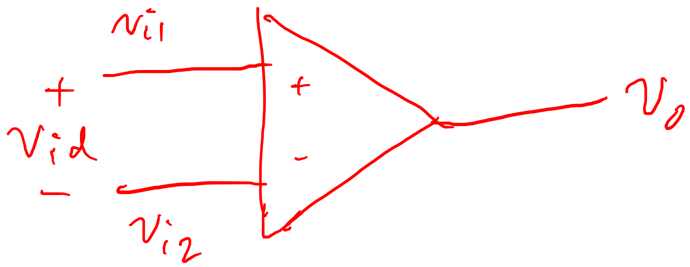
EEE 51: Second Semester 2017 - 2018

Lecture 12

Differential to Single-Ended Conversion

Today

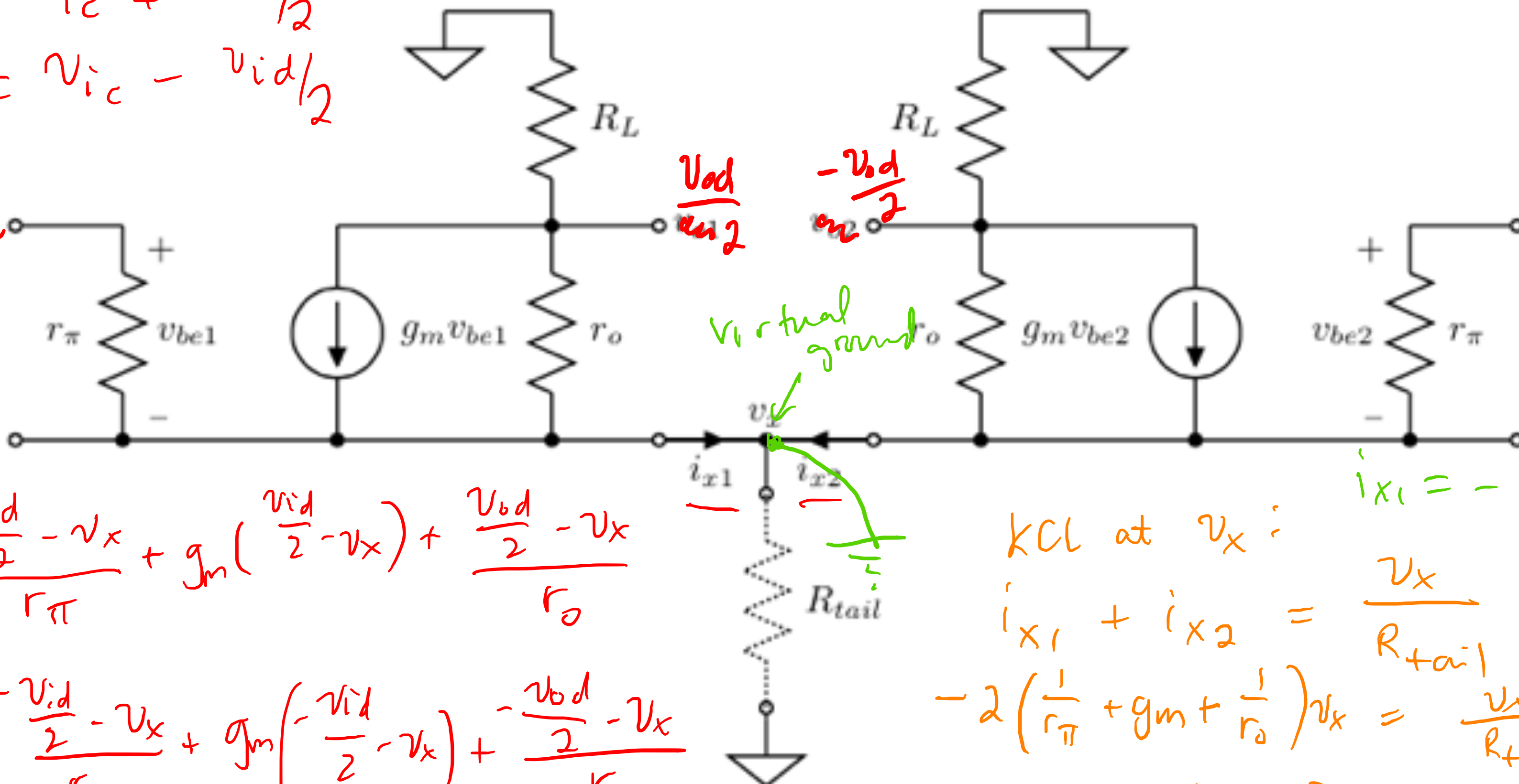
- Small signal analysis of differential circuits
- Differential to single-ended conversion



The Differential-Mode Half Circuit $(v_{ic} = \emptyset)$

$$v_{i1} = v_{ic} + v_{id}/2$$

$$v_{i2} = v_{ic} - v_{id}/2$$



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

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

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

KCL at v_x:

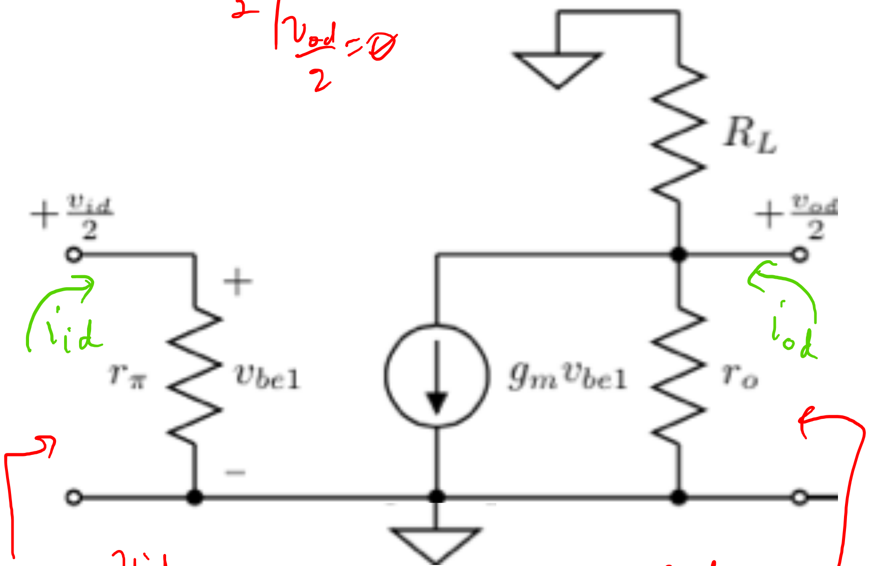
$$i_{x1} + i_{x2} = \frac{v_x}{R_{tail}}$$

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

$$v_x = \emptyset$$

The Differential Half Circuit

$$G_m = \left.\frac{i_{od}}{\frac{v_{id}}{2}}\right|_{\frac{v_{od}}{2}=0} = g_m$$



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

$$R_o = \frac{\frac{v_{od}}{2}}{i_{od}} = r_o // R_L$$

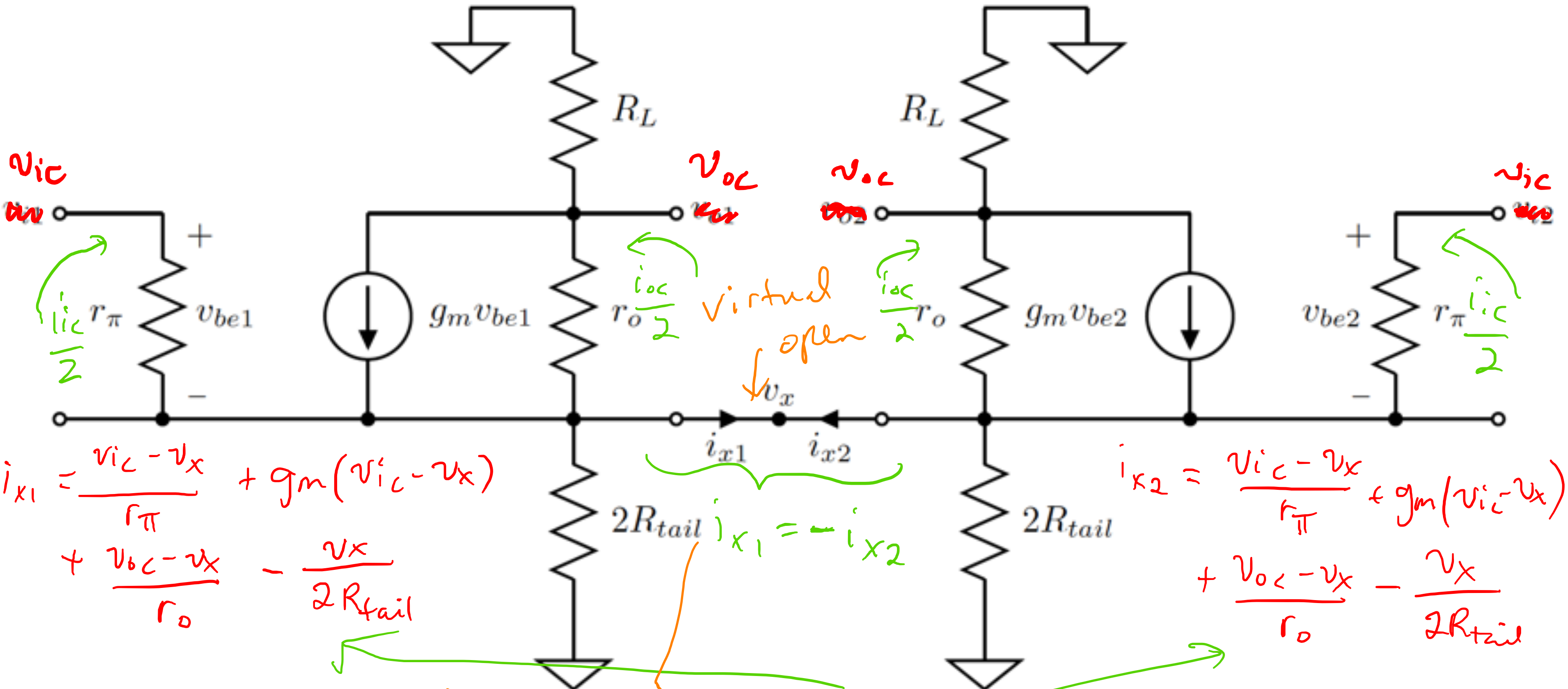
$$A_{dm} = \frac{+\frac{v_{od}}{2}}{+\frac{v_{id}}{2}} = \frac{v_{od}}{v_{id}} = -g_m \cdot \left(r_o \parallel R_L\right)$$

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

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

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

The Common-Mode Half Circuit



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

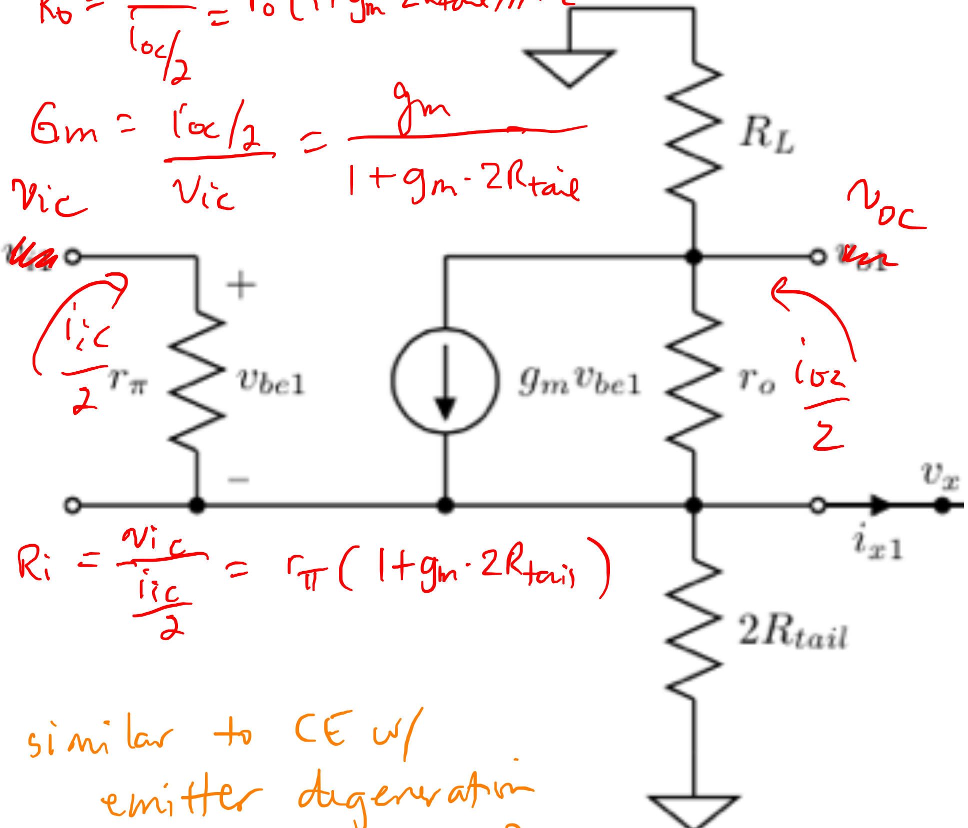
$$i_{x2} = \frac{v_{ic}-v_x}{r_\pi} + g_m(v_{ic}-v_x) + \frac{v_{oc}-v_x}{r_o} - \frac{v_x}{2R_{tail}}$$

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

$i_{x1} = i_{x2} = 0$

$i_{x1} = i_{x2}$

The Common-Mode Half Circuit



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

$$G_m = \frac{i_{oc}/2}{v_{ic}} = \frac{g_m}{1+g_m\cdot 2R_{tail}}$$

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

similar to CE w/ emitter degeneration ($R_E \to 2R_{tail}$)

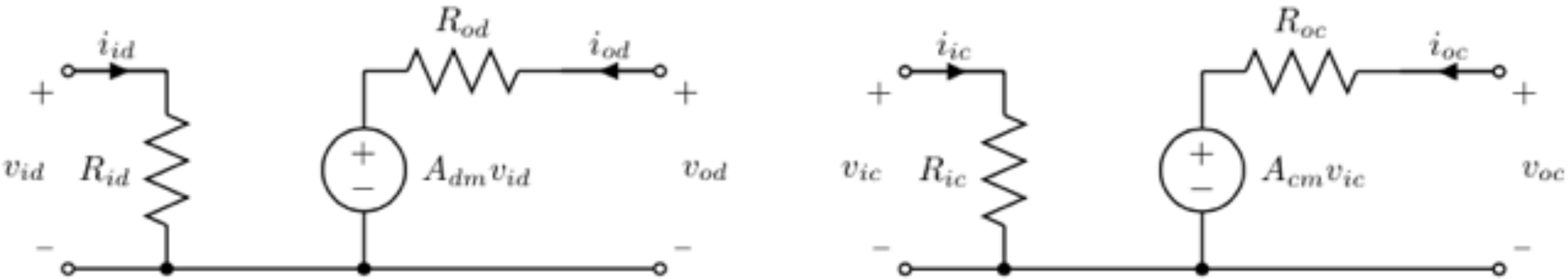
$$A_{cm} = \frac{v_{oc}}{v_{ic}} = -\frac{g_m R_L}{1+2\cdot g_m R_{tail}}$$

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

$$R_{oc} = \frac{v_{oc}}{i_{oc}} = \frac{r_o\left(1+2\cdot g_m R_{tail}\right) \parallel R_L}{2}$$

$$G_{mc} = \frac{i_{oc}}{v_{ic}} = \frac{2g_m}{\left(1+2\cdot g_m R_{tail}\right)}$$

Small-signal model of differential amplifier



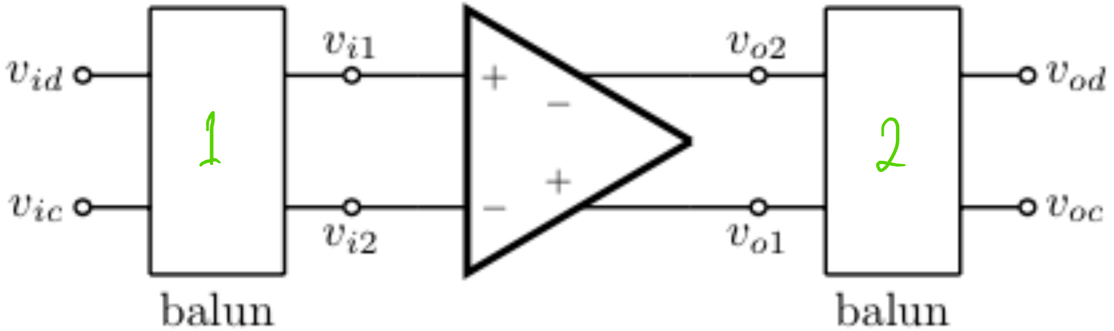
(a) Differential-mode

(b) Common-mode

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

$$v_{o2} = v_{oc} - \frac{v_{od}}{2}$$

The Balun (Balanced - Unbalanced Circuit)



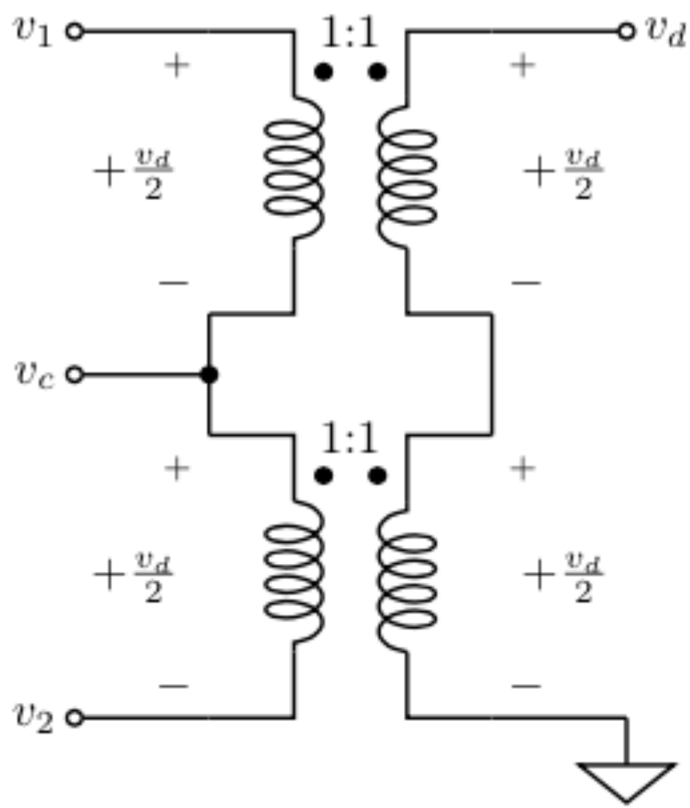
balun 1 : $v_{i1} = v_{ic} + \frac{v_{id}}{2}$

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

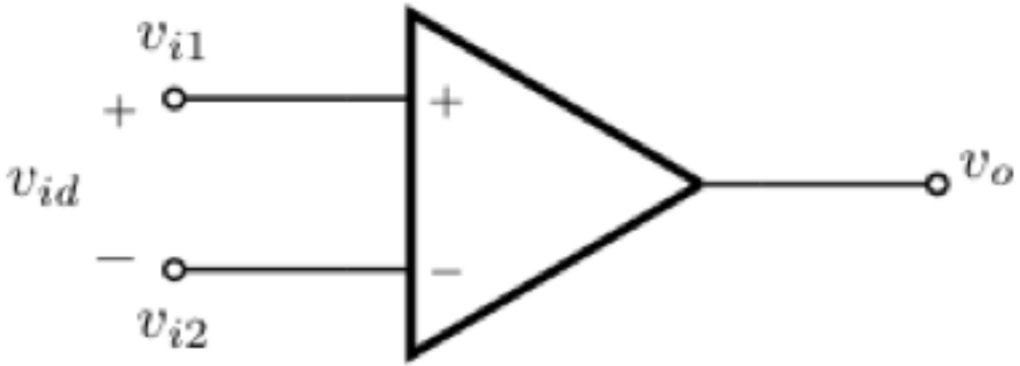
balun 2 : $v_{oc} = \frac{v_{o1} + v_{o2}}{2}$

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

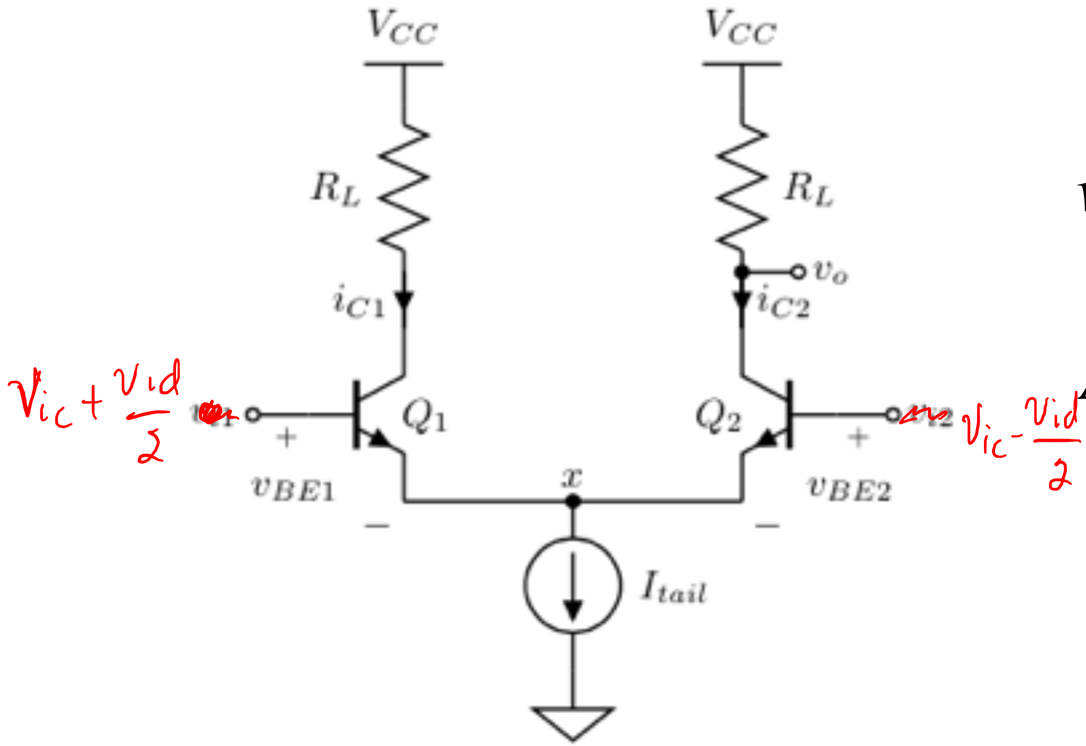
The Balun



Differential to Single-Ended Conversion



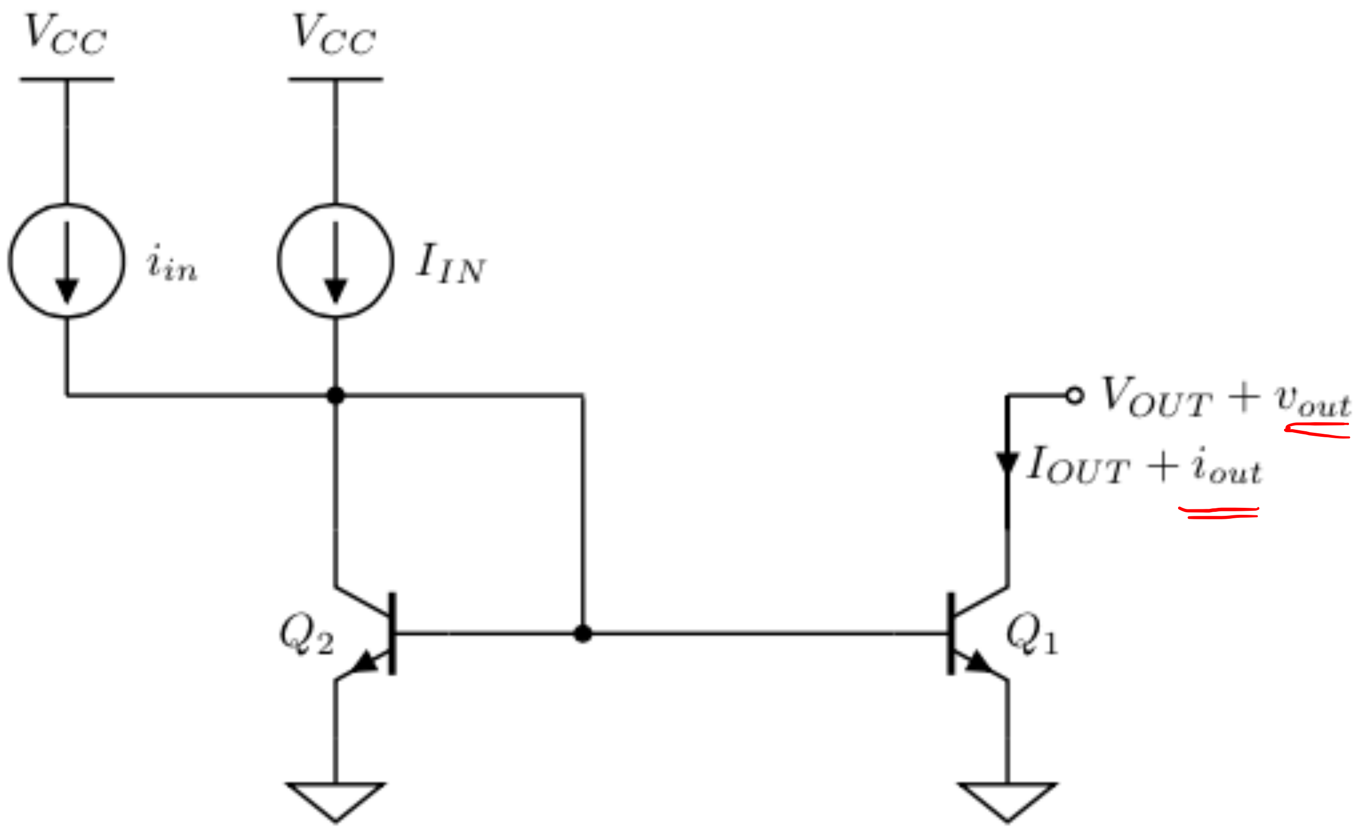
Differential to Single-Ended Conversion



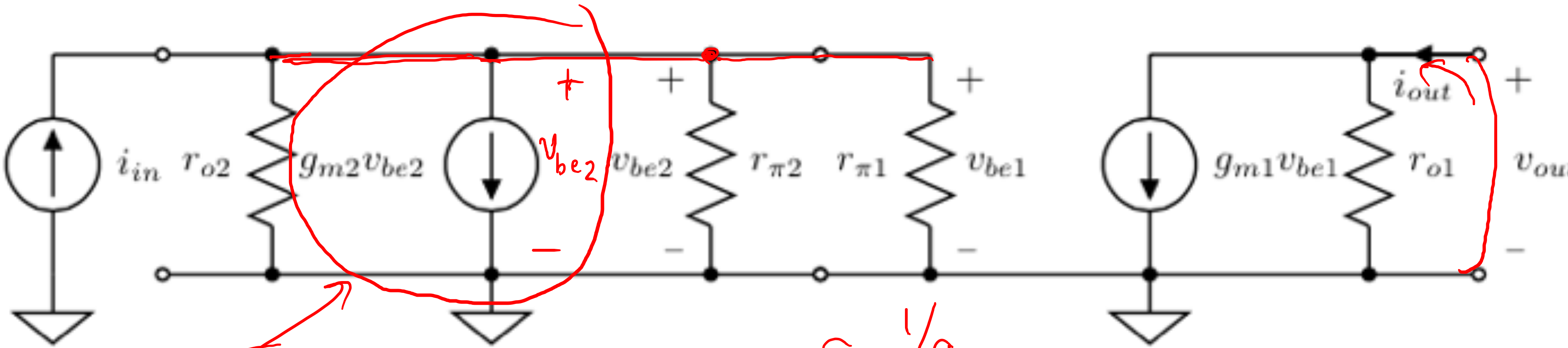
$$v_o = -g_m (r_o \parallel R_L) \cdot \left(-\frac{v_{id}}{2} \right)$$

$$A_v = \frac{v_o}{v_{id}} = \frac{g_m (r_o \parallel R_L)}{2}$$

The Current Mirror Revisited



The Current Mirror Revisited



$\frac{1}{g_{m2}}$

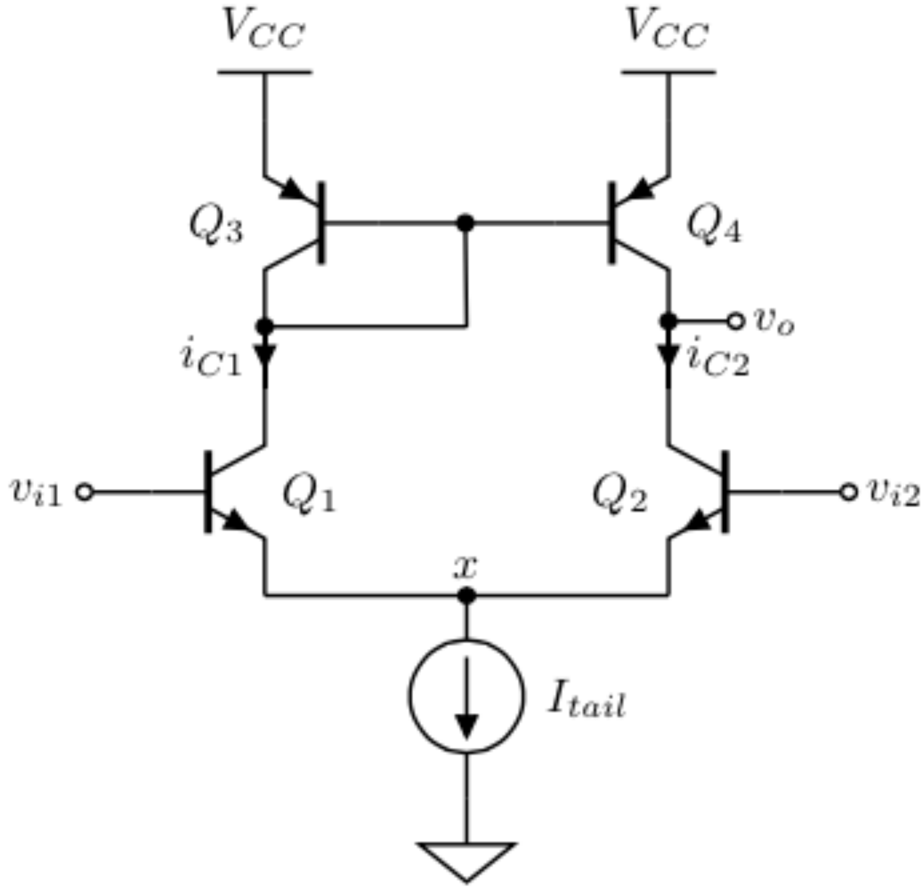
$$v_{be1} = v_{be_2} = i_{in} \cdot \left(\overbrace{\frac{1}{g_{m2}} \| r_{o2} \| r_{\pi1} \| r_{\pi2}}^{\approx 1/g_{m2}} \right) \approx \frac{i_{in}}{g_{m2}}$$

at no load; ($v_{out} = \emptyset$)

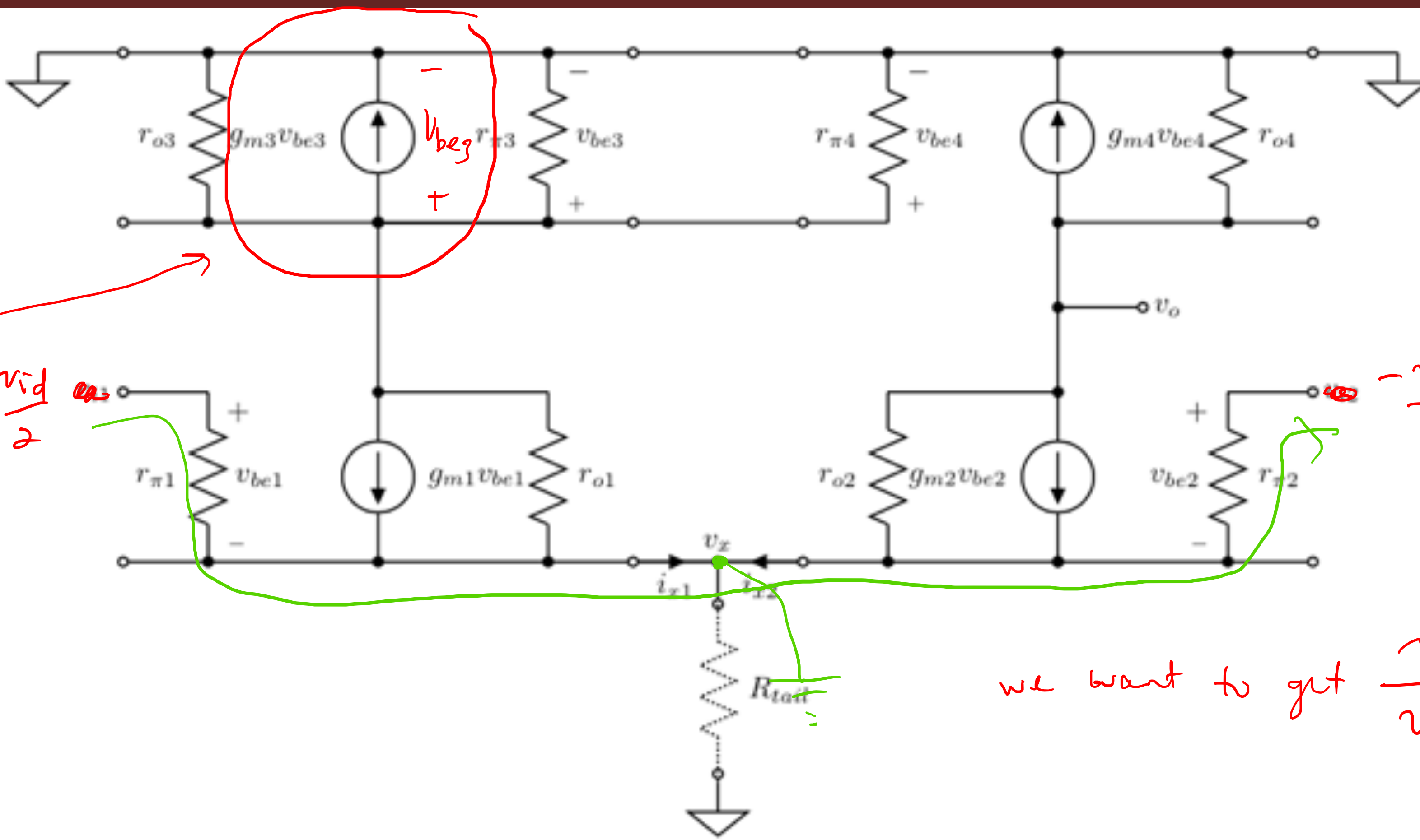
$$i_{out} \approx g_{m1} v_{be1} = \frac{g_{m1}}{g_{m2}} \cdot i_{in} \approx i_{in} \quad \rightarrow \quad \frac{i_{out}}{i_{in}} = 1$$

$g_{m1} = g_{m2}$

Current Mirror Loads



Current Mirror Loads



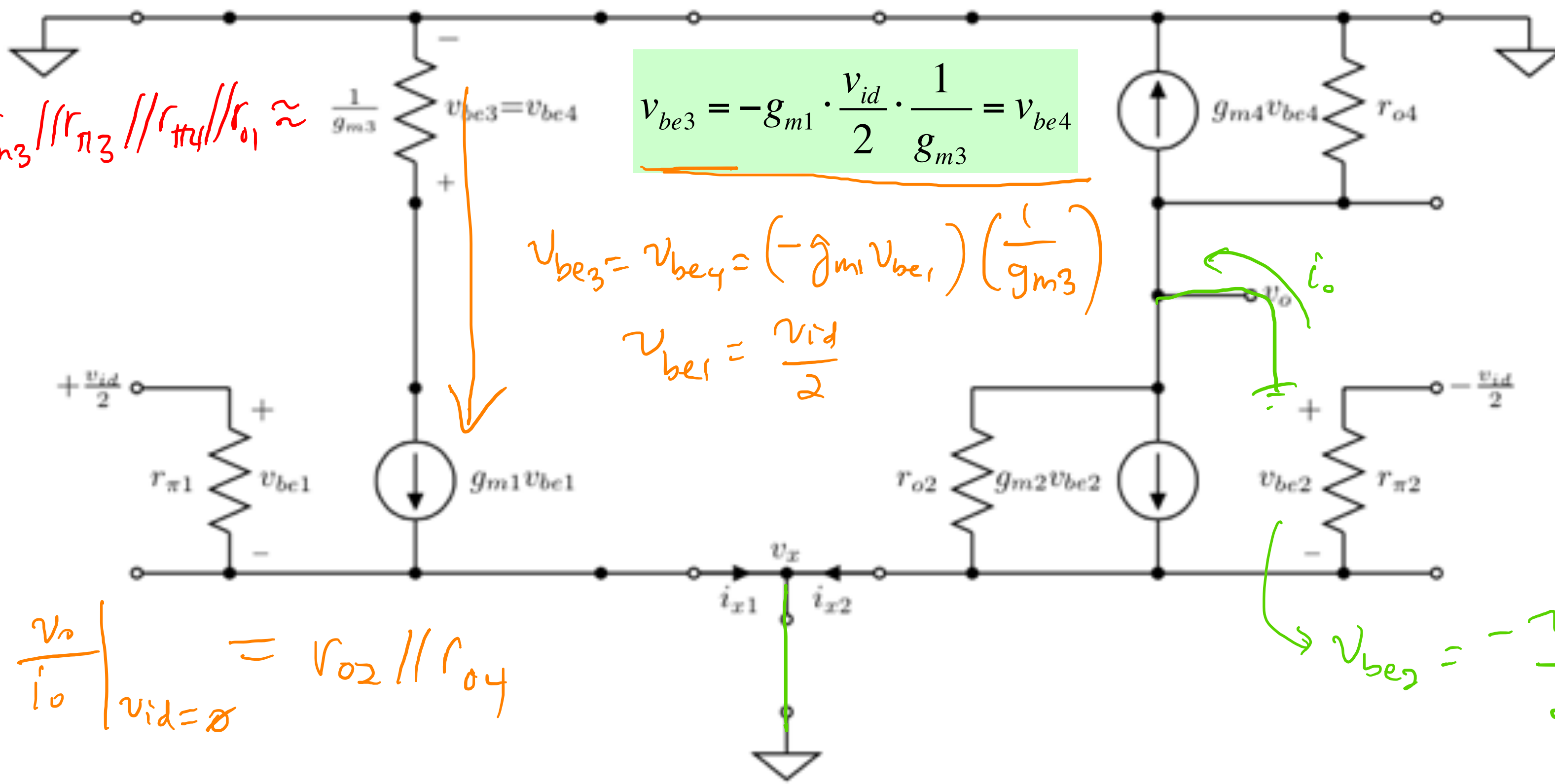
$\frac{1}{g_{m3}}$

$\frac{v_{id}}{2}$

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

we want to get $\frac{v_o}{v_{id}}$

Current Mirror Loads



$$r_{o3} // \frac{1}{g_{m3}} // r_{\pi 3} // r_{\pi 4} // r_{o1} \approx \frac{1}{g_{m3}}$$

$$v_{be3} = -g_{m1} \cdot \frac{v_{id}}{2} \cdot \frac{1}{g_{m3}} = v_{be4}$$

$$v_{be3} = v_{be4} = (-g_{m1} v_{be1}) \left(\frac{1}{g_{m3}}\right)$$

$$v_{be1} = \frac{v_{id}}{2}$$

i_o

$$v_{be2} = -\frac{v_{id}}{2}$$

$$R_o = \frac{v_o}{i_o}\bigg|_{v_{id}=0} = r_{o2} // r_{o4}$$

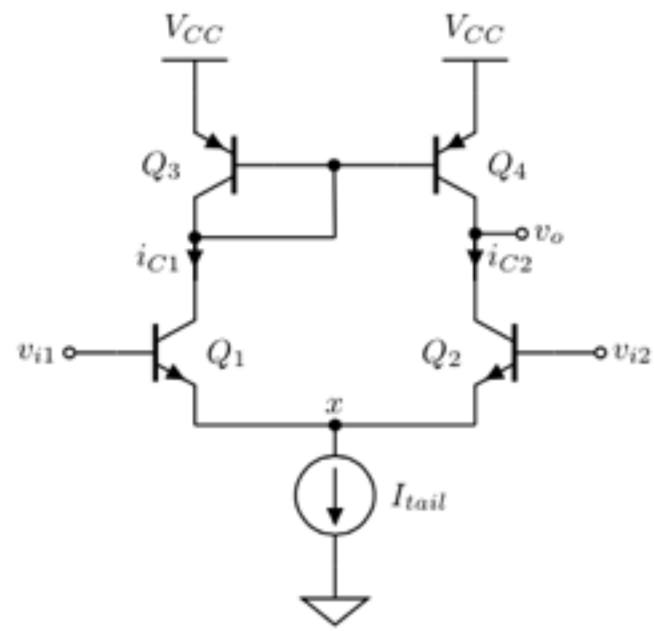
at no load, $i_o = g_{m4} \cdot v_{be4} + g_{m2} \cdot v_{be2} = -g_{m4} \cdot g_{m1} \cdot \frac{v_{id}}{2} \cdot \frac{1}{g_{m3}} - g_{m2} \cdot \frac{v_{id}}{2}$

($v_{out} = 0$)

Current Mirror Loads

$$i_o = g_{m4}\cdot v_{be4} + g_{m2}\cdot v_{be2} = -\cancel{g_{m4}}\cdot g_{m1}\cdot\frac{v_{id}}{2}\cdot\frac{1}{\cancel{g_{m3}}} - g_{m2}\cdot\frac{v_{id}}{2}$$

If $g_{m1} = g_{m2} = g_m$ and $g_{m3} = g_{m4}$,



$$i_o = -g_m \cdot v_{id}$$; $$\frac{i_o}{v_{id}} = -g_m$$

$$G_m = -g_m$$

$$R_o = (r_{o2} \parallel r_{o4})$$

$$A_v = \frac{v_o}{v_{id}} = -G_m R_o = +g_{m2}(r_{o2} \parallel r_{o4})$$

Next Meeting

- Compound Amplifiers