EE210: Microelectronics-I

Lecture-32: Differential Amplifiers_4

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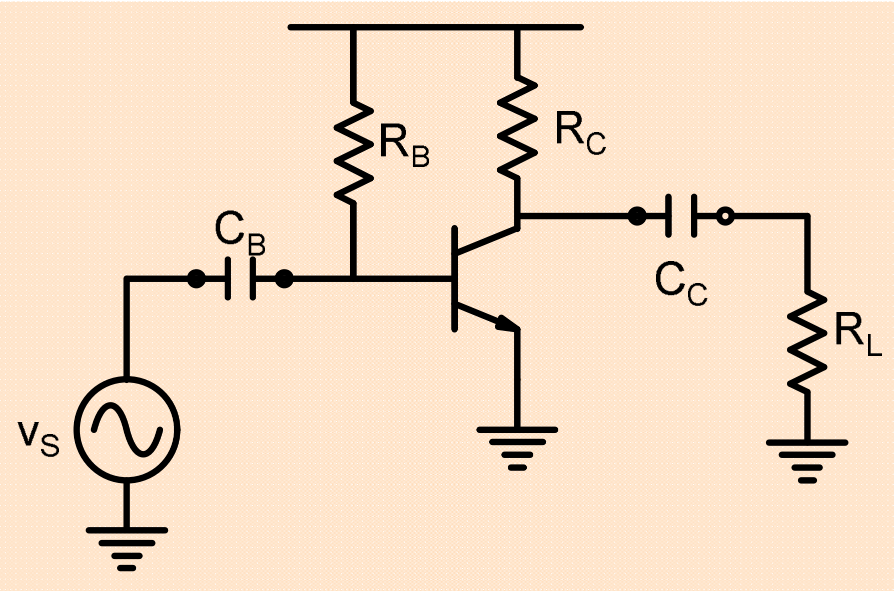
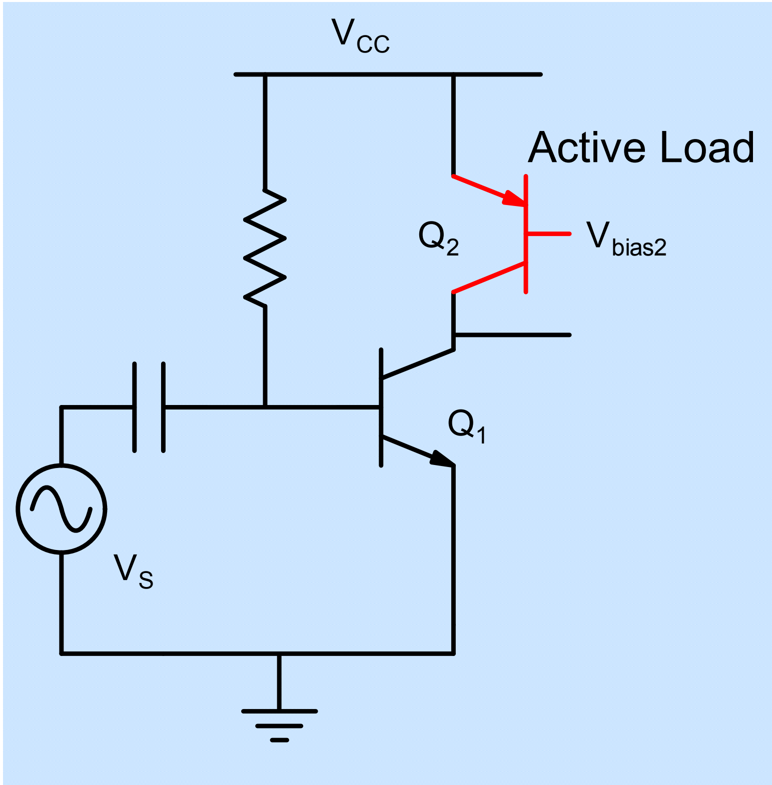
G-Number

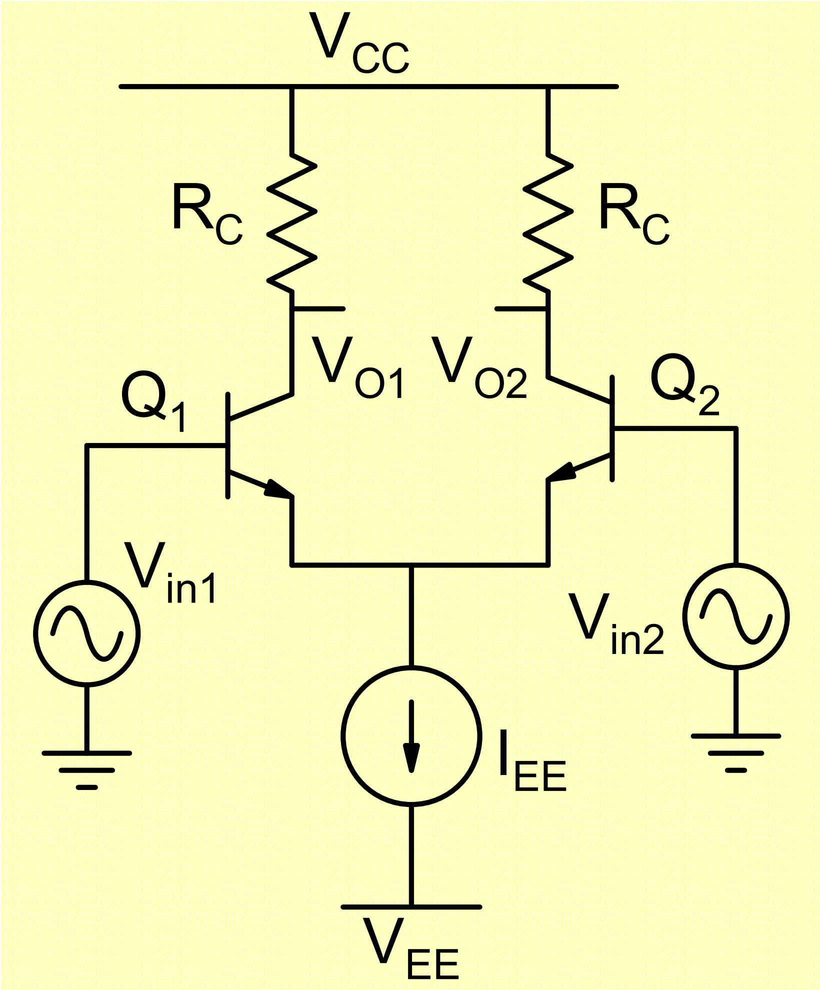


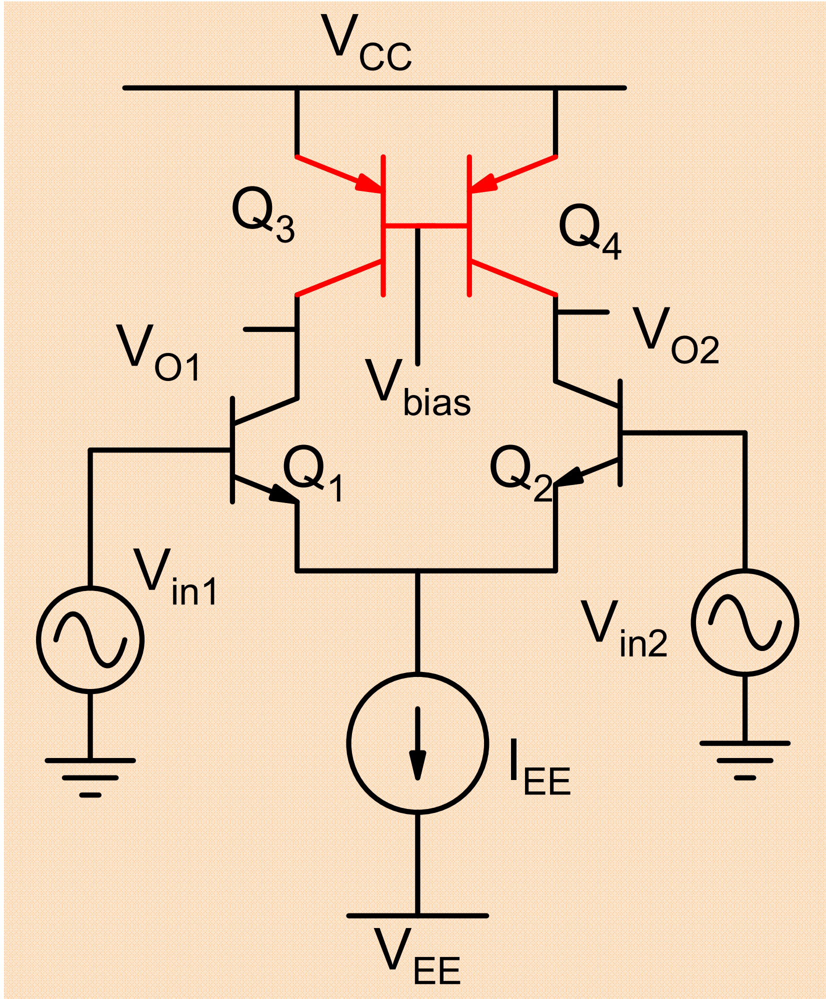


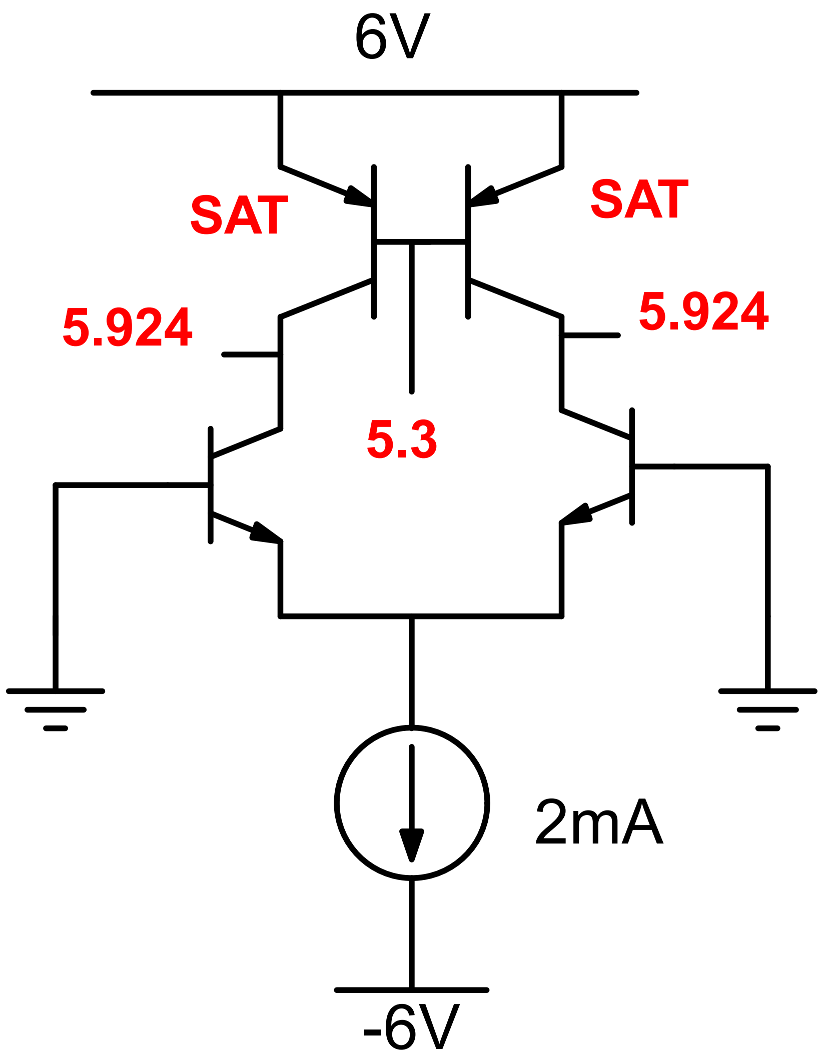
$$A_V < \frac{I_{CQ} R_C}{V_T}$$

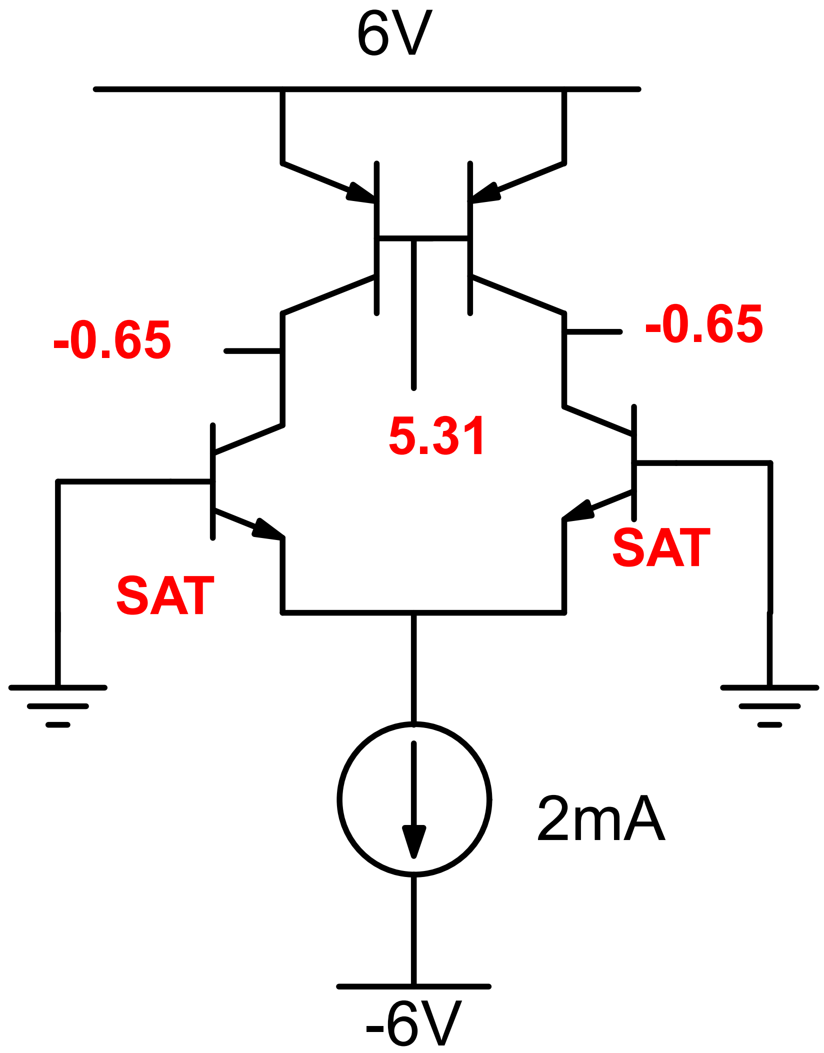
$$\left| A_V \right| = \frac{1}{V_T} \times \frac{V_{AN} \times V_{AP}}{V_{AN} + V_{AP}}$$

Differential Amplifier with Active Load









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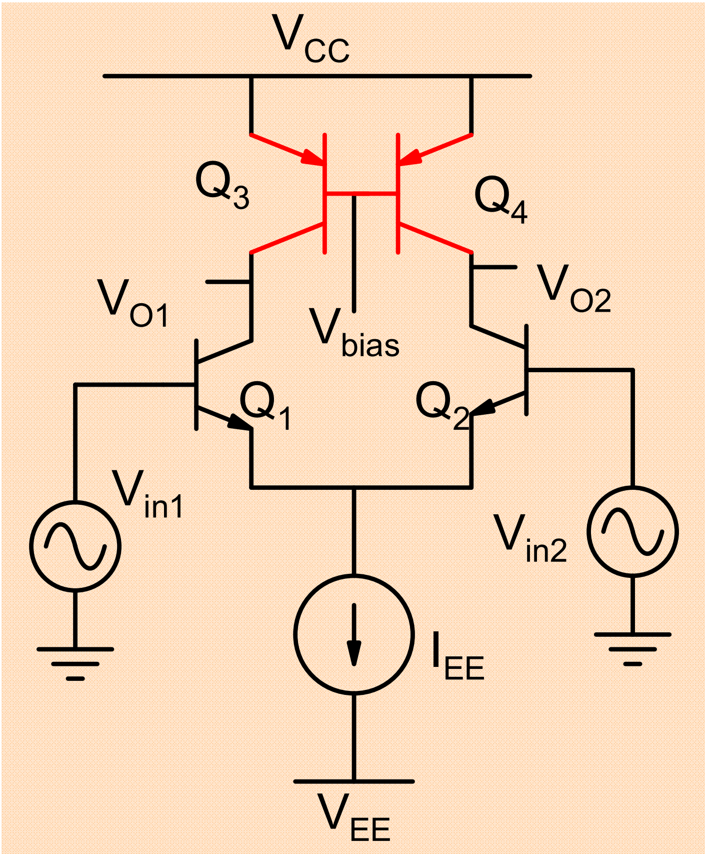
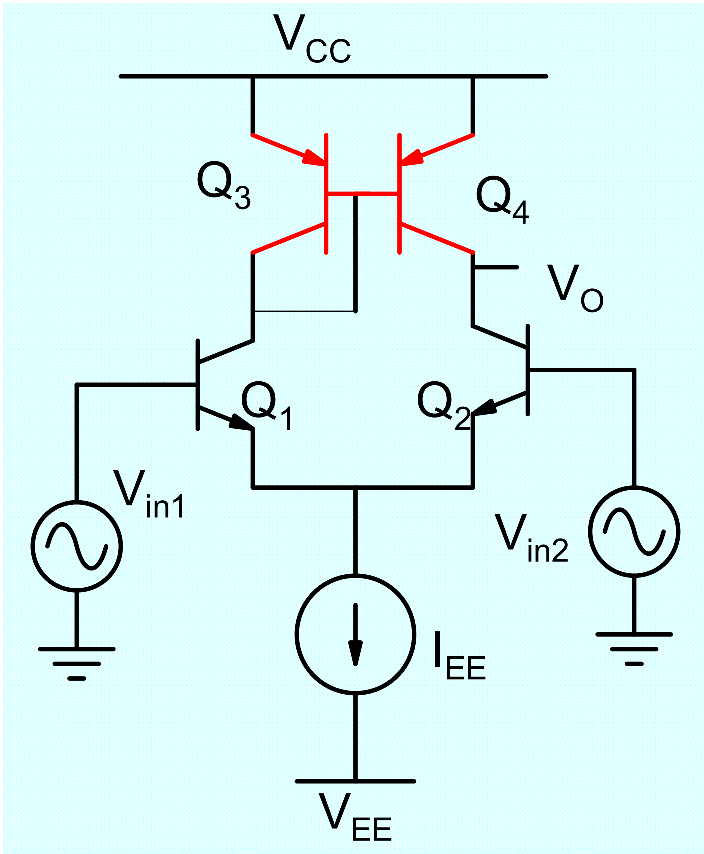
Differential amplifier with current mirror load



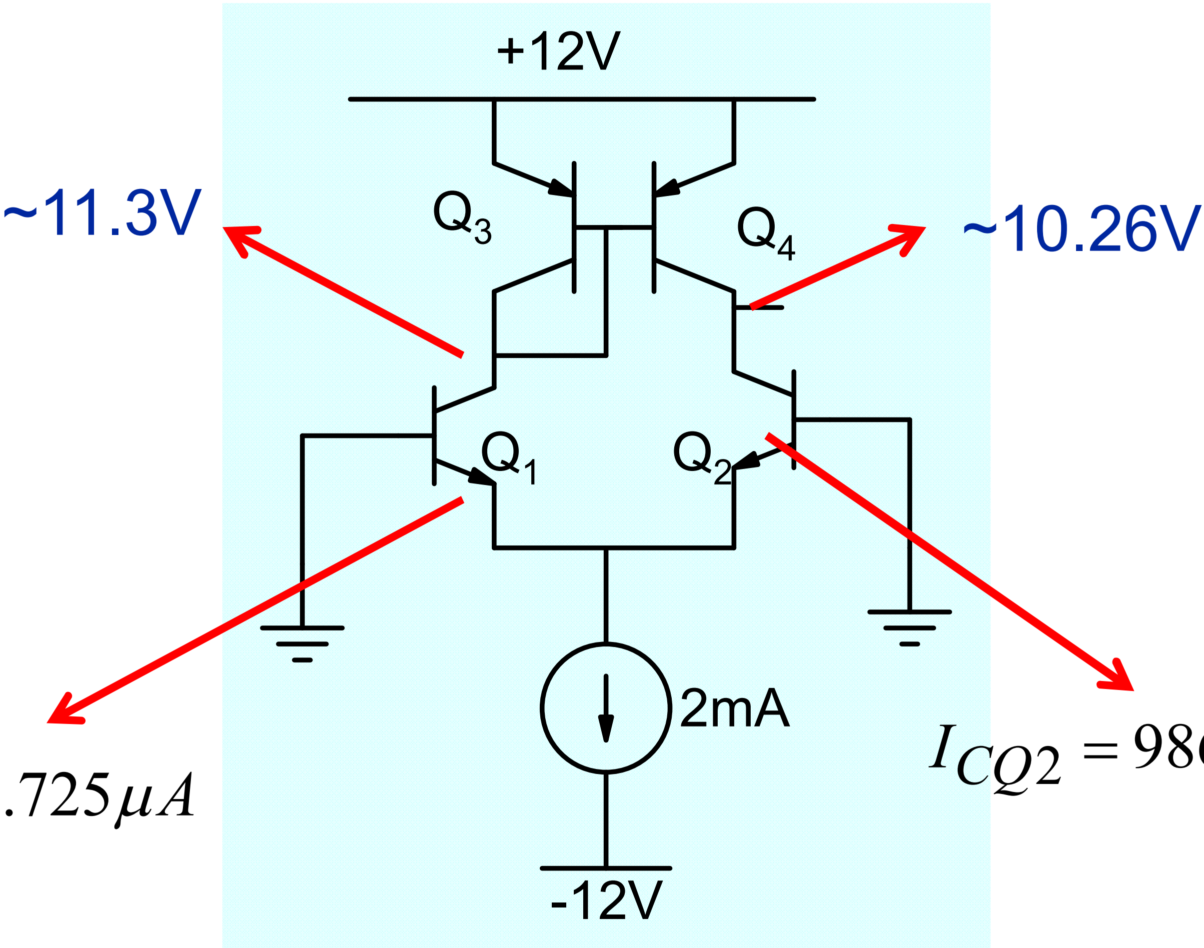


Bias point is stable, high differential gain and low common mode gain are obtained in this circuit

Note that Q1 & Q2 are matched and Q3 &Q4 are matched

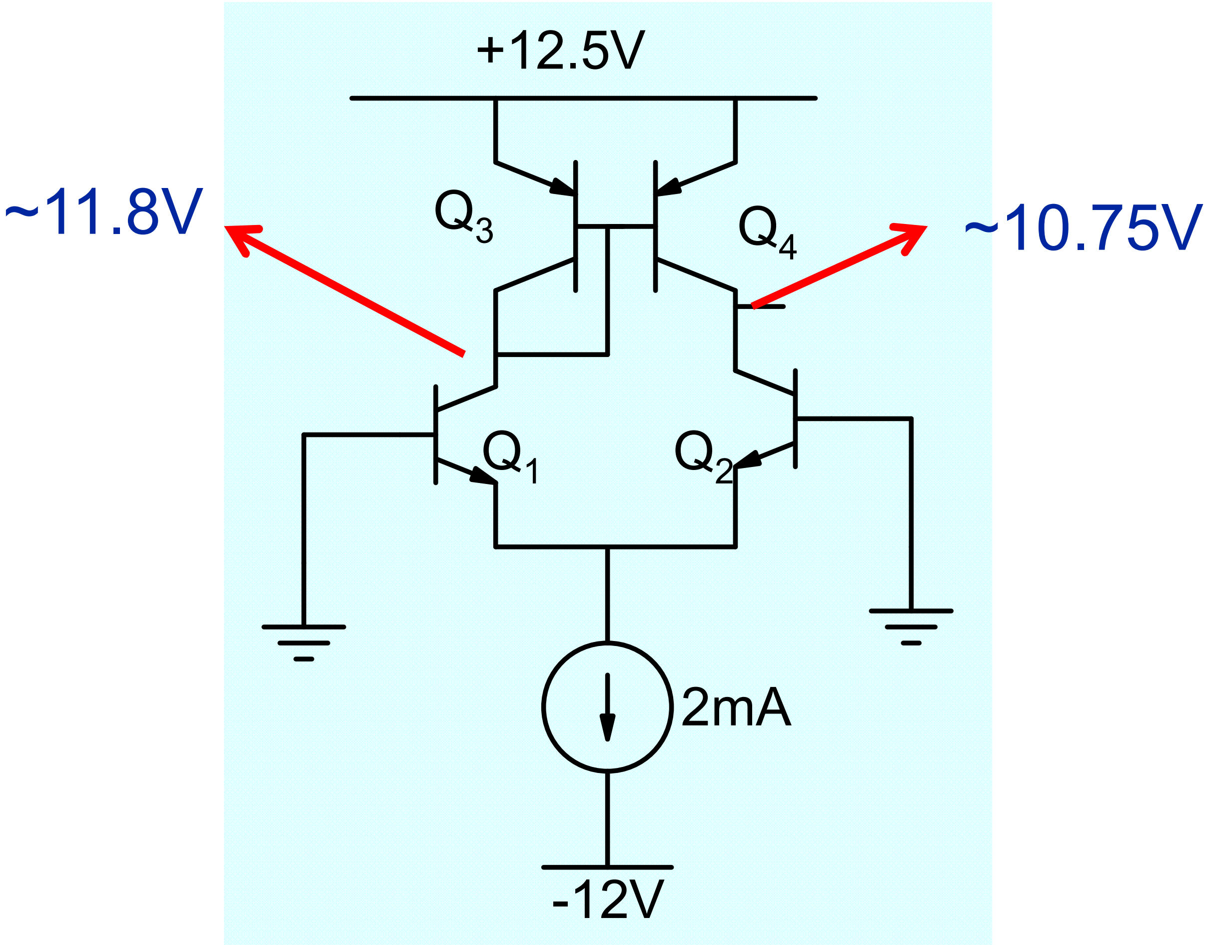
Example

$$\beta_n = \beta_p = 100$$



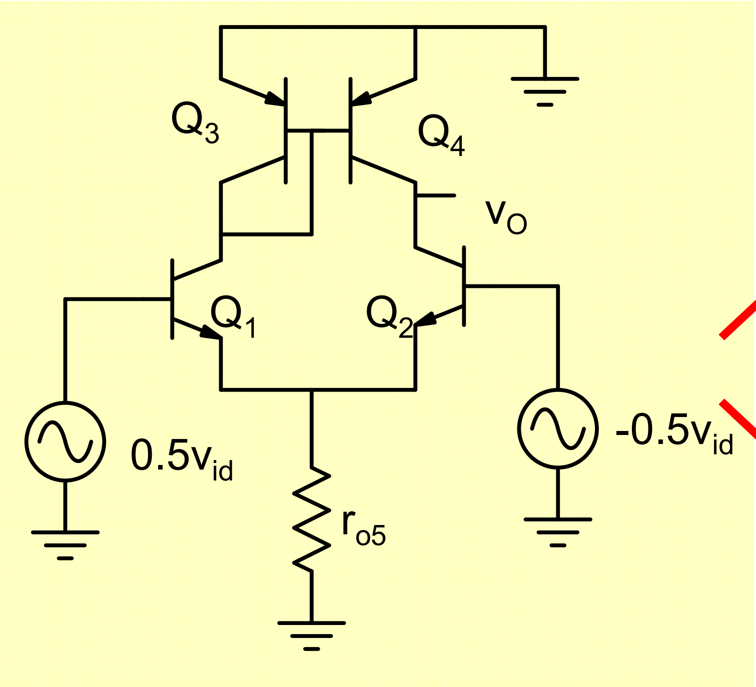
$I_{CQ1} = 995.725\mu A$

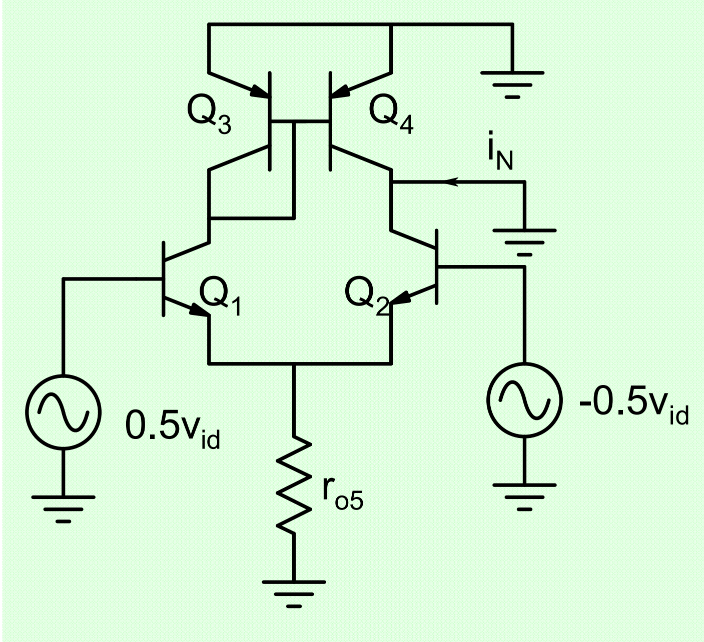
$I_{CQ2} = 986.384\mu A$

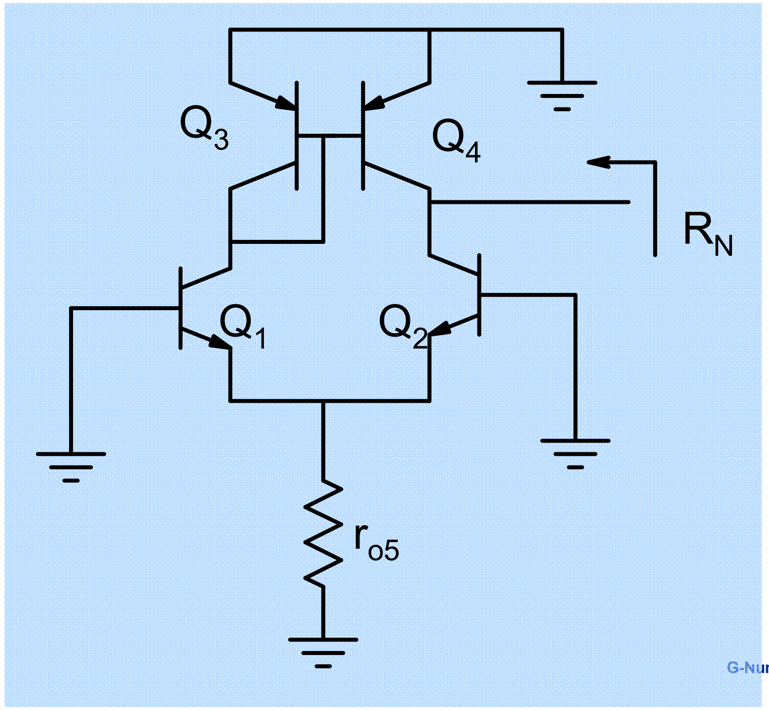


Bias point is much less sensitive !

Differential Mode Analysis







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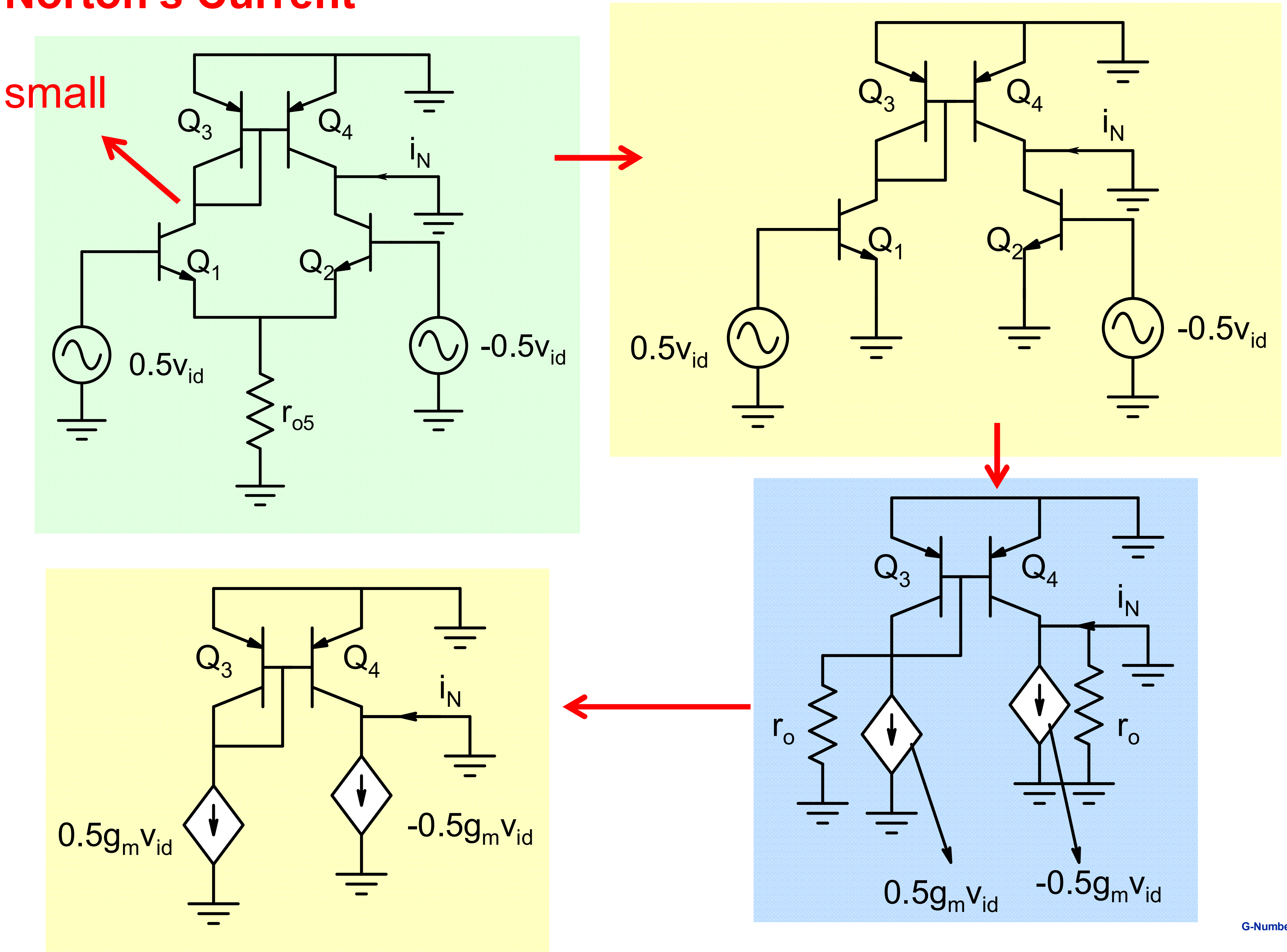
Norton's Current



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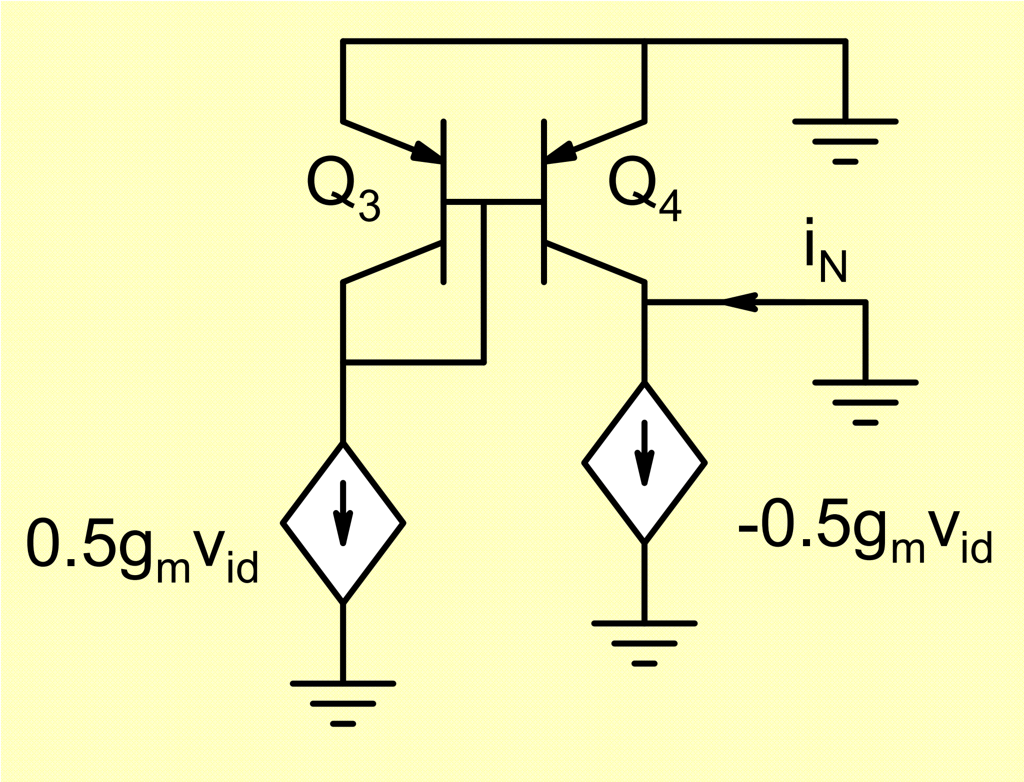
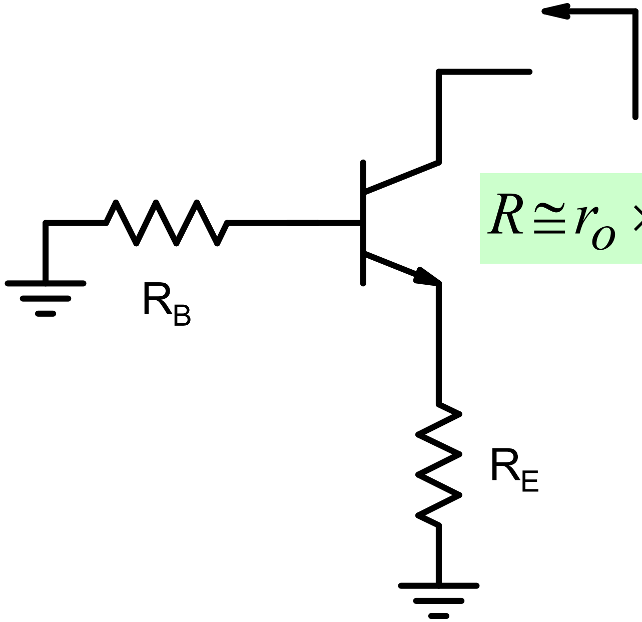
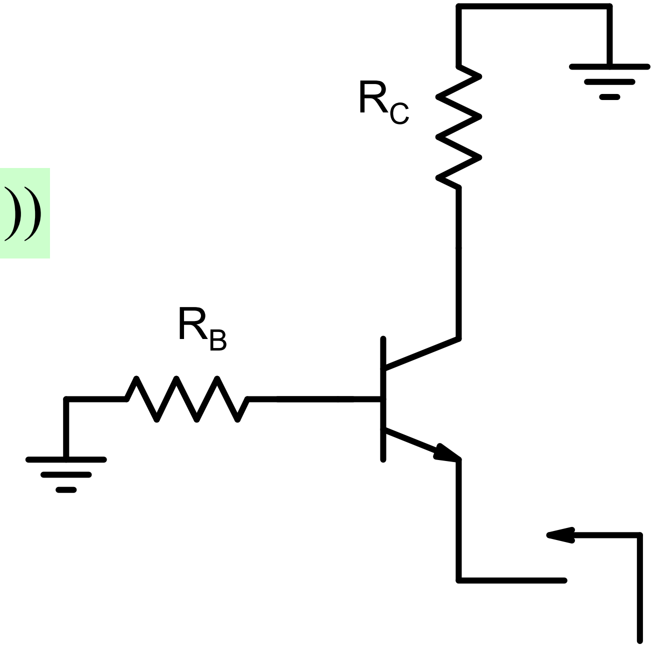


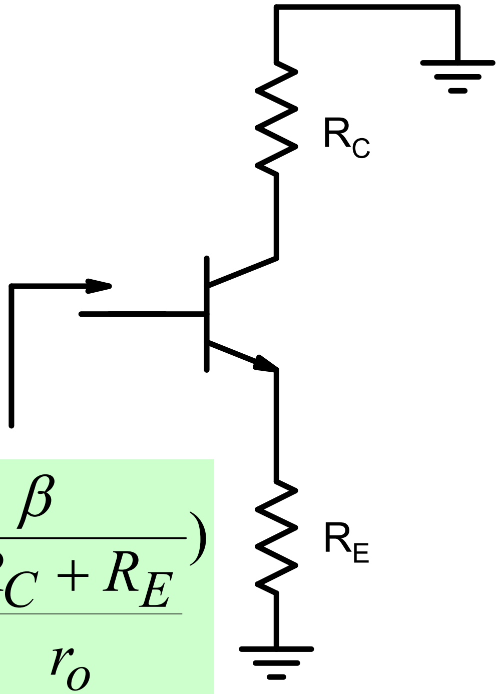
$$i_N = -0.5 g_m v_{id} - -0.5 g_m v_{id}$$
$$= -g_m v_{id}$$



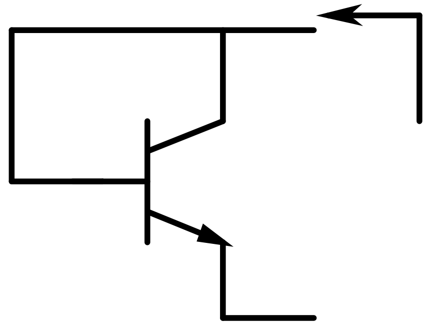
$$R \cong r_o \times (1 + g_m \times R_E \| (R_B + r_\pi))$$



$$R \cong \frac{(R_C + r_o)(R_B + r_\pi)}{R_B + r_\pi + R_C + r_o + \beta r_o}$$



$$R \cong r_\pi + R_E\left(1 + \frac{\beta}{1 + \frac{R_C + R_E}{r_o}}\right)$$



$$R \cong \frac{1}{g_m}$$

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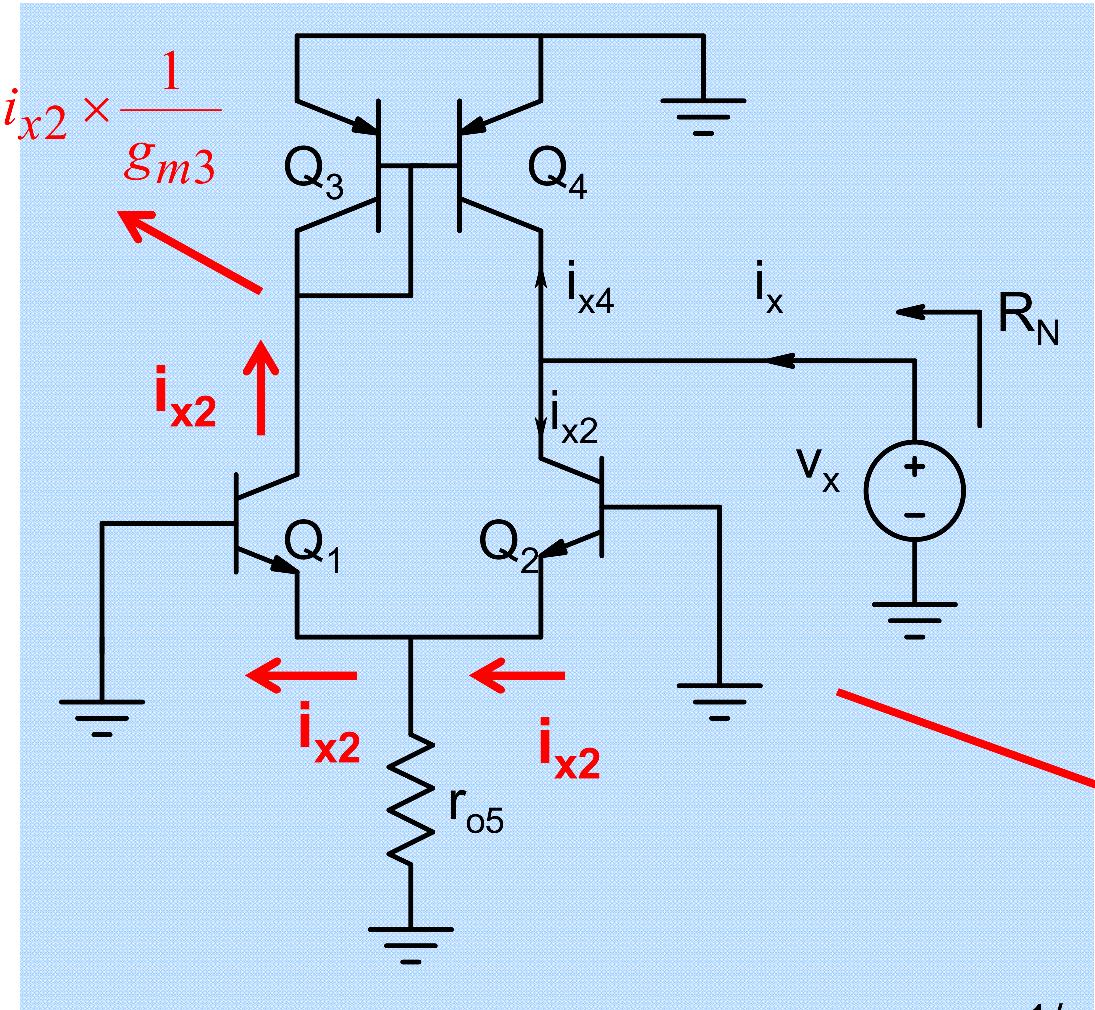
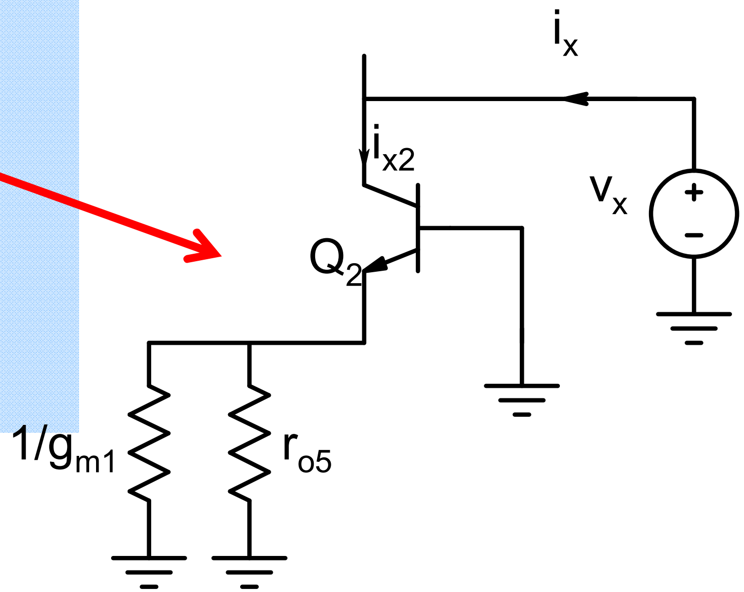
Norton's Resistance

$$v_{b4} = i_{x2} \times \frac{1}{g_{m3}}$$

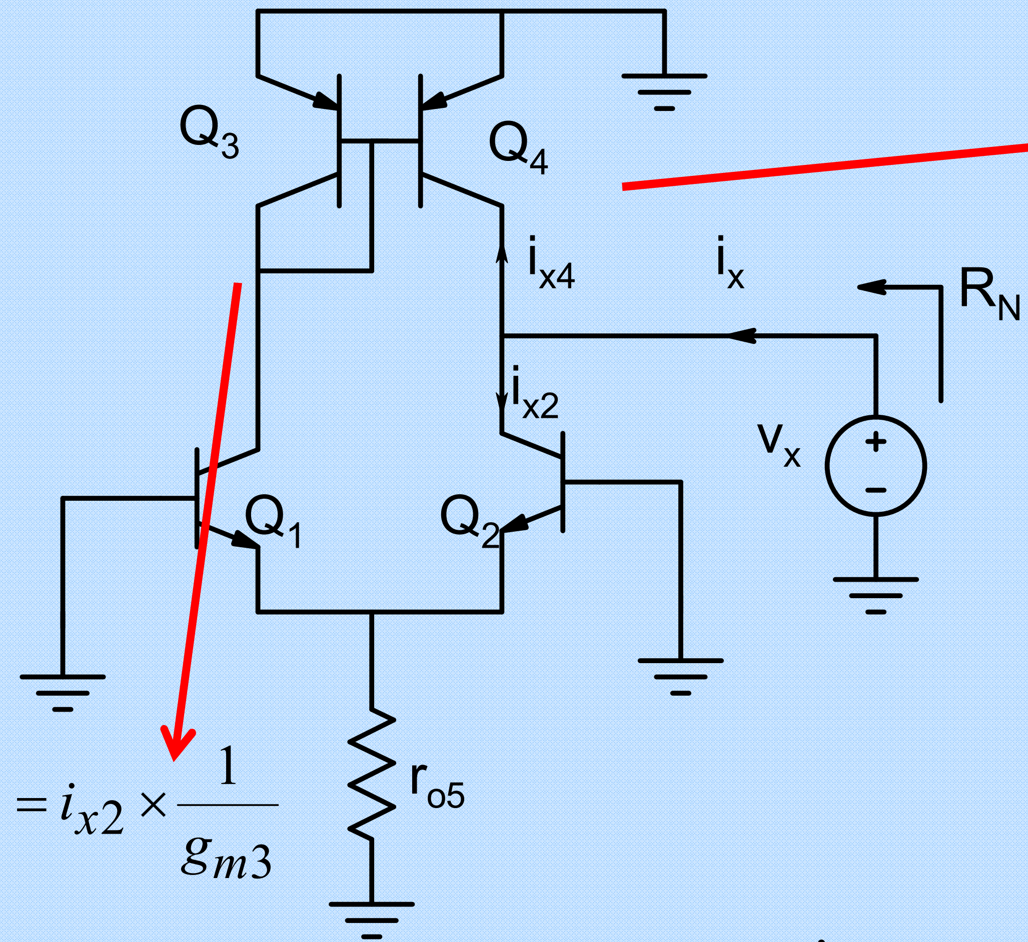


$$\frac{1}{R_N} = \frac{i_x}{v_x} = \frac{i_{x2}}{v_x} + \frac{i_{x4}}{v_x}$$

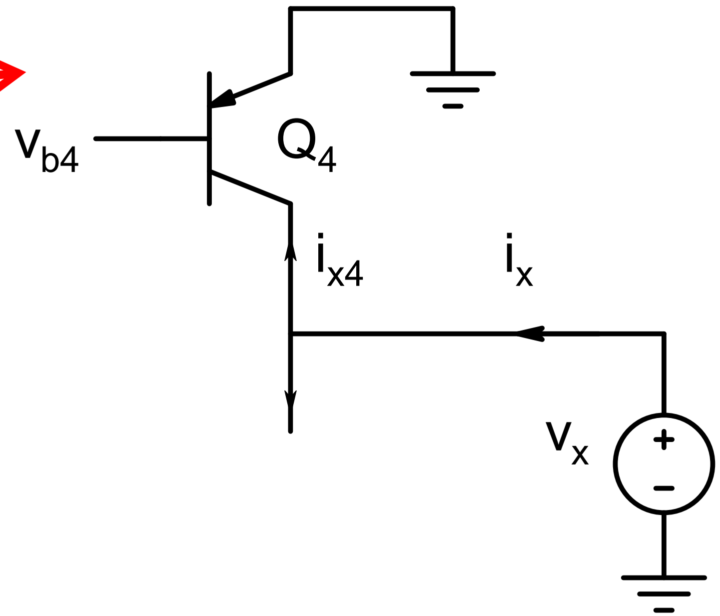


$$i_{x2} = \frac{v_x}{r_{o2} \times (1 + g_m \times \frac{1}{g_m})} = \frac{v_x}{2 r_{o2}}$$

G-Number

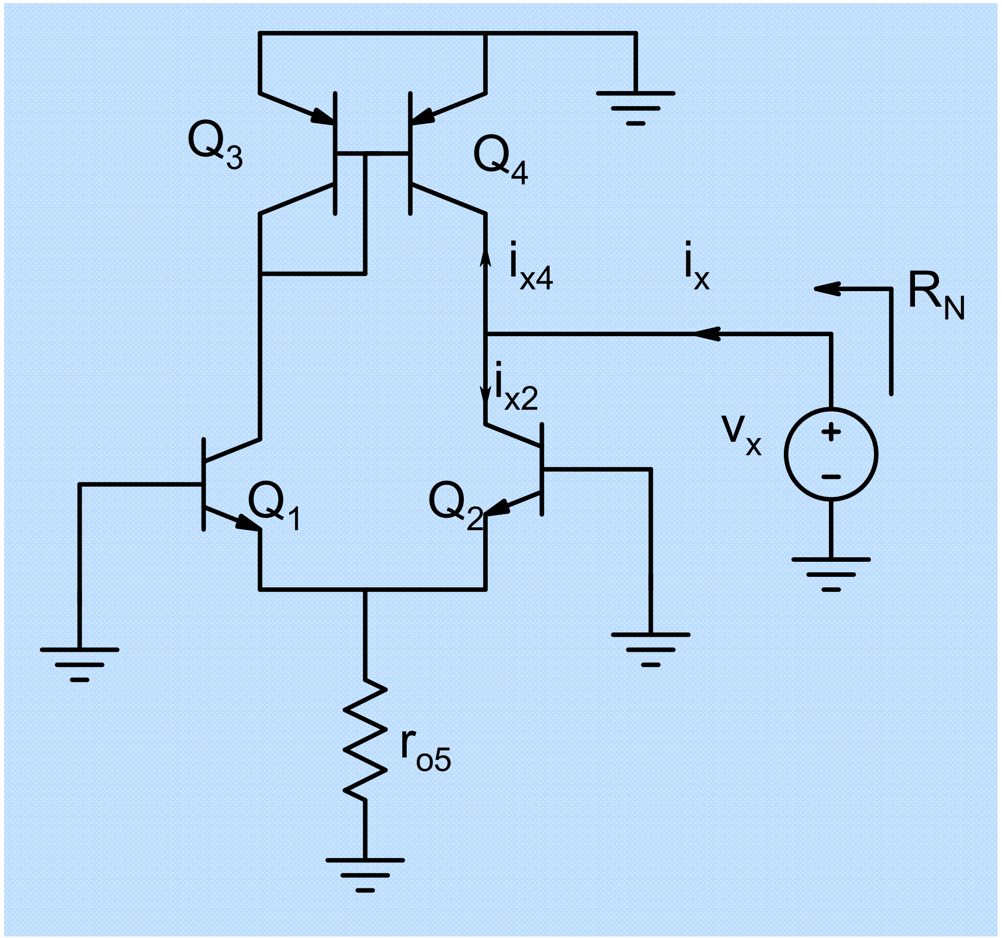


$$v_{b4} = i_{x2} \times \frac{1}{g_{m3}}$$



$$i_{x4} = g_{m4} \times v_{b4} + \frac{v_x}{r_{o4}}$$

$$= g_{m4} \times i_{x2} \times \frac{1}{g_{m3}} + \frac{v_x}{r_{o4}} = i_{x2} + \frac{v_x}{r_{o4}}$$

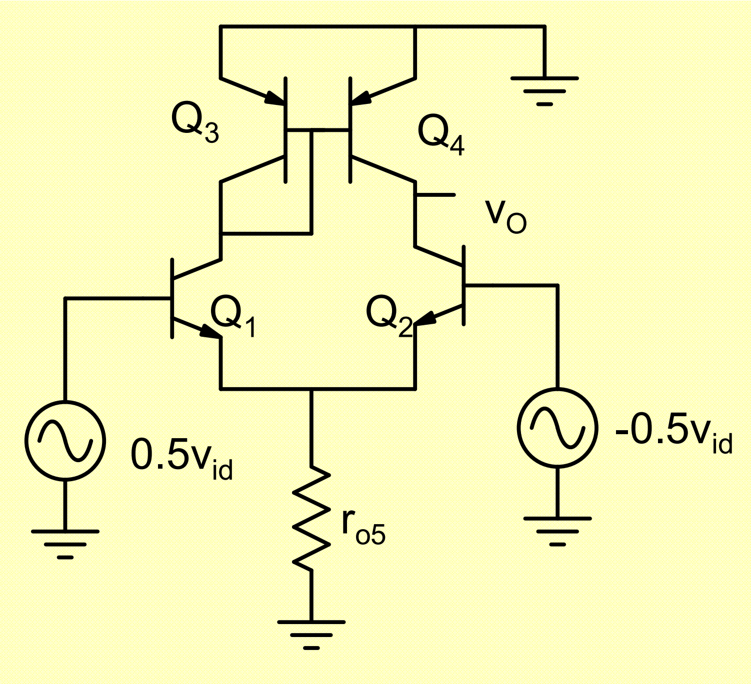


$$i_{x2} = \frac{v_x}{2r_{o2}}$$

$$i_{x4} = i_{x2} + \frac{v_x}{r_{o4}}$$

$$\frac{1}{R_N} = \frac{i_x}{v_x} = \frac{i_{x2}}{v_x} + \frac{i_{x4}}{v_x} = \frac{1}{r_{o2}} + \frac{1}{r_{o4}}$$

Differential Mode Analysis

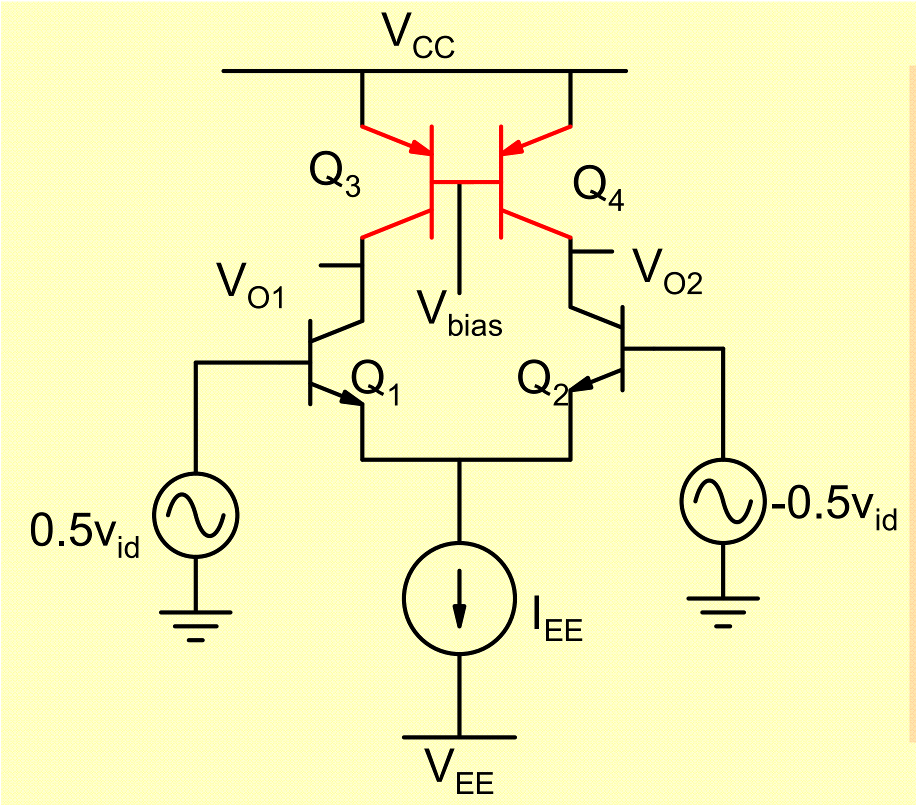


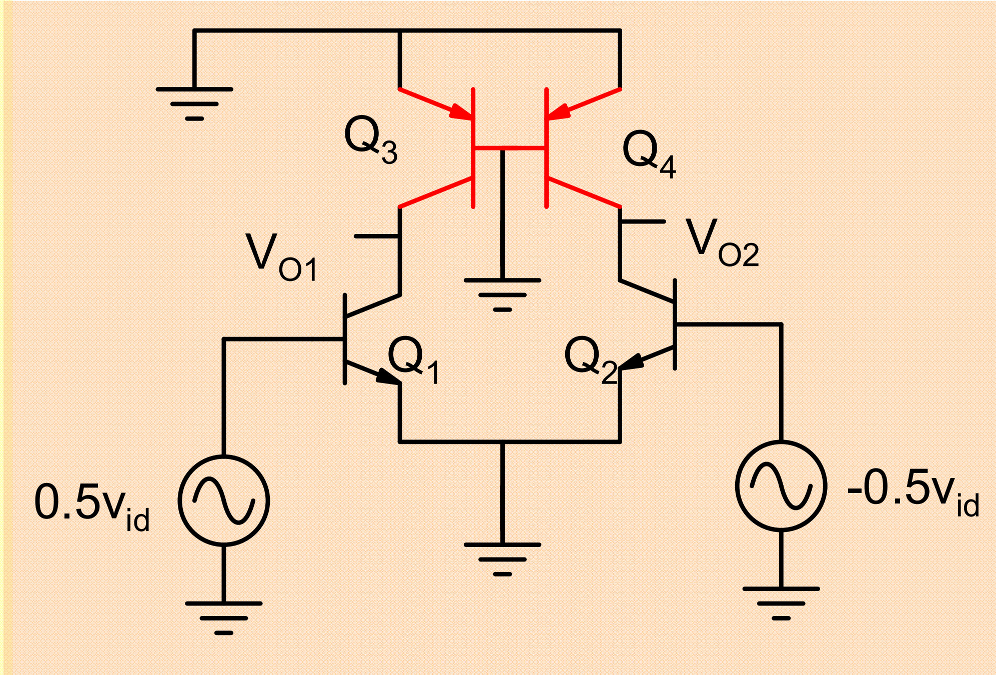
$$i_N = -g_m v_{id}$$

$$R_N = r_{o2} \| r_{o4}$$

$$A_{dm} = \frac{v_o}{v_{id}} = -\frac{i_N \times R_N}{v_{id}} = g_{m1} \times r_{o2} \| r_{o4}$$

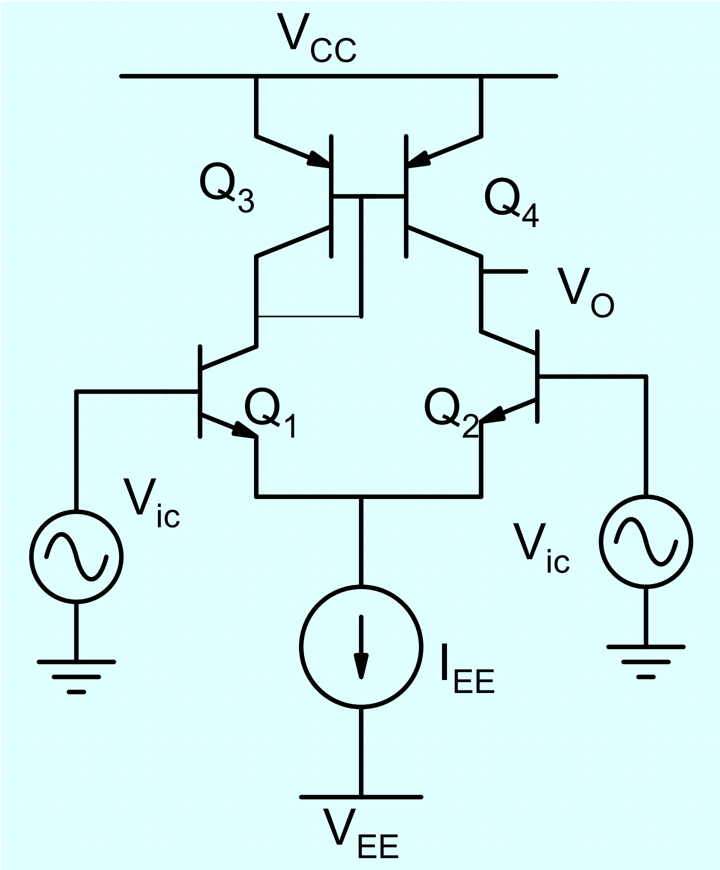
$$R_O = r_{o2} \| r_{o4}$$

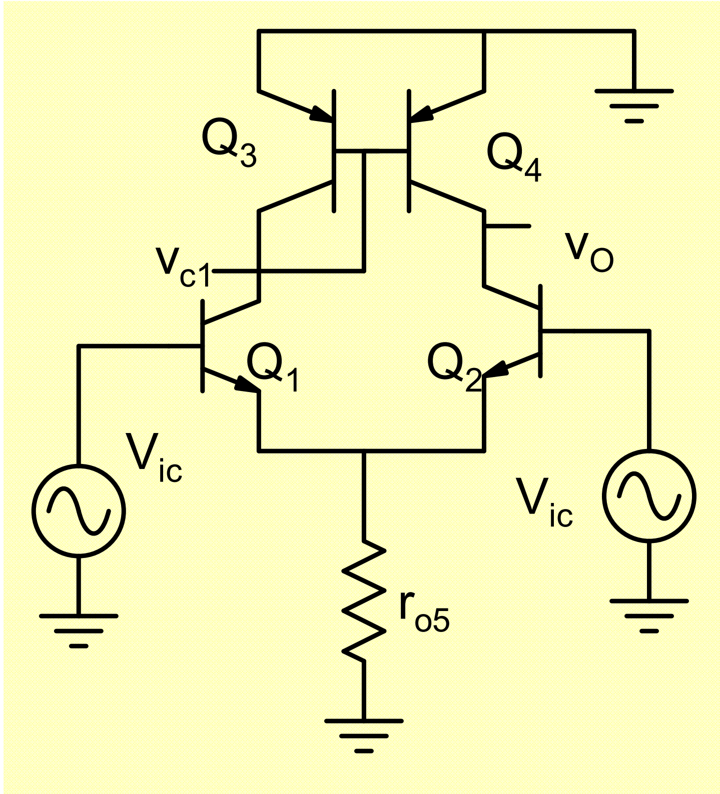


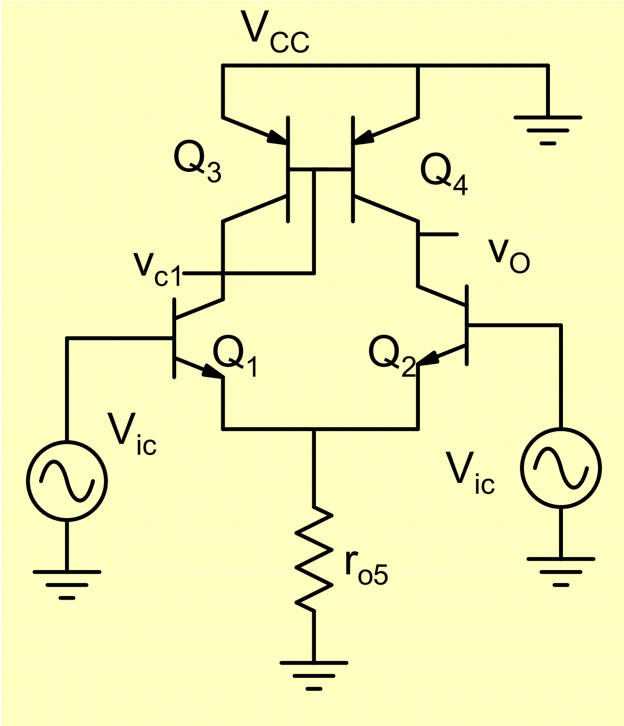


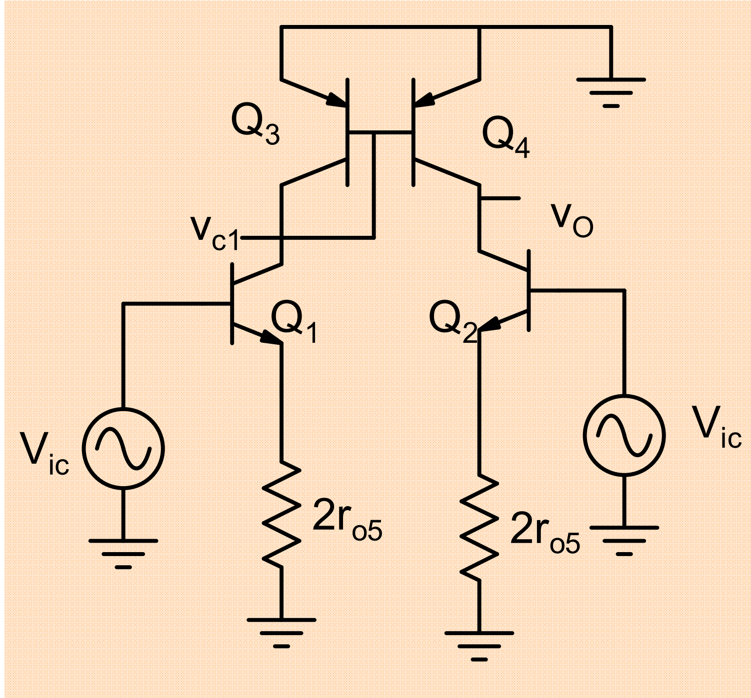
$$A_{dm} = \frac{v_{o2}}{v_{id}} = 0.5 g_m \times r_{o2} \| r_{o4}$$

Common Mode Analysis



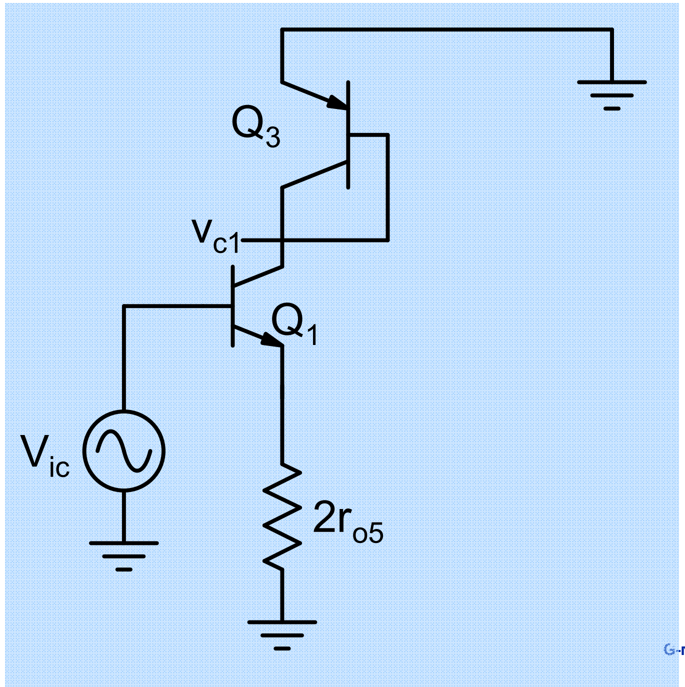


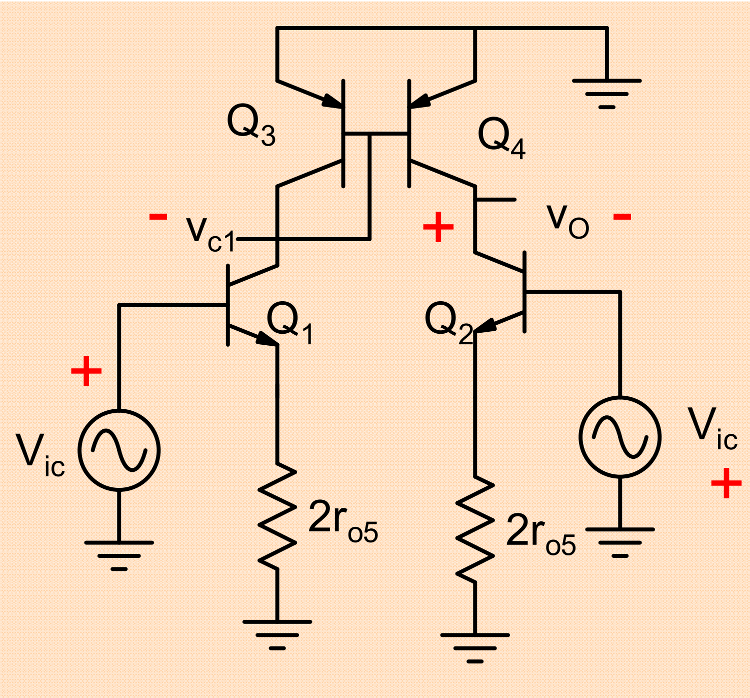


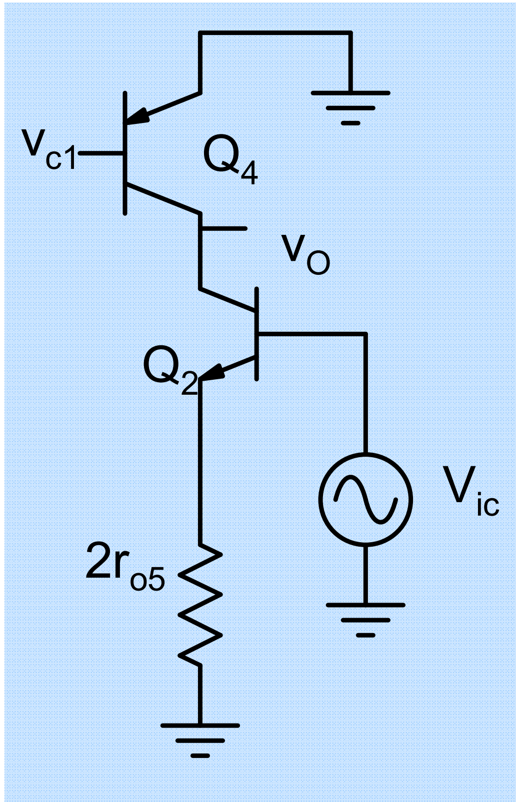


$$\frac{v_{c1}}{v_{ic}} = -\frac{g_{m1} \times \dfrac{1}{g_{m3}}}{1 + 2g_{m1}r_{O5}}$$

$$\cong -\frac{1}{2g_{m1}r_{O5}}$$

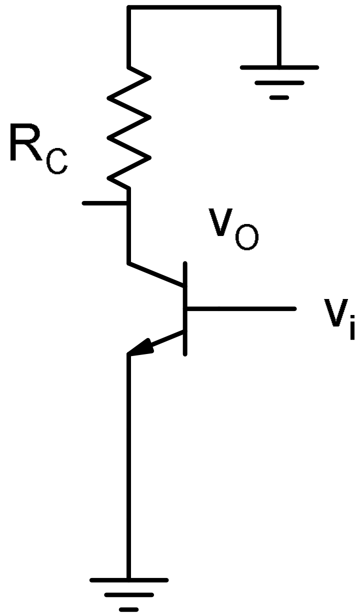




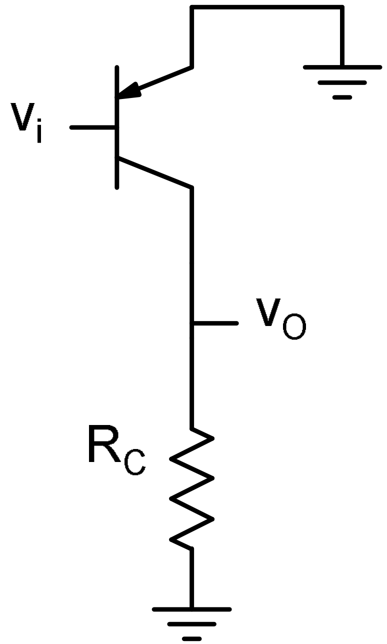


$$v_{c1} \cong -\frac{v_{ic}}{2 g_{m1} r_{O5}}$$

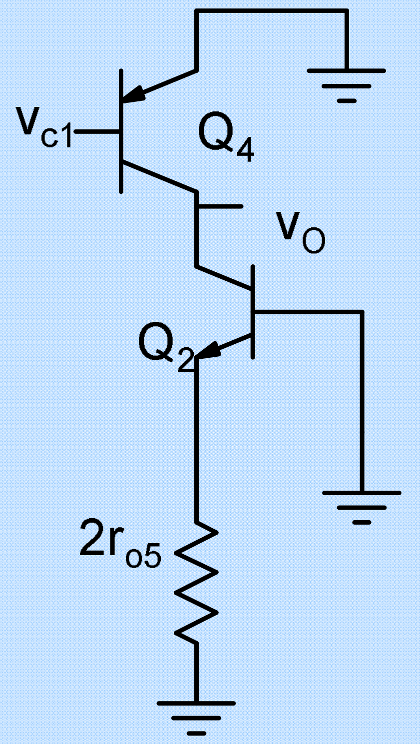
-



$$\frac{v_o}{v_i} = -g_m \times R_C \| r_o$$

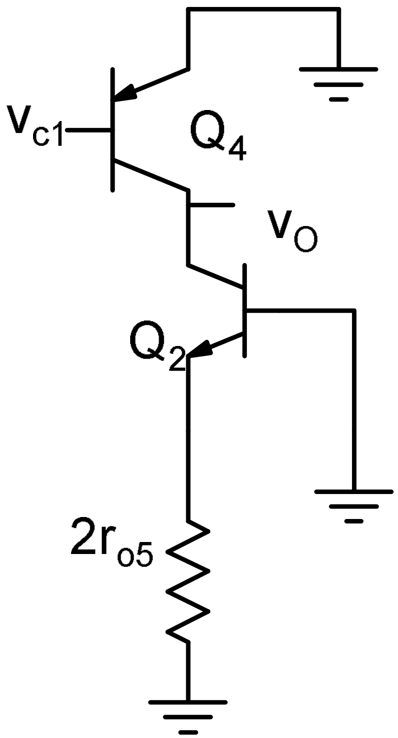


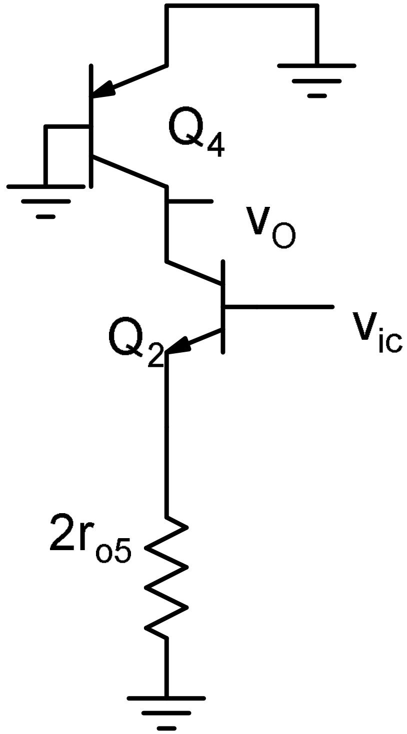
$$\frac{v_o}{v_i} = -g_m \times R_C \| r_o$$

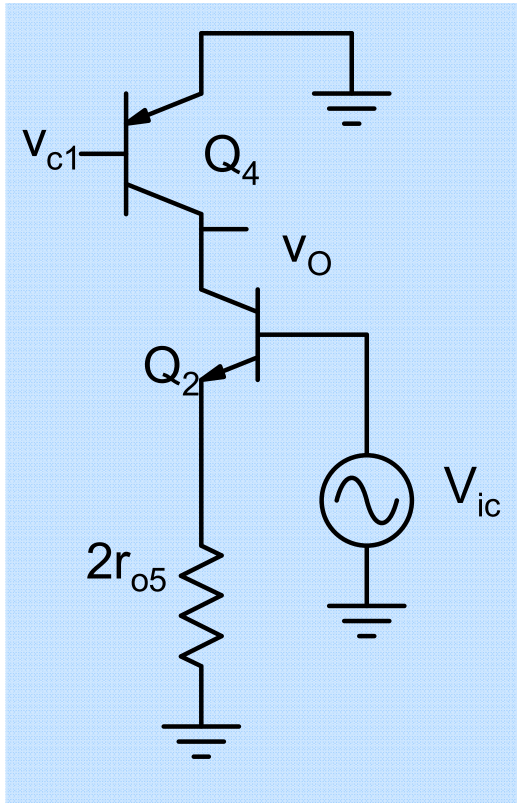


$$\frac{v_o}{v_{c1}} = -g_{m4} \times r_{o4} \| r_{down}$$

$$\cong -g_{m4} \times r_{o4}$$





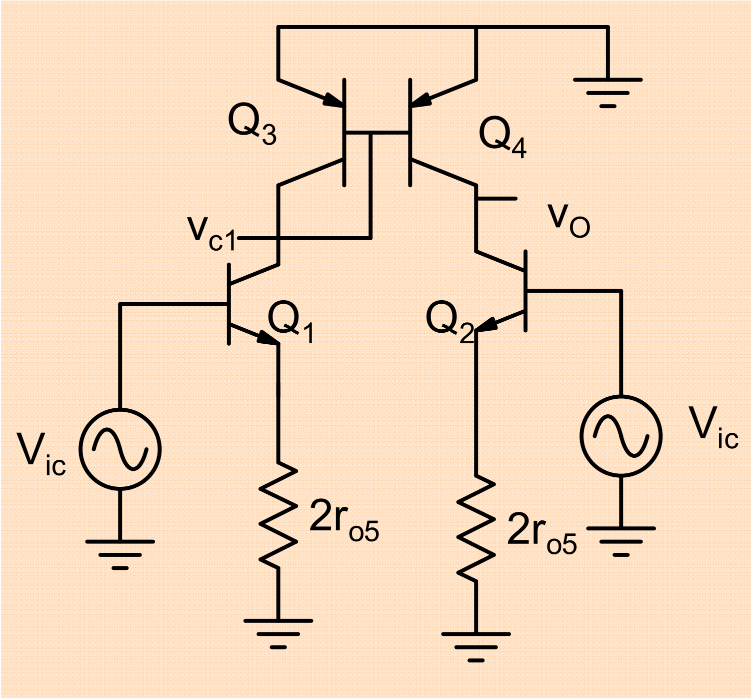


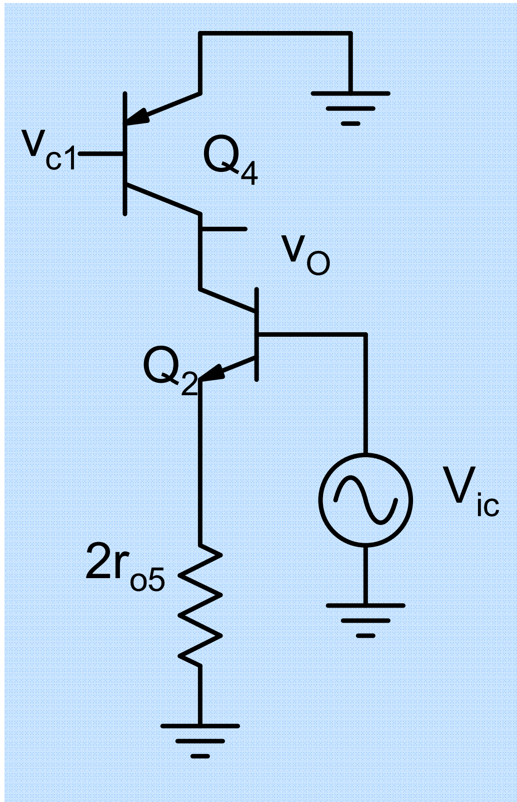
$$\frac{v_o}{v_{c1}} = -g_{m4} \times r_{o4} \| r_{down}$$

$$\cong -g_{m4} \times r_{o4}$$

$$\frac{v_o}{v_{ic}} = -\frac{g_{m2}}{1 + g_{m2} \times 2r_{o5}} \times r_{o4} \| r_{down}$$

$$\cong -\frac{r_{o4}}{2r_{o5}}$$





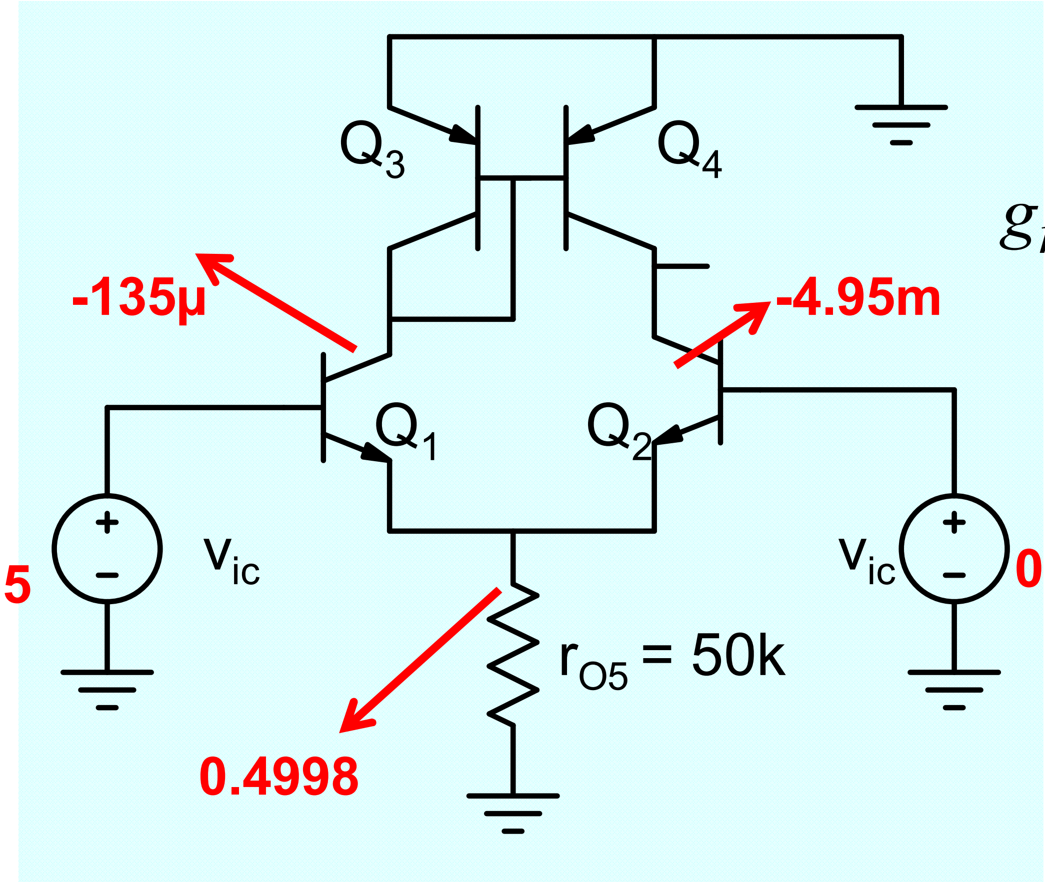
$$v_{c1} \cong -\frac{v_{ic}}{2g_{m1}r_{O5}}$$

$$v_o \cong -v_{ic} \times \frac{r_{o4}}{2r_{o5}} - v_{c1} \times g_{m4} \times r_{o4}$$

$$\cong -v_{ic} \times \frac{r_{o4}}{2r_{o5}} + v_{c1} \times g_{m4} \times \frac{r_{o4}}{2r_{o5}} = 0$$

More accurate calculations are needed but common mode gain is expected to be quite small

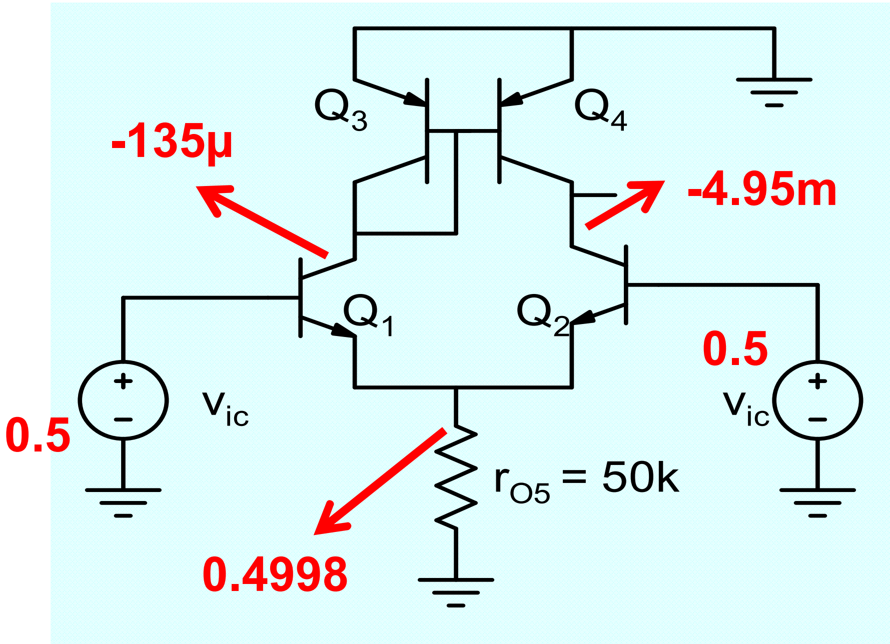
Example



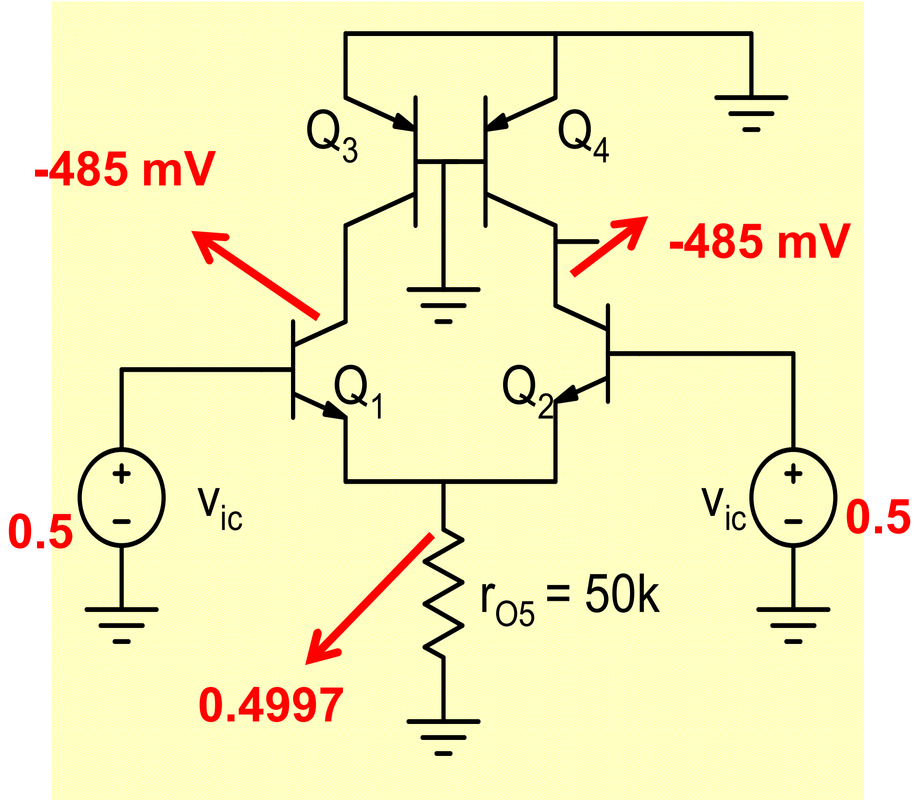
$$g_m = 38.5m\Omega^{-1}; r_o = 100k\Omega$$

$$A_{cm} = .01$$

$$v_{c1} \cong -\frac{v_{ic}}{2g_{m1}r_{O5}} = -0.13mV$$



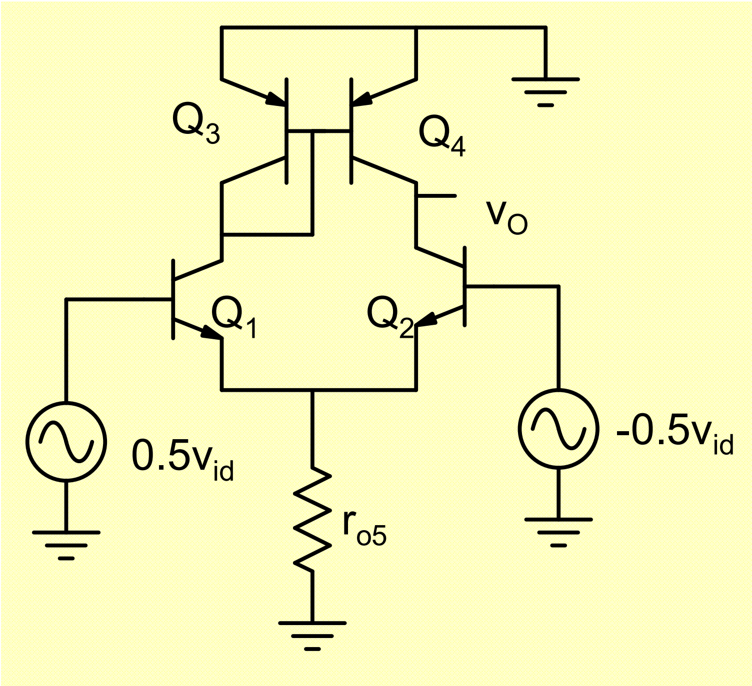
$$A_{cm} = .01$$



$$A_{cm} \sim 1$$

Common Mode gain is much higher !

Summary



$$i_N = -g_m v_{id}$$

$$R_N = r_{o2} \| r_{o4}$$

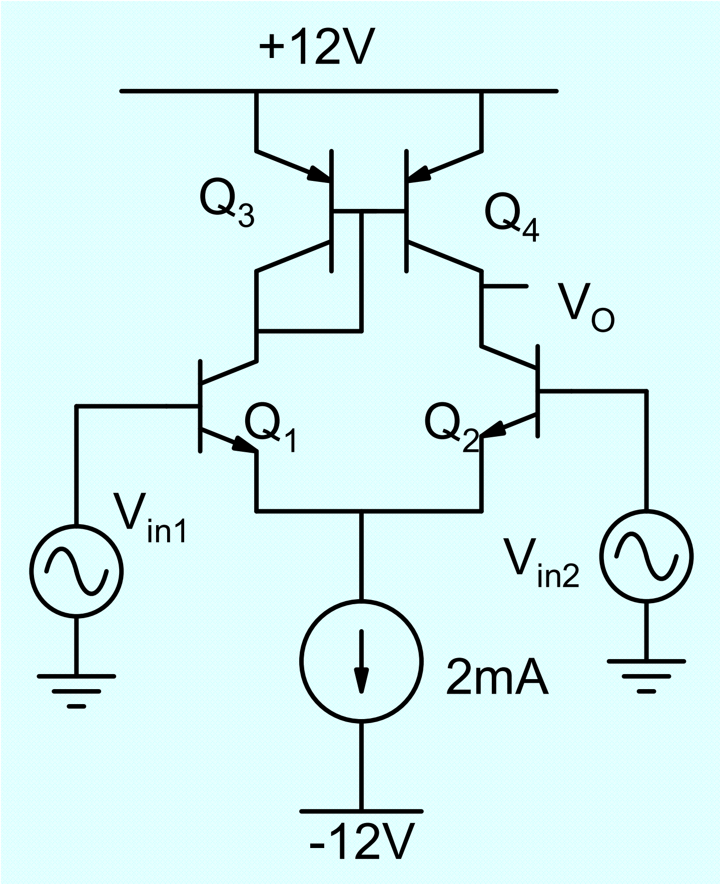
$$A_{dm} = \frac{v_o}{v_{id}} = -i_N \times R_N = g_{m1} \times r_{o2} \| r_{o4}$$

$$R_O = r_{o2} \| r_{o4}$$

$$A_{cm} =$$

$$cmrr =$$

Example



Bias Point

$$I_{EE} = 2mA$$

$$I_{CQ1} = I_{CQ2} = 1mA$$

$$g_{m1} = 38.46m\square \text{ ; } r_{o2} = 100k\Omega$$

$$r_{o5} = 50k\Omega$$

$$A_{dm} = -1.9\times10^{3}\text{ ; } R_{id} = 5.2K\Omega$$

$$A_{cm} = -10^{-2}\text{ ; } R_{ic} = 1.14M\Omega$$

$$CMRR = 1.9\times10^{5} = 105.5dB$$

From simulation

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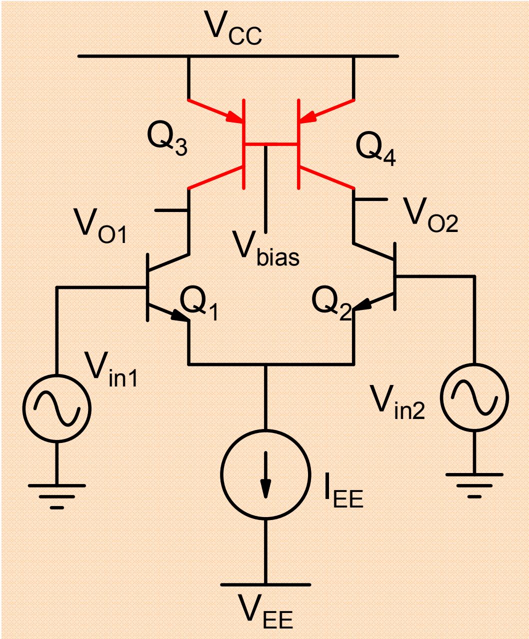
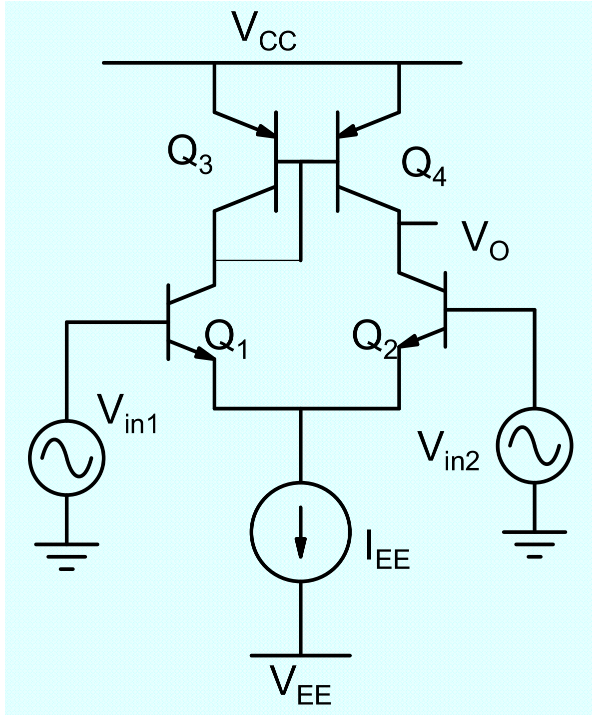
The difference a single wire can make !



Additional bias source and sensitive Q-point

$$A_{dm} = 0.5 g_{m1} \times r_{o2} \| r_{o4}$$

$$A_{cm} \cong -\frac{r_{o3}}{2 r_{O5}}$$



Stable bias point

$$A_{dm} = g_{m1} \times r_{o2} \| r_{o4}$$

$$A_{cm} \cong \text{ much smaller}$$

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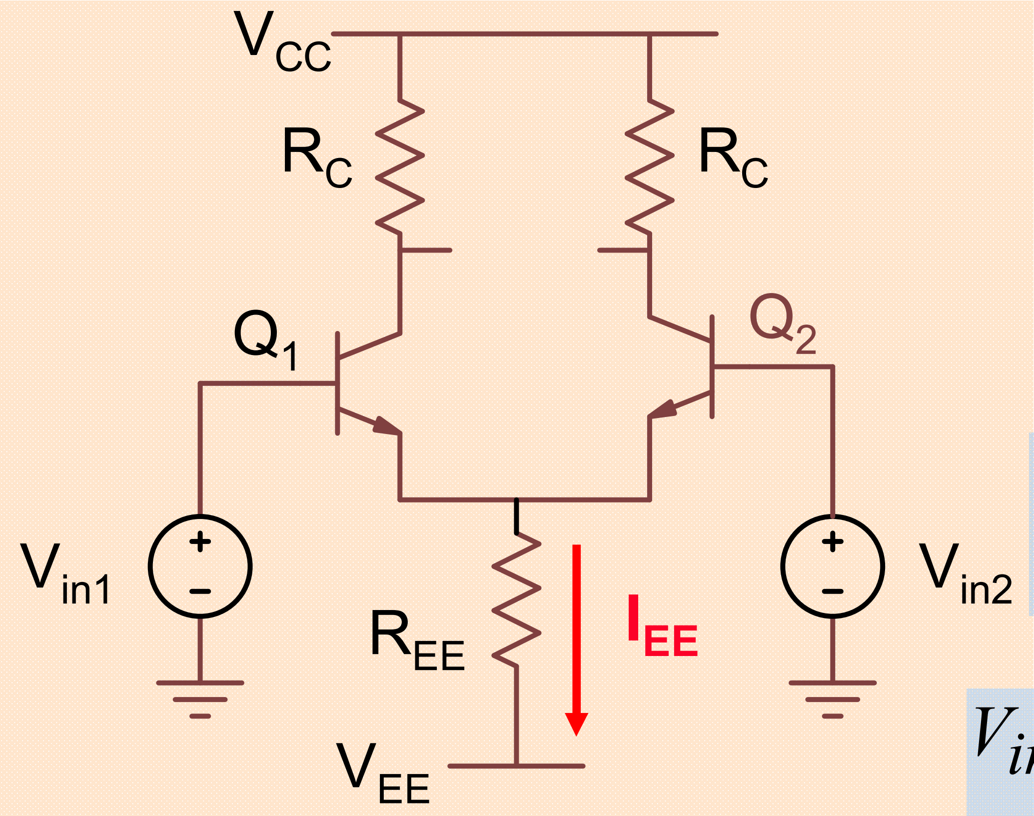
General Large Signal Analysis



$$I_{EE} \cong I_{C1} + I_{C2}$$

$$I_{C1} = A \times J_S \times \exp\left(\frac{V_{BE1}}{V_T}\right)$$

$$I_{C2} = A \times J_S \times \exp\left(\frac{V_{BE2}}{V_T}\right)$$

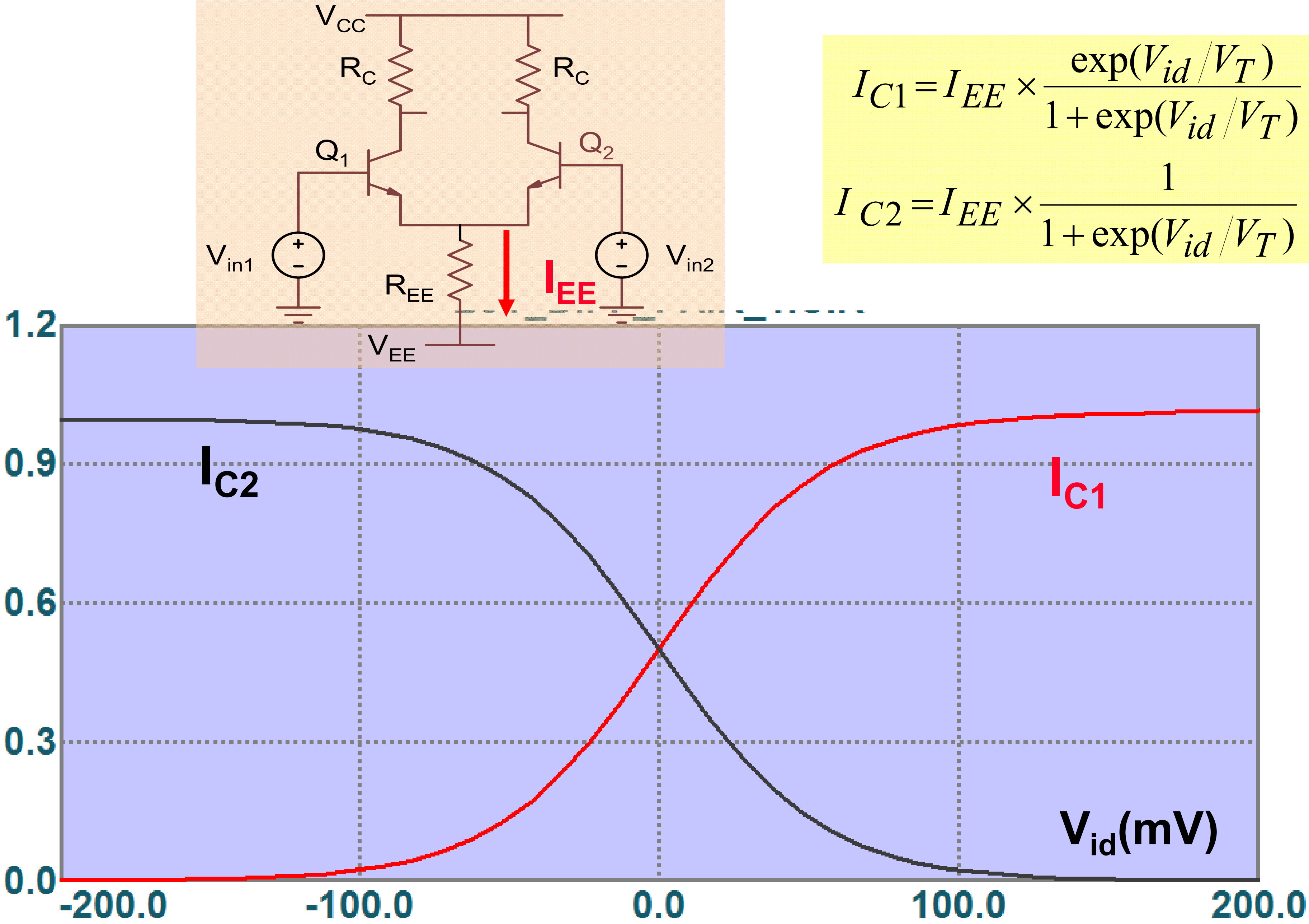
$$V_{in1} - V_{BE1} - V_{EB2} - V_{in2} = 0$$

$$V_{BE1} - V_{BE2} = V_{in1} - V_{in2}$$

$$I_{C1} = I_{EE} \times \frac{\exp(V_{id}/V_T)}{1+\exp(V_{id}/V_T)}\ ;\ I_{C2} = I_{EE} \times \frac{1}{1+\exp(V_{id}/V_T)}$$

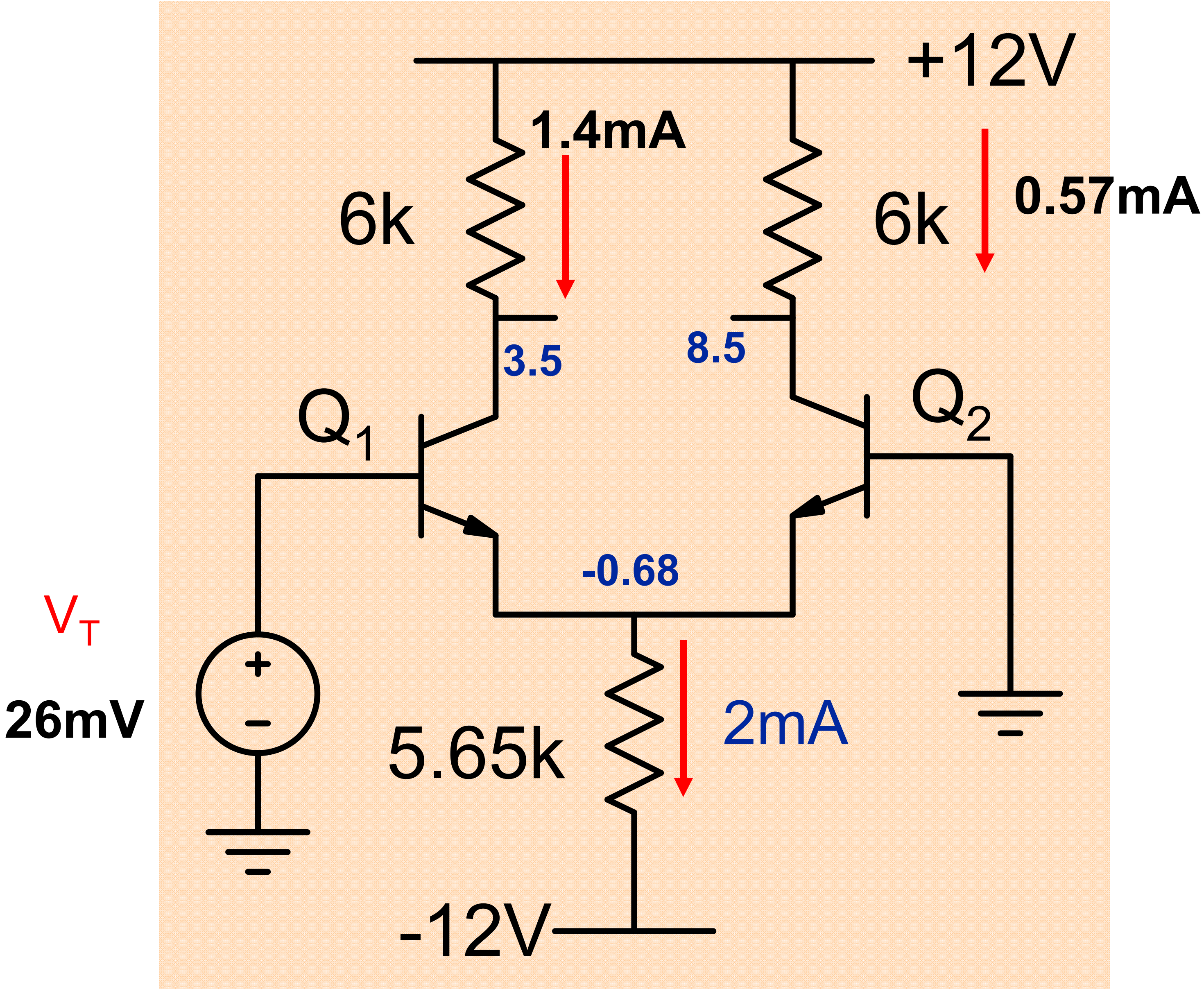
$$I_{C1} = I_{EE} \times \frac{\exp(V_{id}/V_T)}{1+\exp(V_{id}/V_T)}$$

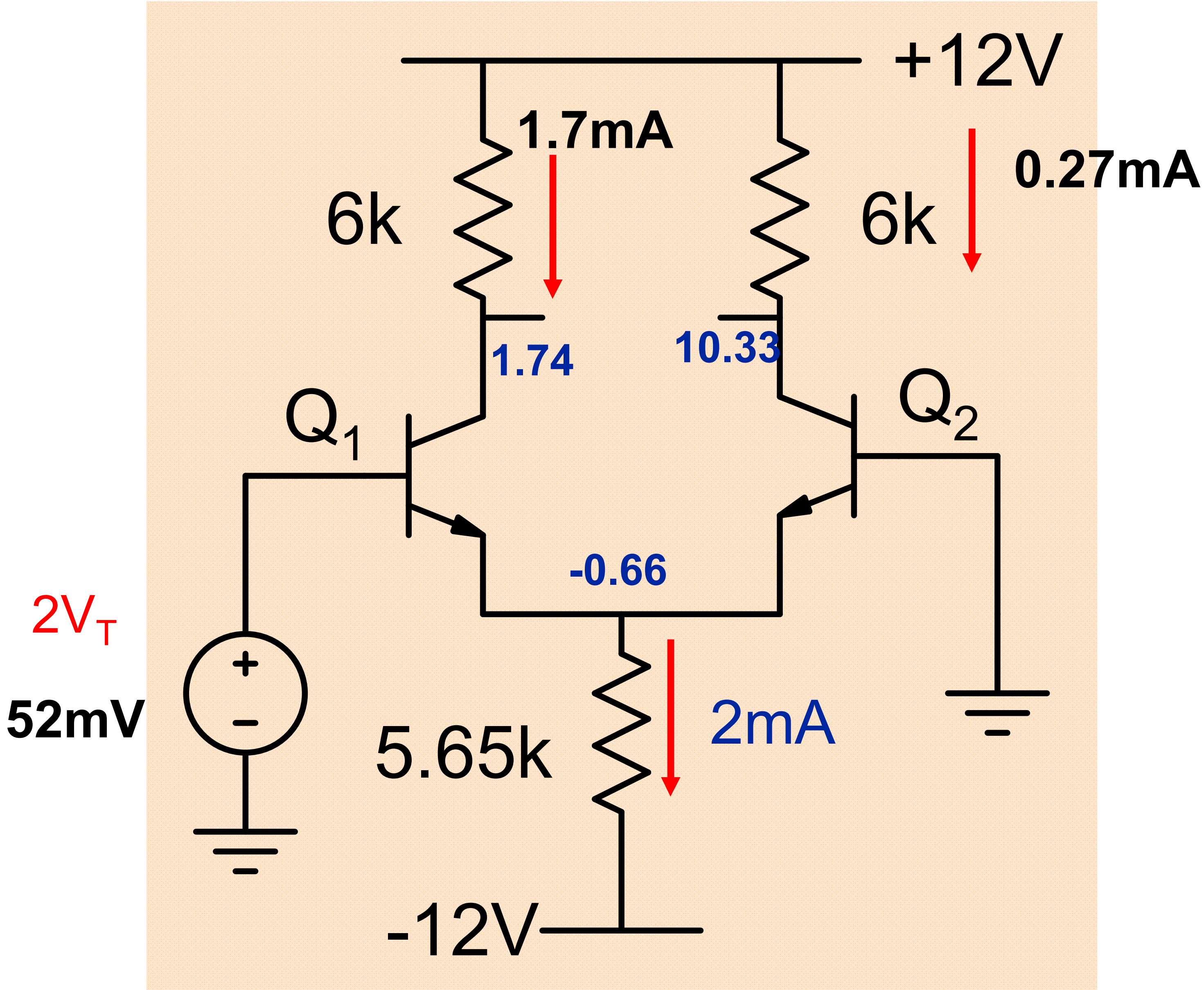
$$I_{C2} = I_{EE} \times \frac{1}{1+\exp(V_{id}/V_T)}$$

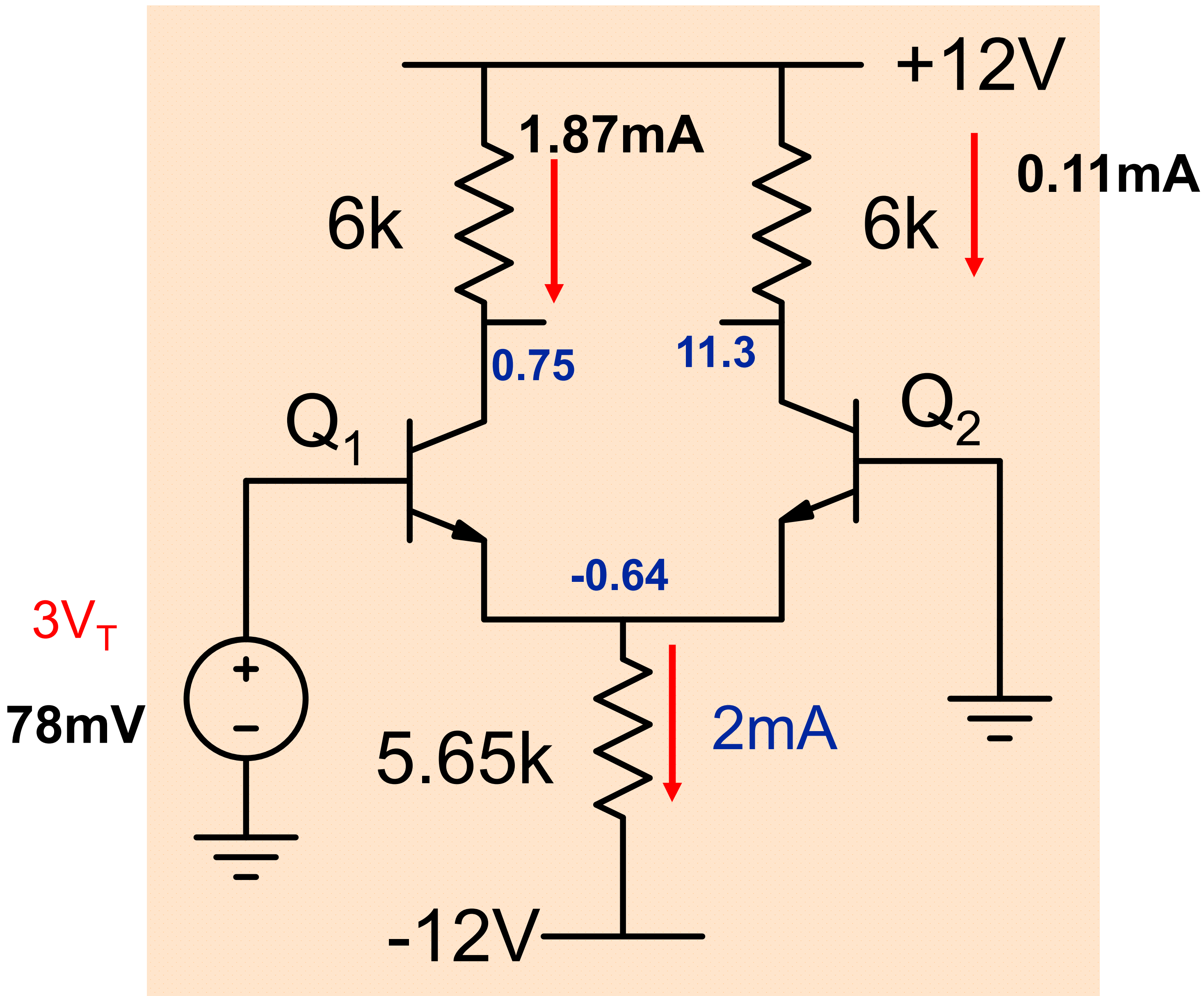


Current I_{EE} switches between the two transistors

Current Switching




+12V
1.7mA
0.27mA
6k
6k
1.74
10.33
Q1
Q2
-0.66
2VT
52mV
5.65k
2mA
-12V



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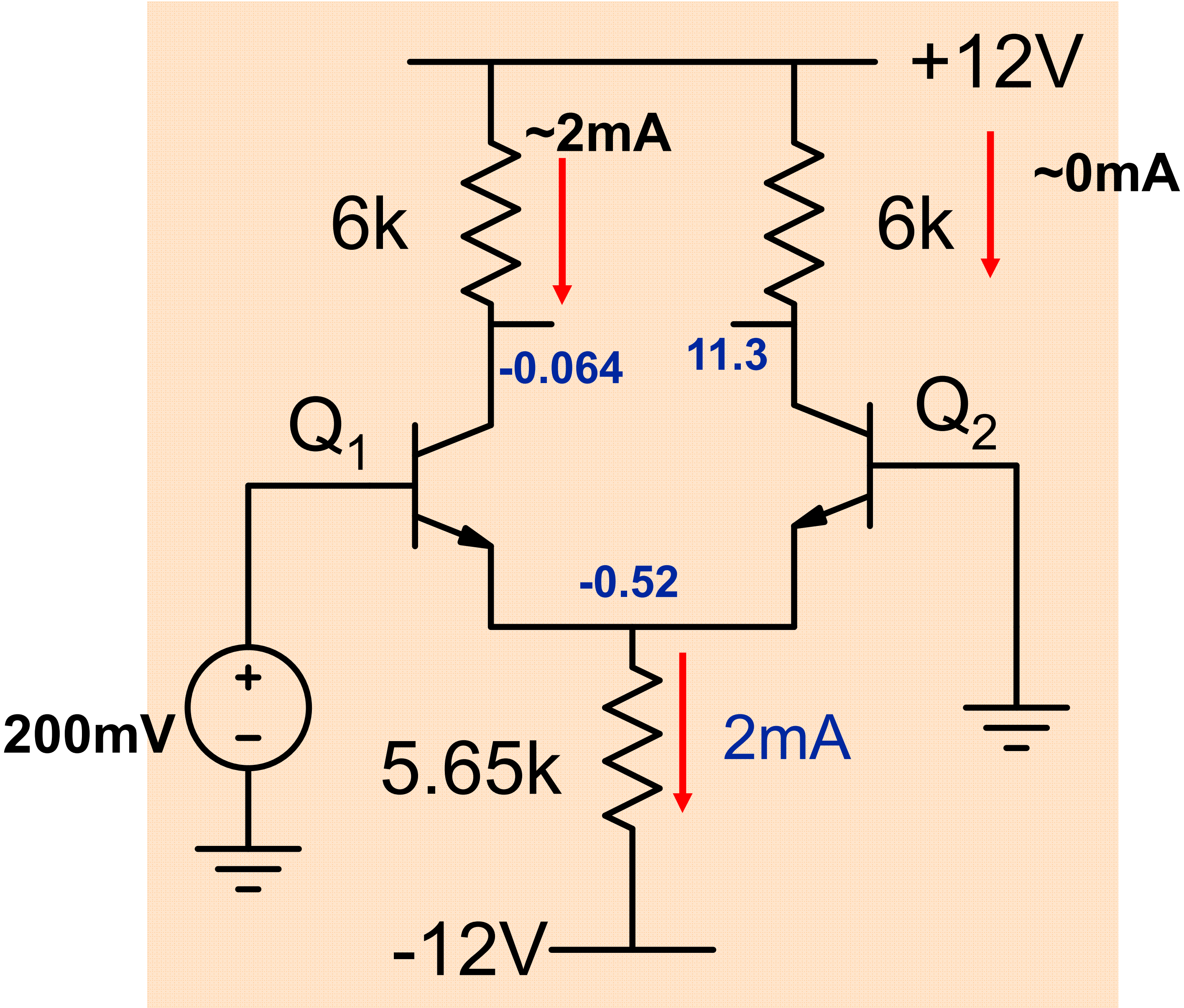
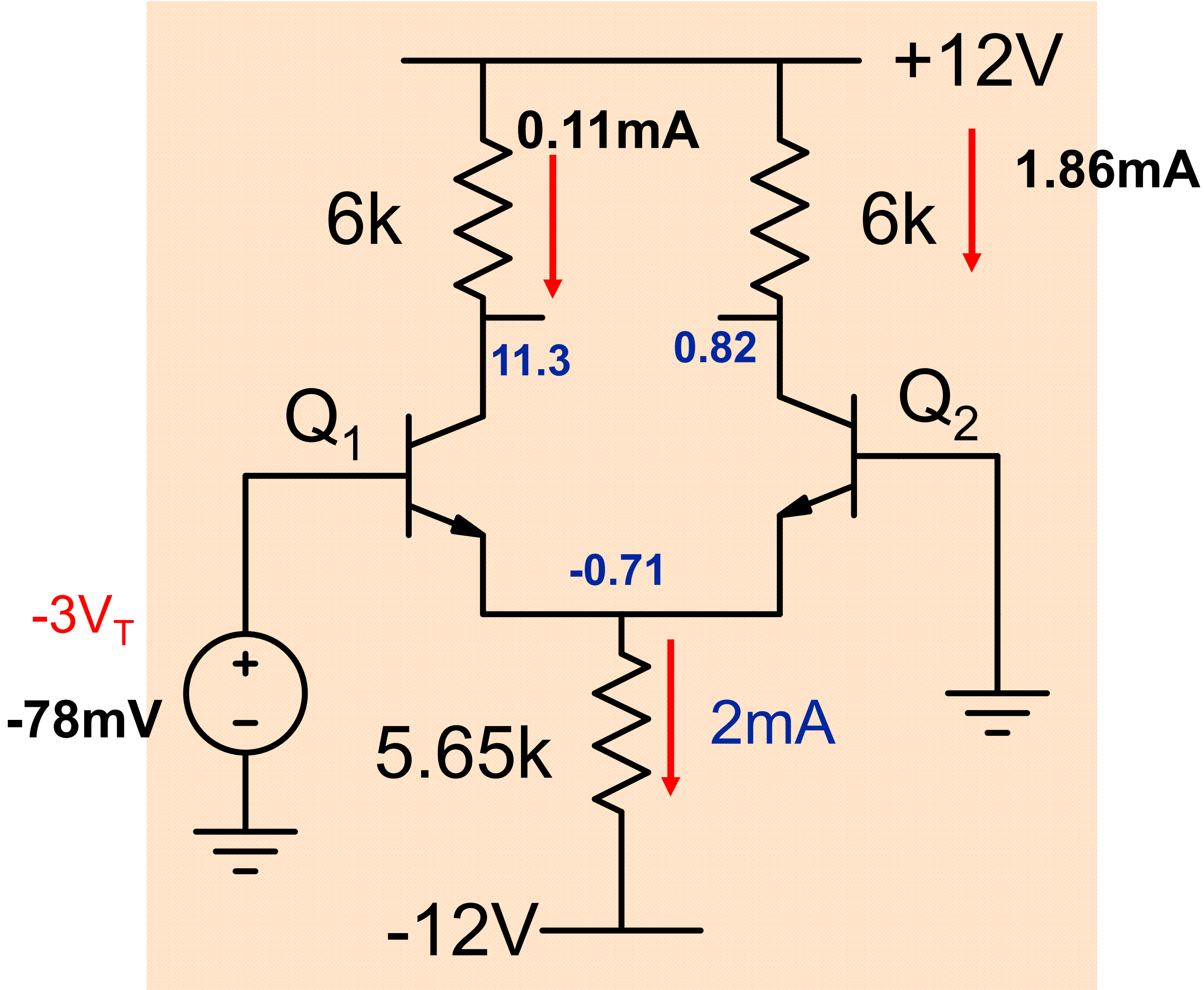
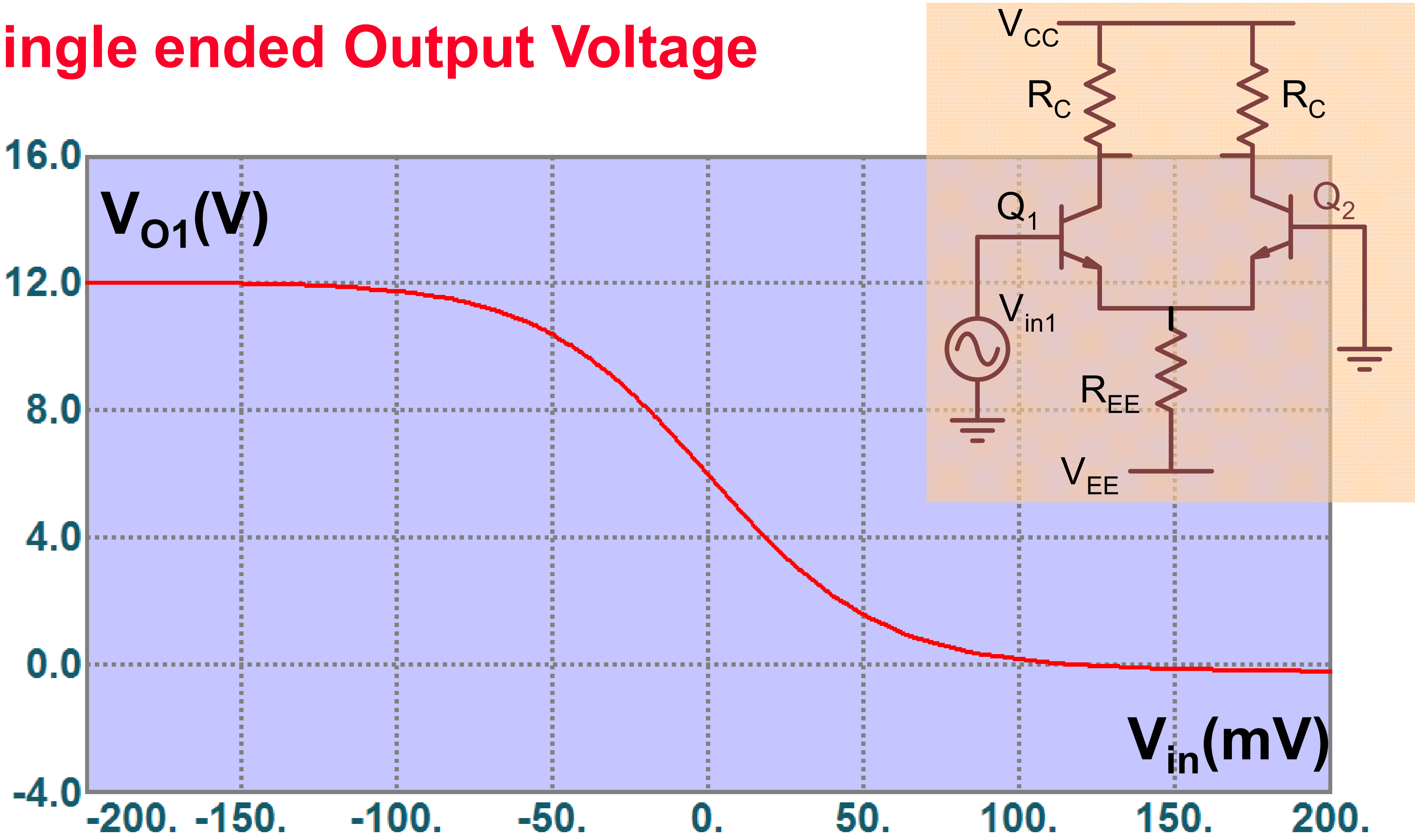
How low can the output go?



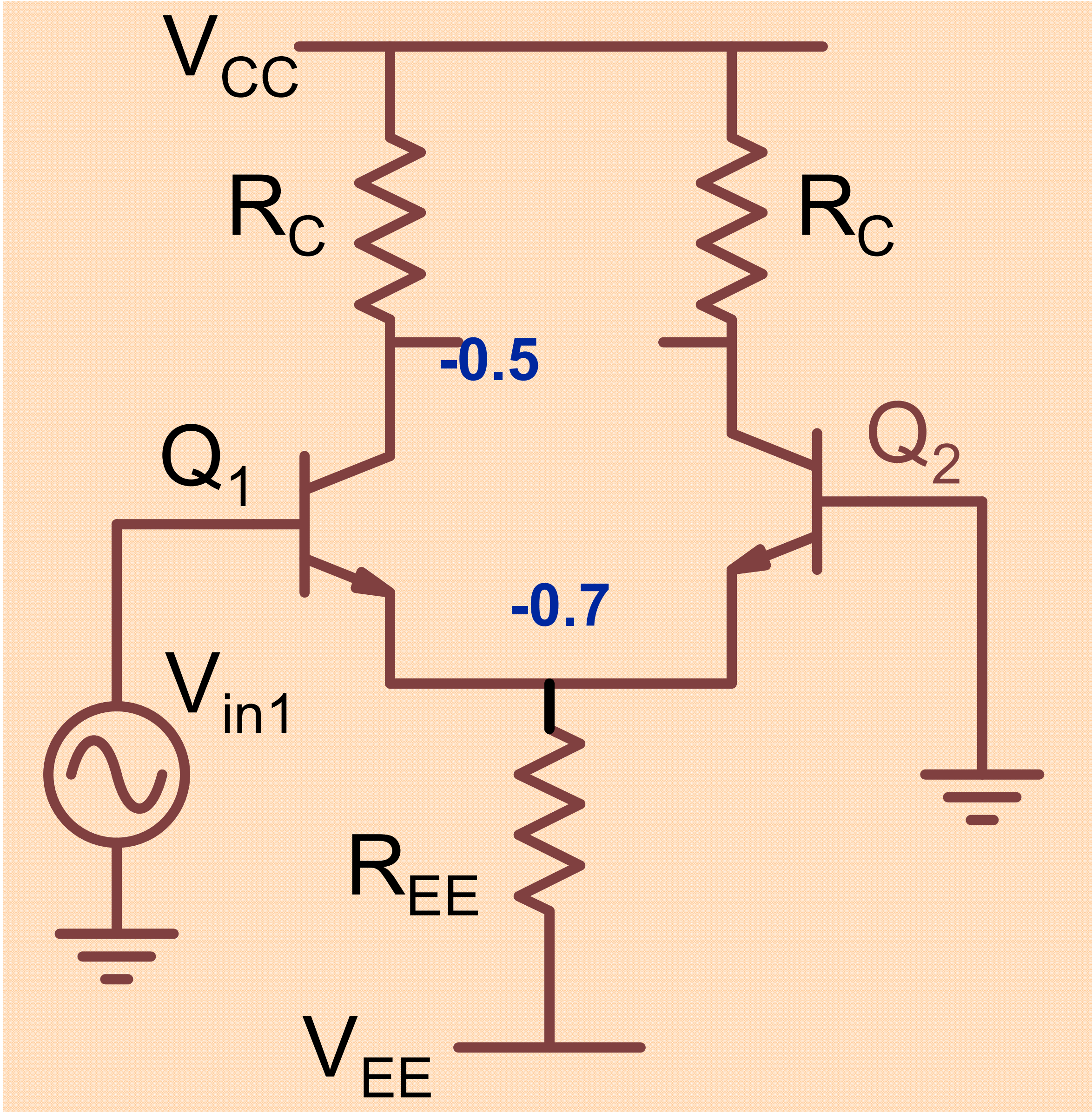

+12V
0.11mA
1.86mA
6k
6k
11.3
0.82
Q1
Q2
-0.71
-3VT
-78mV
2mA
5.65k
-12V

Single ended Output Voltage

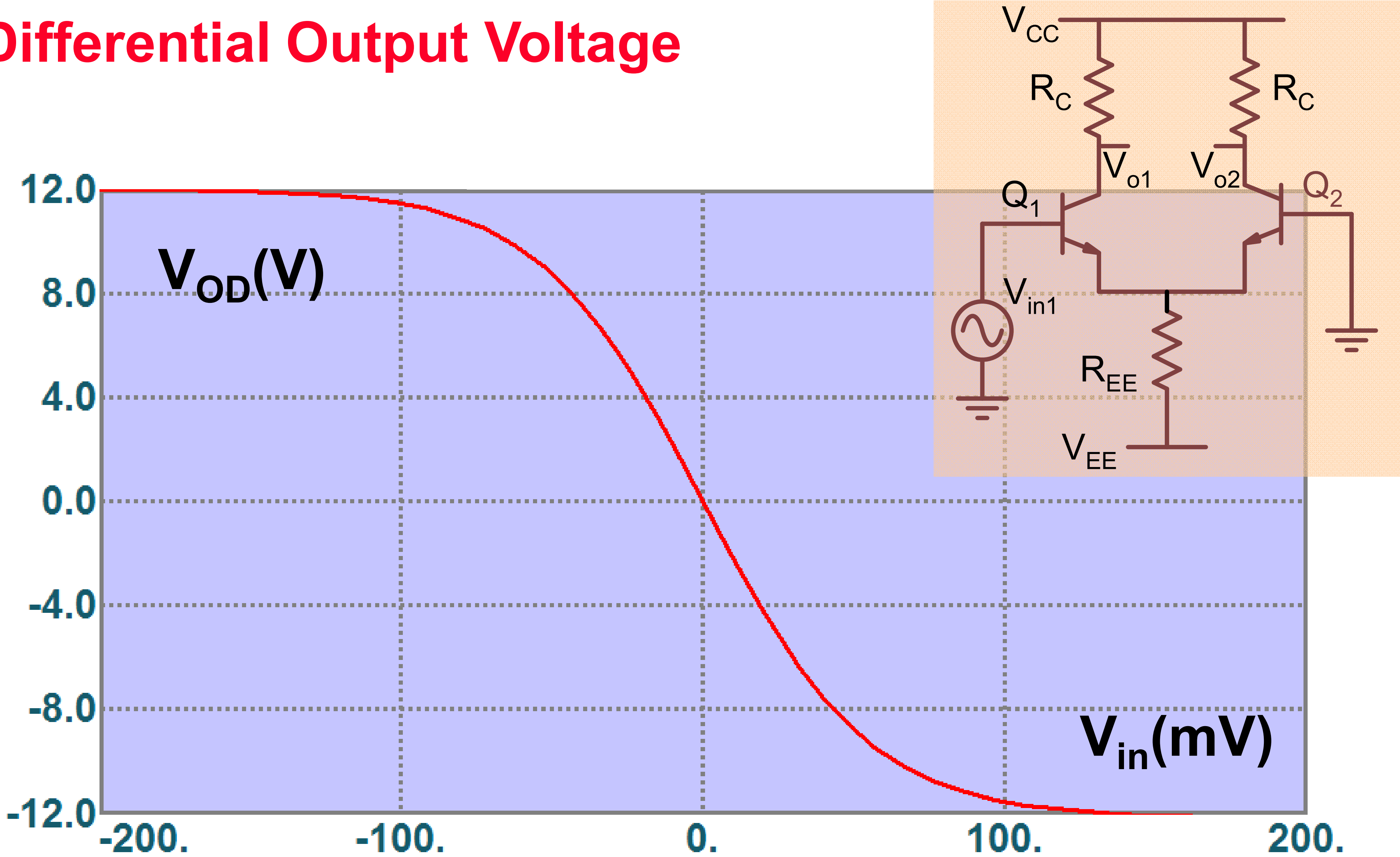


Poor Negative Swing

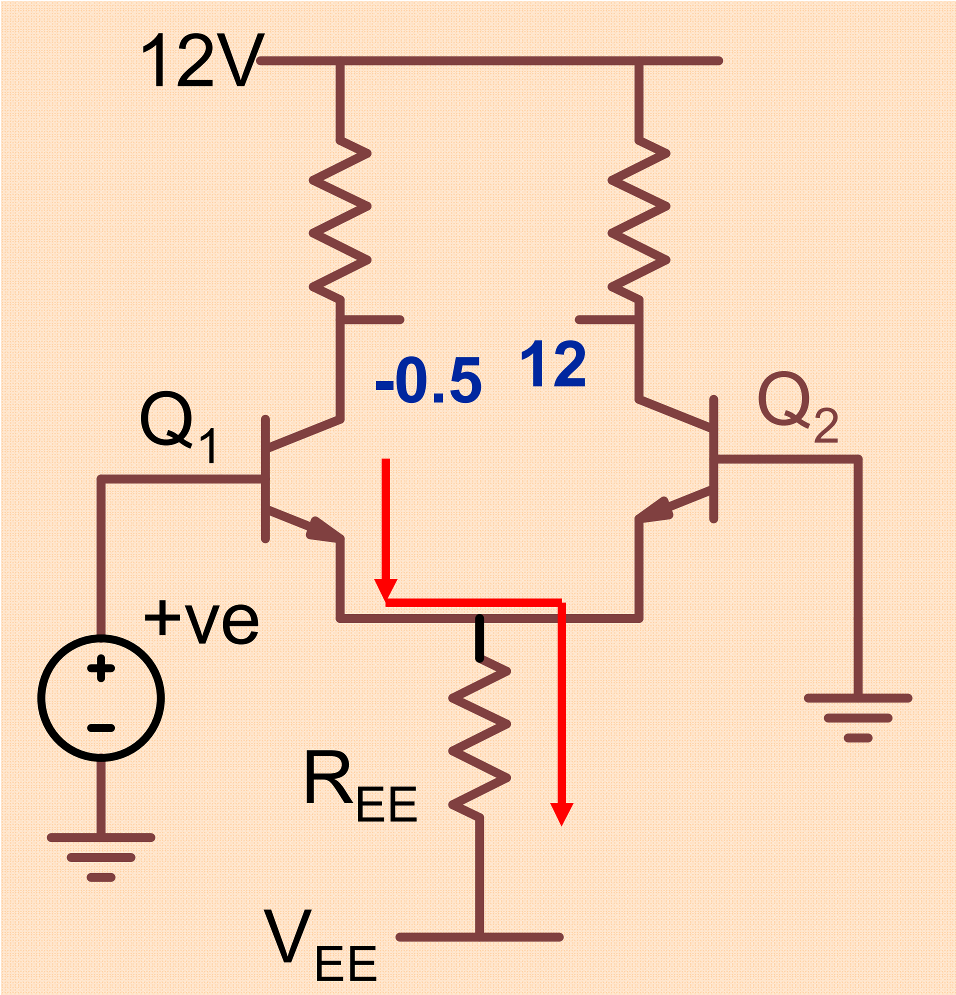
Negative Swing

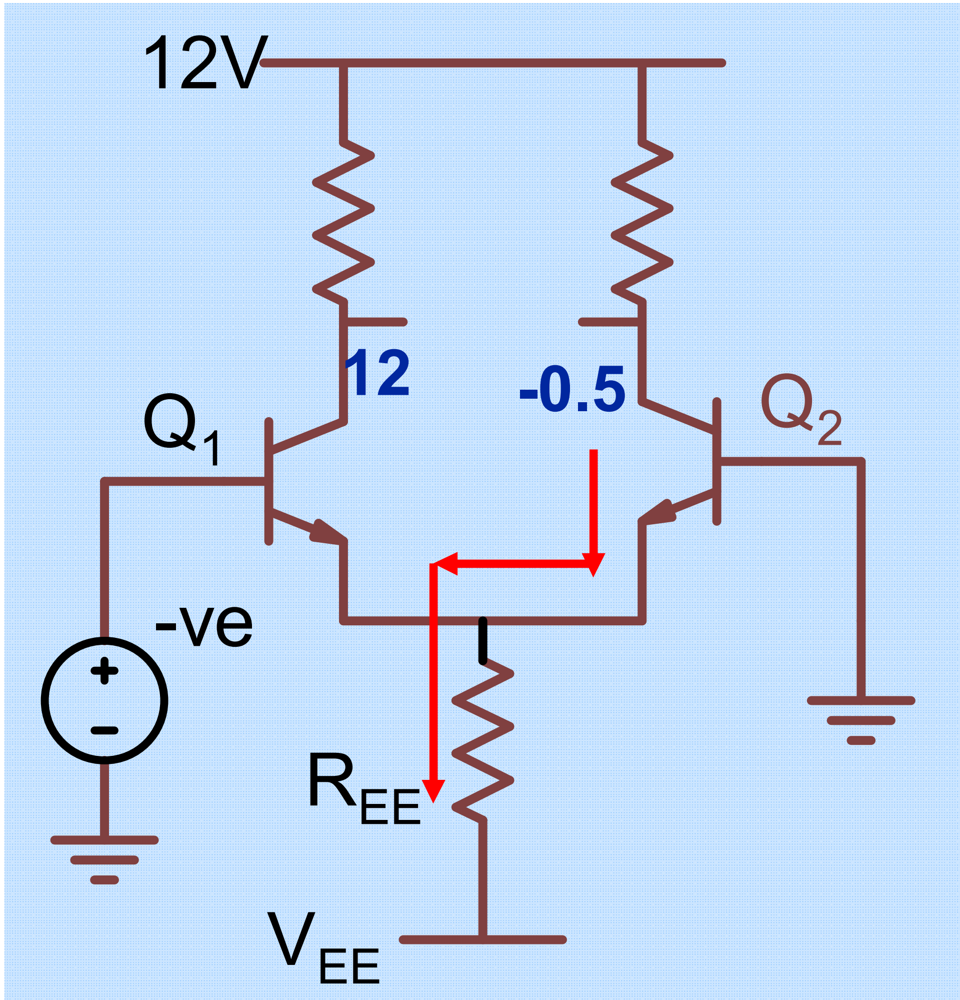


Differential Output Voltage



Swing is perfect !


12V
-0.5
12
Q1
Q2
+ve
REE
VEE


12V
12
-0.5
Q1
Q2
-ve
REE
VEE