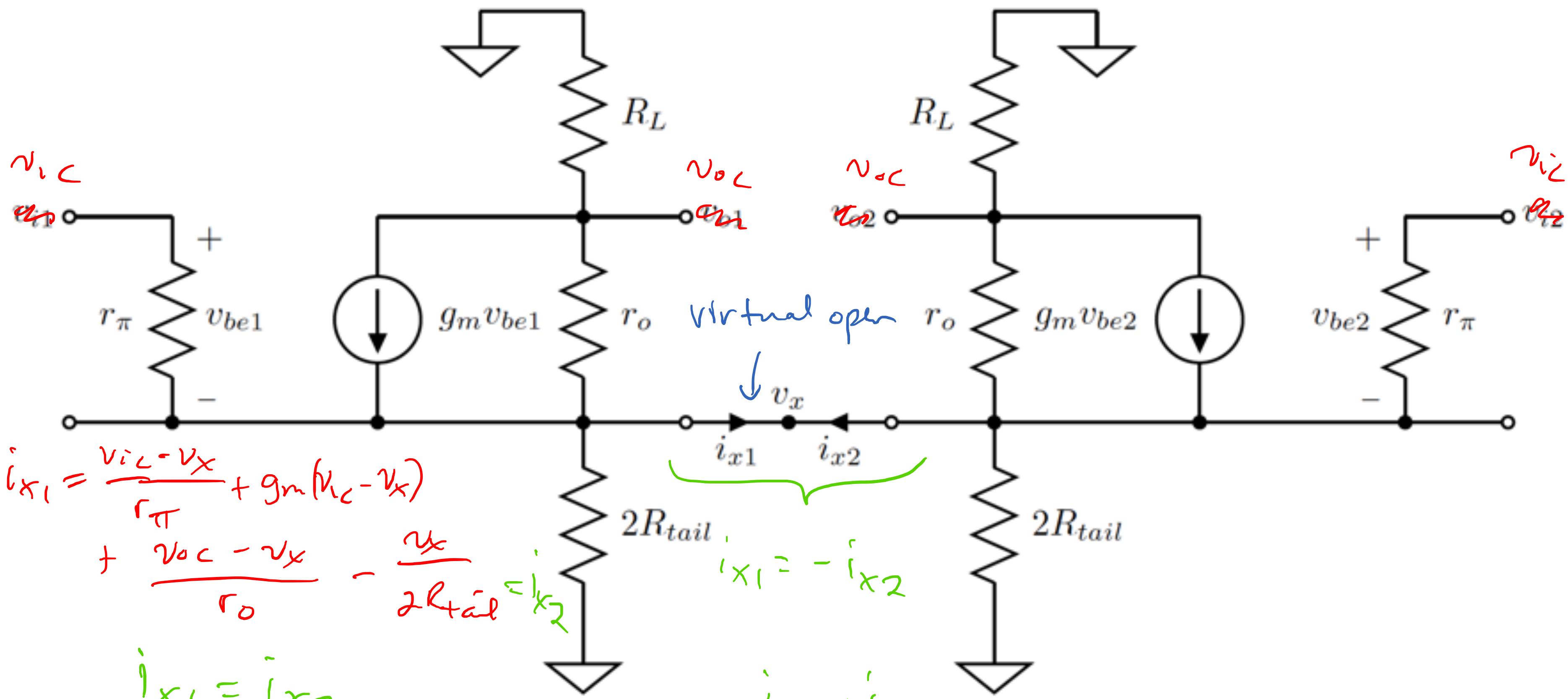
$$R_{out} = \left(\frac{\frac{v_{od}}{2}}{i_{od}} = r_o \,//\, R_L\right) 2$$

Small-signal equivalent circuit

* purely common mode signals ($v_{id} = 0$)



The Common-Mode Half Circuit



$$i_{x1} = \frac{v_{ic} - v_x}{r_\pi} + g_m(v_{ic} - v_x) + \frac{v_{oc} - v_x}{r_o} - \frac{v_x}{2R_{tail}} = i_{x2}$$

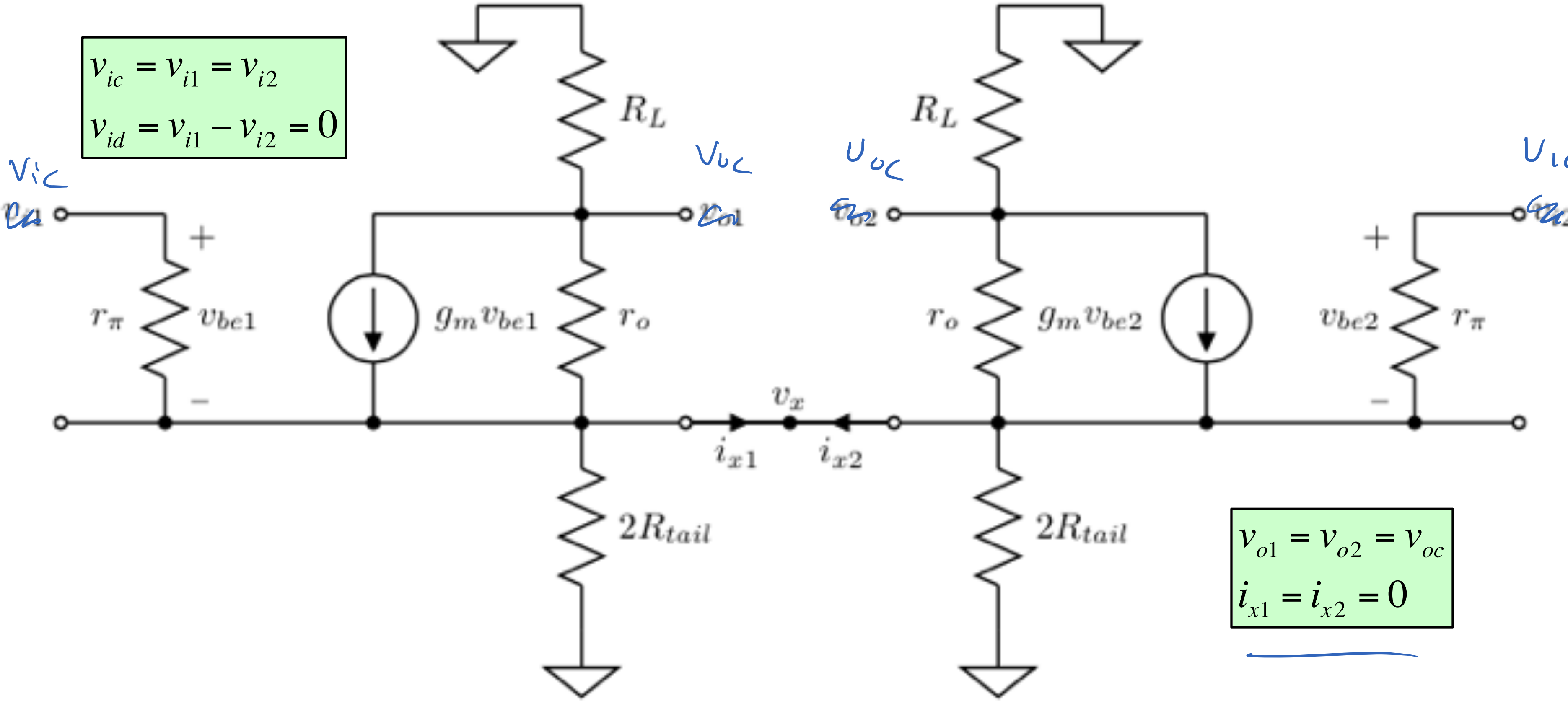
$$i_{x1} = -i_{x2}$$

$$i_{x1} = i_{x2}$$

$$i_{x1} = i_{x2} = \emptyset$$

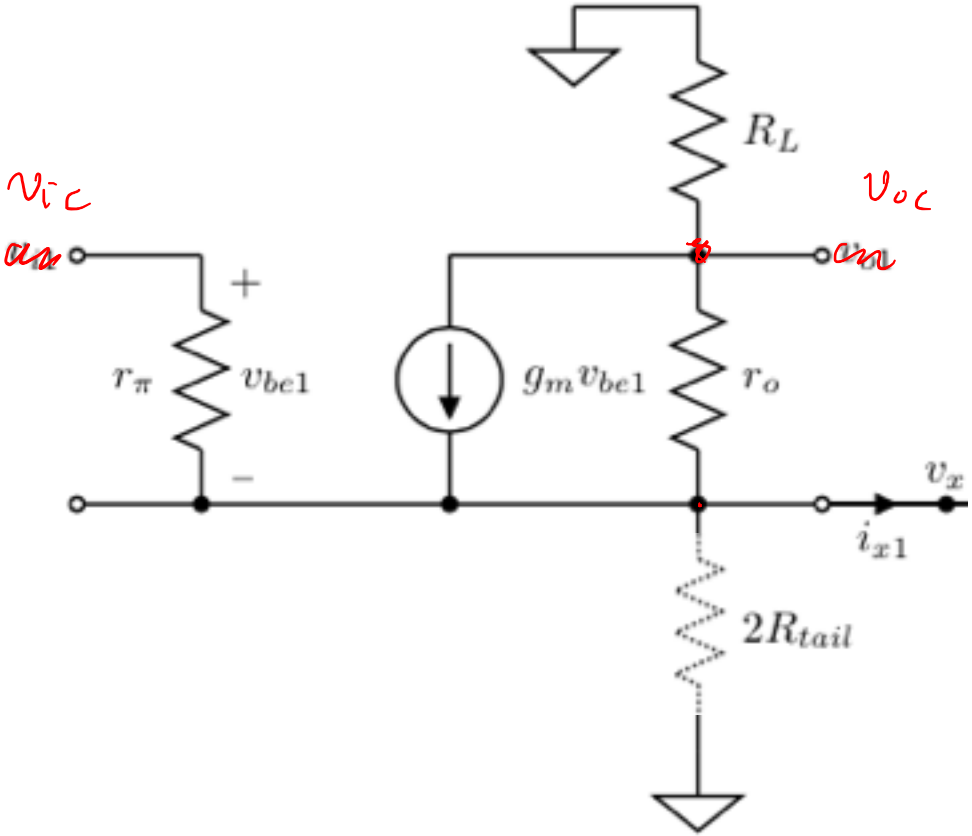
Half-circuit analysis (CM)

$$v_{ic} = v_{i1} = v_{i2}$$
$$v_{id} = v_{i1} - v_{i2} = 0$$



$$v_{o1} = v_{o2} = v_{oc}$$
$$i_{x1} = i_{x2} = 0$$

Half-circuit analysis (CM)



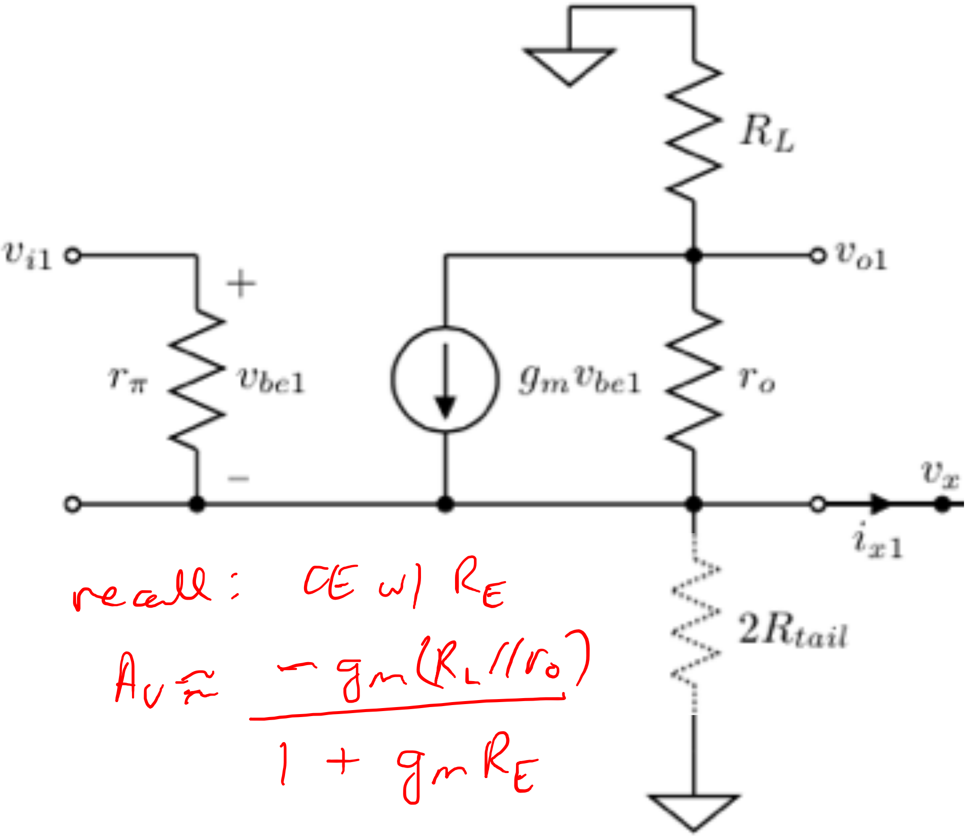
if I_{tail} is ideal $(2R_{tail} \to \infty)$

$$\frac{v_x - v_{ic}}{r_\pi} + \frac{v_x - v_{oc}}{r_o} - g_m (v_{ic} - v_x) = 0$$

$$\frac{v_{oc}}{R_L} = \frac{v_{ic} - v_x}{r_\pi}$$

$$v_{oc} = v_{ic} \cdot \frac{R_L}{R_L + r_o + r_\pi (1 + g_m r_o)}$$

Half-circuit analysis (CM)



recall: CE w/ R_E

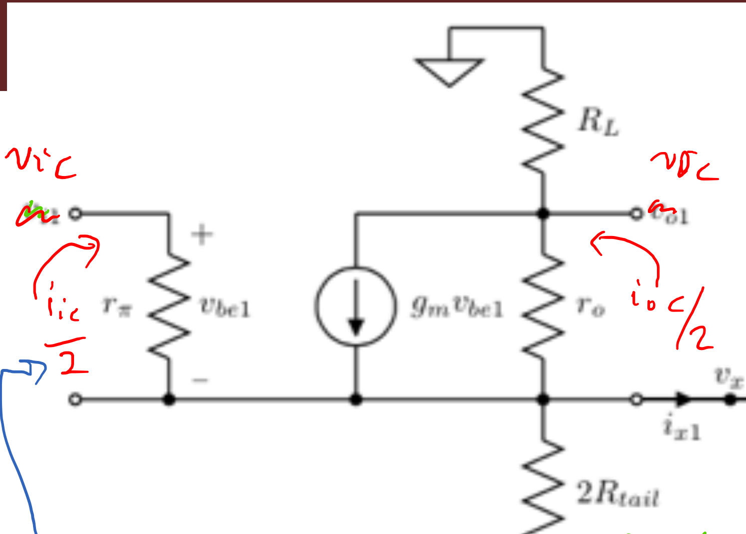
$$A_v \approx \frac{-g_m(R_L // r_o)}{1 + g_m R_E}$$

$$A_{cm} = \frac{v_{oc}}{v_{ic}} = \frac{R_L}{R_L + r_o + r_\pi(1 + g_m r_o)}$$

$$A_{cm} \approx \frac{R_L}{r_\pi g_m r_o} \approx \frac{R_L}{\frac{\beta}{g_m} g_m r_o} \approx \frac{R_L}{\beta \cdot r_o} \approx 0$$

If current source is not ideal:

$$A_{cm} = -\frac{g_m R_L}{1 + 2 \cdot g_m R_{tail}}$$



$$R_{in} = \left(\frac{v_{ic}}{\frac{i_{ic}}{2}} = r_\pi(1+g_m 2R_{tail})\right)\frac{1}{2}$$

$$R_{out} = \frac{v_{oc}}{\frac{i_{oc}}{2}} = r_o(1+g_m 2R_{tail}) // R_L$$

$$A_{cm} = \frac{v_{oc}}{v_{ic}} = \frac{-g_m(r_o // R_L)}{1+g_m(2R_{tail})}$$

$$R_{ic} = \frac{v_{ic}}{i_{ic}} = \frac{r_\pi(1+g_m(2R_{tail}))}{2}$$

$$R_{oc} = \frac{v_{oc}}{i_{oc}} = \frac{r_o(1+g_m(2R_{tail})) // R_L}{2}$$

$$G_{mc} = \frac{-A_{cm}}{R_{oc}} \approx \frac{2g_m}{1+2g_m R_{tail}}$$

Next Meeting

- Finish up discussion of Differential Circuits
- Compound Amplifiers