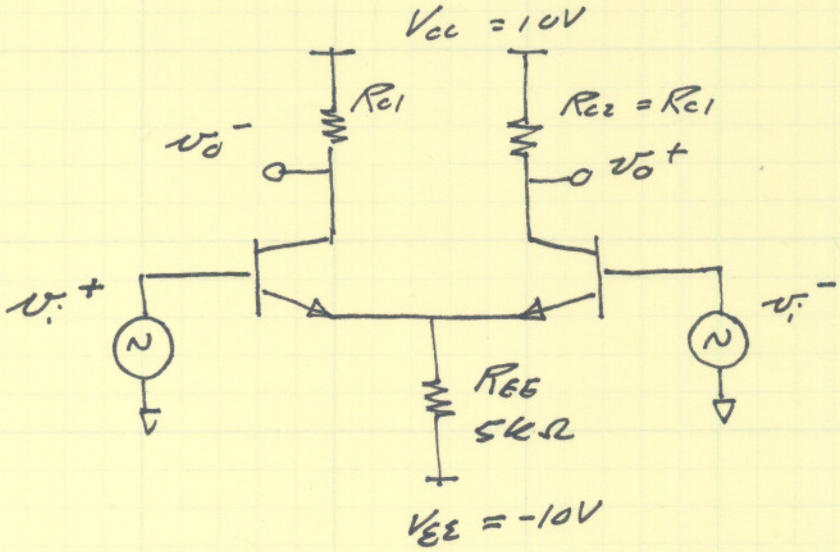
ECE137A Notes set 8

Differential Amplifiers

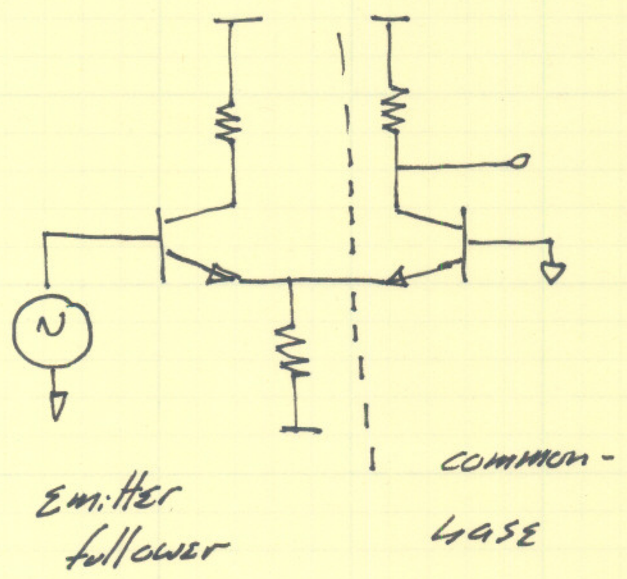


$\beta = 100$

$V_A = 100V$

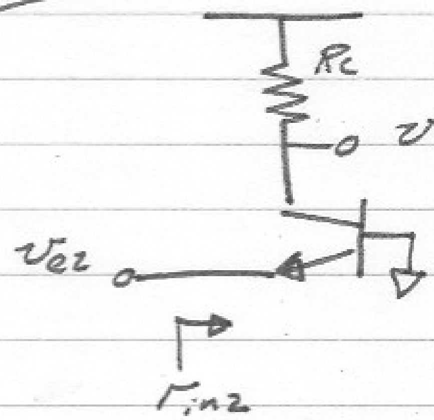
$R_{C1} = R_{C2} = 3k\Omega$

First consider "single-ended input" $\Rightarrow v_i^- = 0V$



Stage 2

Common base

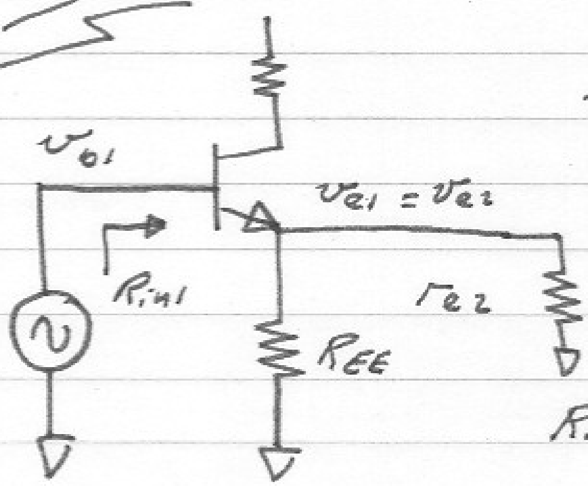


$$v_{c2}/v_{e2} \cong \frac{R_o}{r_e(1+R_c/R_o)}$$

$$\cong \frac{R_o \| R_c}{r_e}$$

$$r_{in2} = r_{e2}(1+R_c/R_o) \cong r_{e2}$$

Stage 1



$$\frac{v_{e1}}{v_{b1}} = \frac{R_{Leq}}{R_{Leq}+r_{e1}} \cong \frac{R_{EE}\|r_{e2}}{r_{e1}+R_{EE}\|r_{e2}}$$

$$\cong \frac{r_{e2}}{r_{e1}+r_{e2}} = 1/2$$

$$R_{in1} = (\beta+1)(r_{e1}+R_{Leq1})$$

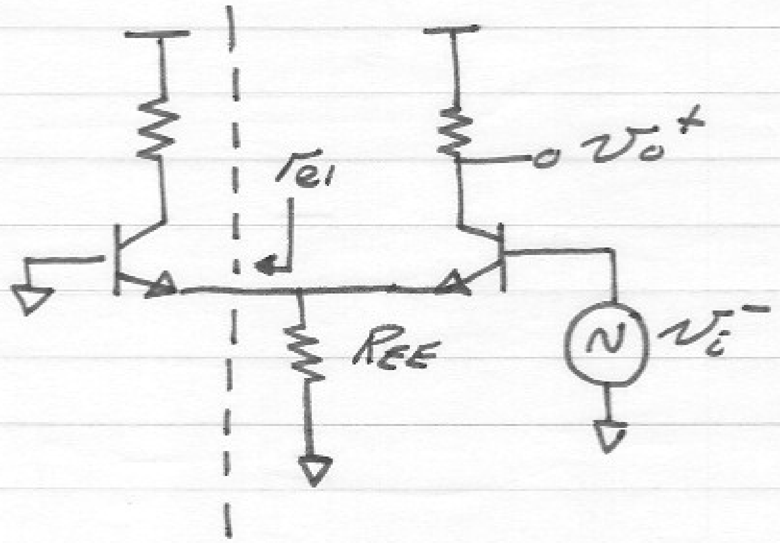
$$= (\beta+1)(r_{e1}+r_{e2}\|R_{EE})$$

$$\cong (\beta+1)(r_{e1}+r_{e2})$$

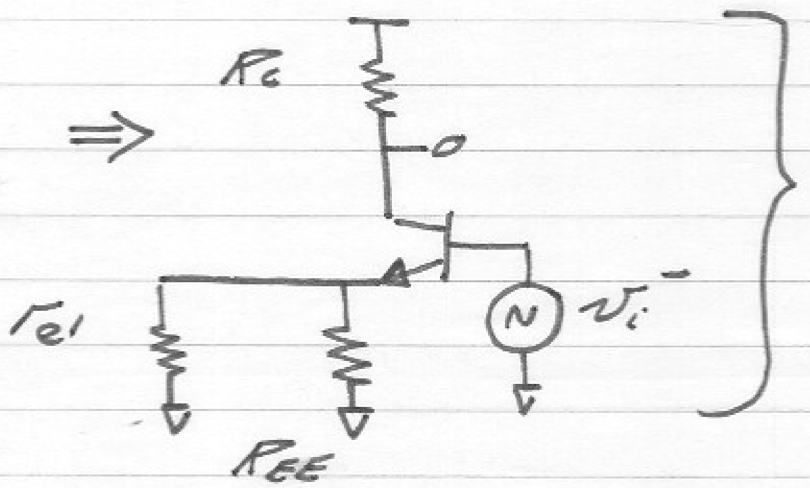
overall

$$\frac{v_{c2}}{v_i^{+}} = \frac{v_{out}^{+}}{v_i^{+}} \cong \frac{R_c}{r_{e2}} \; \frac{r_{e2}}{r_{e1}+r_{e2}} = \frac{R_c}{r_{e1}+r_{e2}}$$

Now consider case when $v_o^+ = 0$



$\Rightarrow$



Common emitter!

$R_C \| R_{out2}$, neglect r_{out2}

$$\frac{v_o^+}{v_i^-} = \frac{-R_{Leq}}{r_{e2} + r_{e1} \| R_{EE}} \cong \frac{-R_C}{r_{e1} + r_{e2}}$$

We thus get the same gain, except for a reversal of signs

$$\Rightarrow v_{out}^+ \cong \frac{R_C}{r_{e1} + r_{e2}} \left(v_o^+ - v_o^- \right)$$

Another – easier – way to analyze the differential amplifier:

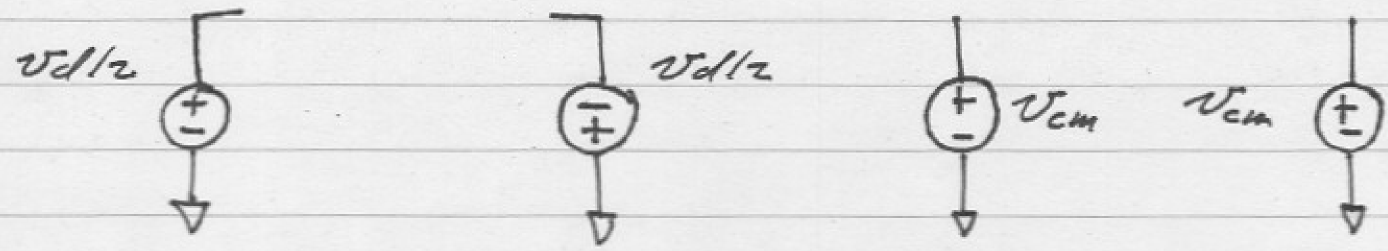
<u>Differential and Common-mode gains:</u>

differential signal: $v_d = v_i^+ - v_i^-$

common-mode (average) signal: $v_{cm} = (v_i^+ + v_i^-)/2$

We want to amplify the differential signal not the common-mode signal.

Differential | Common-Mode



$$\left.\begin{aligned} v_d &= v_i^+ - v_i^- \\ v_{cm} &= \frac{v_i^+ + v_i^-}{2} \end{aligned}\right\} \Longleftrightarrow \left\{\begin{aligned} v_i^+ &= v_{cm} + v_d/2 \\ v_i^- &= v_{cm} - v_d/2 \end{aligned}\right.$$

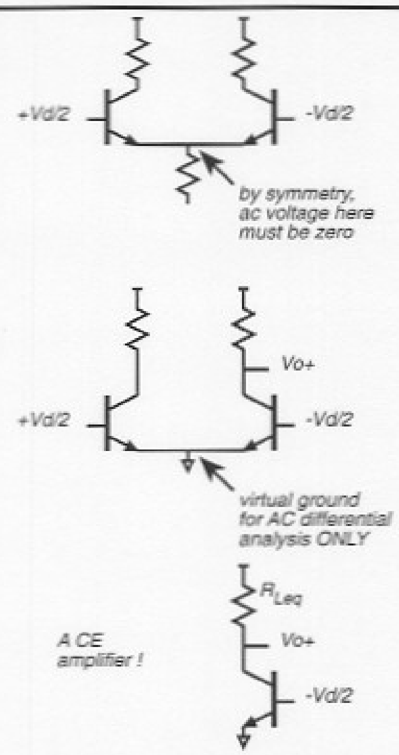
Differential Gain

$$\frac{V_o}{(-V_d/2)} = \frac{-R_{Leq}}{r_{e2}}$$

Hence

$$\frac{V_o}{V_d} = \frac{R_{Leq}}{2r_{e2}} = \frac{R_{Leq}}{(r_{e1}+r_{e2})}$$

Because $r_{e1} = r_{e2}$



Common-Mode Gain

$$A_{CM} = \frac{V_o}{V_{CM}} = \frac{-R_{Leq}}{r_{e2}+2R_{EE}} \cong \frac{-R_{Leq}}{2R_{EE}}$$

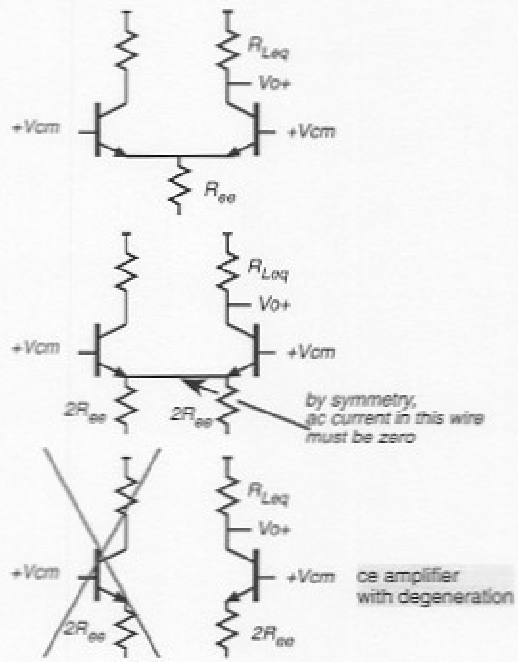
But we have already found that

$$A_D = \frac{V_o}{V_d} = \frac{R_{Leq}}{2r_{e2}} = \frac{R_{Leq}}{(r_{e1}+r_{e2})}$$

So the common-mode rejection ratio :

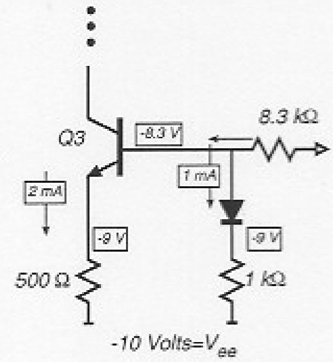
$$CMRR = \frac{A_D}{A_{CM}} = \frac{R_{EE}}{r_e}$$

where $r_e = r_{e1} = r_{e2}$

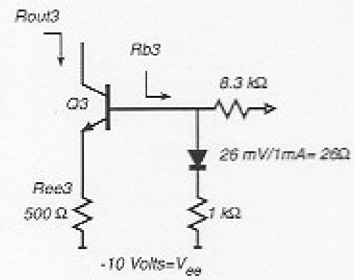


Constant-current source for increased CMRR

The simple voltage divider + diode forces 1.0 Volts across the emitter resistor → pick Ree for desired current.

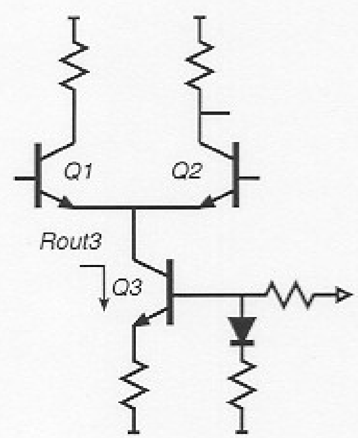


$$R_{out3} = r_{ce3}\left[1 + \frac{R_{EE3}}{r_{e3}} \frac{R_{be3}}{R_{be3} + R_{E3} + R_{b3}}\right] = 994\ \text{k}\Omega$$

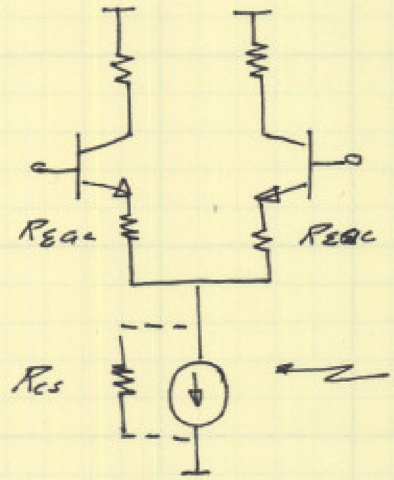


Constant-current source for increased CMRR

$$CMRR = \frac{R_{out3}}{r_{e1,2}} = \frac{994k\Omega}{26\Omega}$$

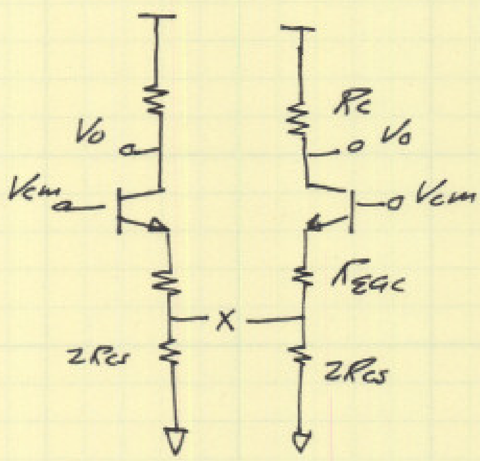


Differential pair with degeneration:



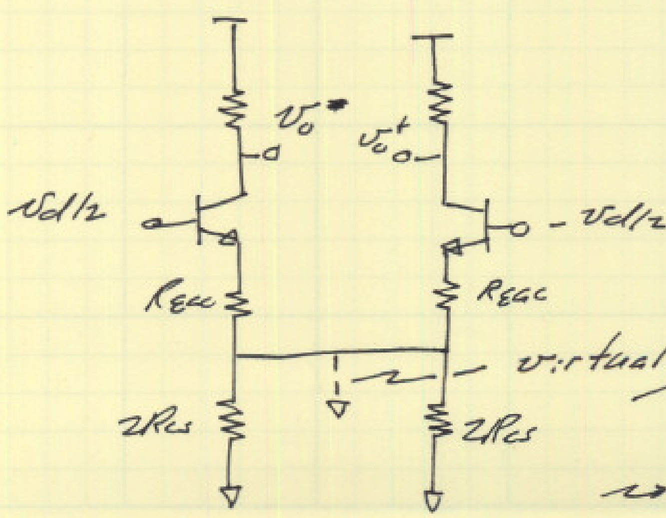
Norton equivalent of active or passive current source

Common-mode:



$$\frac{V_o}{V_{cm}} \cong \frac{R_C \,//\, R_{out,collector}}{r_E + R_{EGC} + 2R_{CS}}$$

Differential:

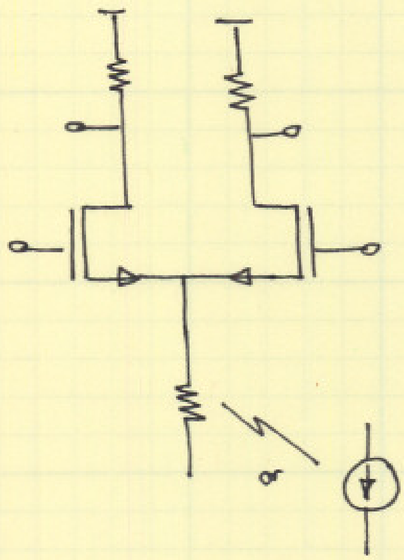


$$v_o/v_d = \frac{R_C \,//\, R_{out,collector}}{2(r_E + R_{EGC})}$$

virtual ground

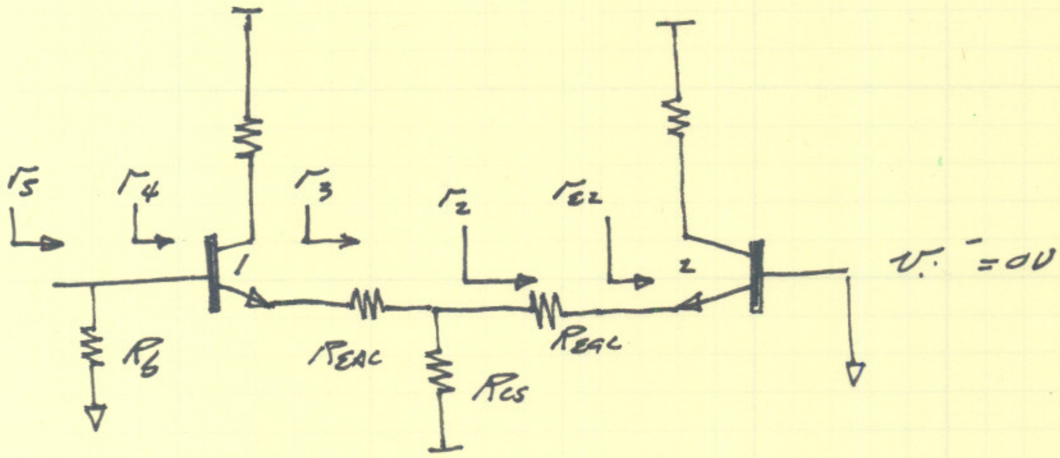
→ CMRR is reduced

we can also construct differential amplifiers from MOSFETs, thus



... and the analysis is identical to that of the bipolar implementation.

Differential stage input impedances



$r_2 = r_{E2} + R_{EAC}$

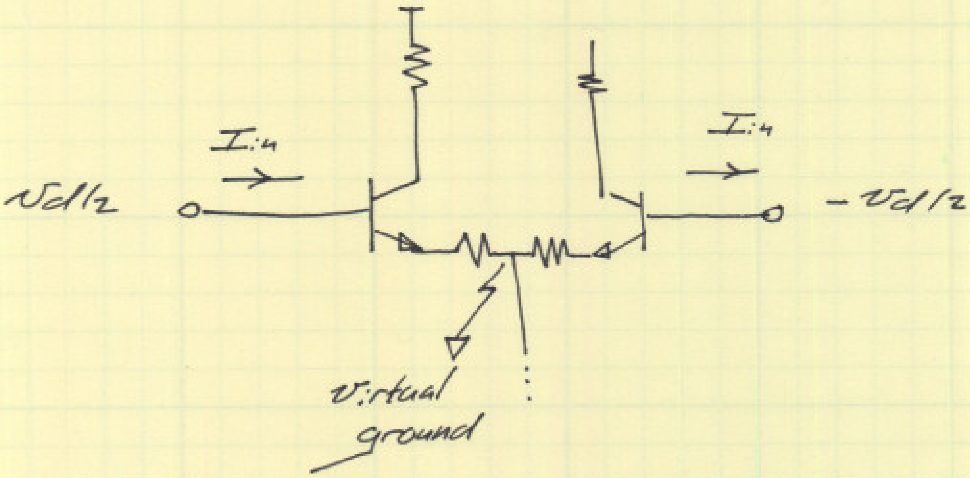
$r_3 = R_{EAC} + r_2 // R_{CS} \cong 2R_{EAC} + r_{E2}$
...if R_{CS} is large

$r_4 = \beta(r_{E1} + r_3) \cong 2\beta(r_E + R_{EAC})$

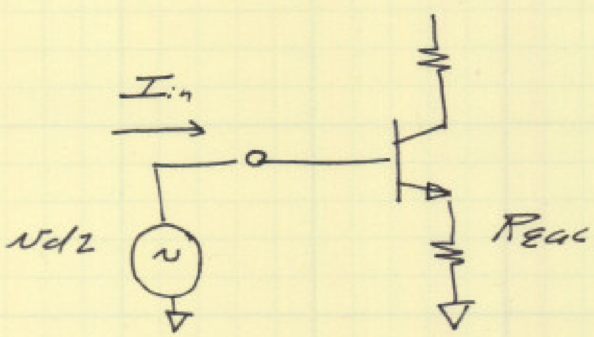
$r_5 = R_6 // r_4.$

This is the single-ended input impedance.

Differential input impedance



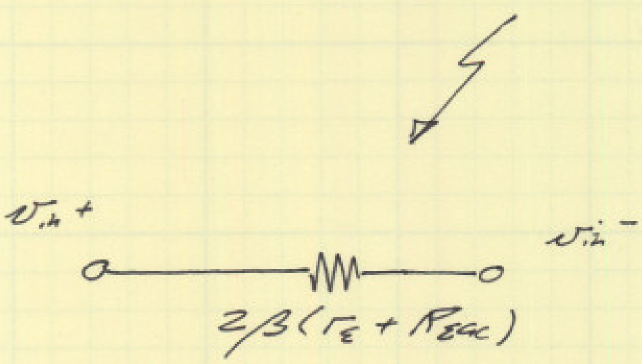
again use symmetry:



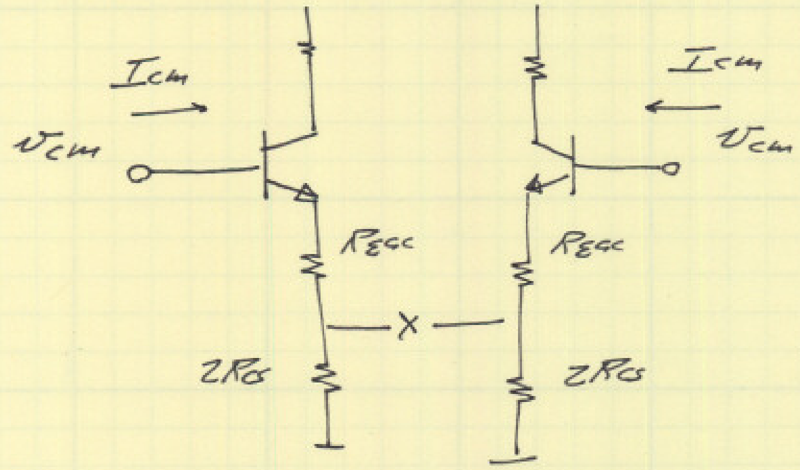
$$\frac{(v_d/2)}{I_{in}} = \beta(R_{Eac} + r_E)$$

$$v_d/I_{in} = 2\beta(r_E + R_{Eac})$$

$$= R_{in,\ differential}$$

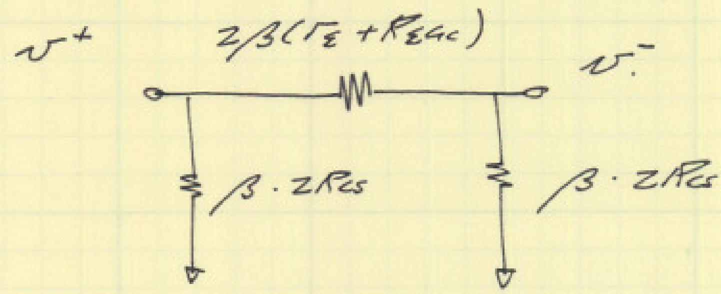


Common-Mode input impedance:



$$v_{cm}/I_{cm} = \beta\,(r_E + R_{EGC} + 2R_{CS}) \sim 2\beta R_{CS}$$
$$= R_{in,\,cm}$$

Total input model:



the input impedance must be modelled by
3 resistors
because there are three