EE210: Microelectronics-I

Lecture-30: Differential Amplifiers_2

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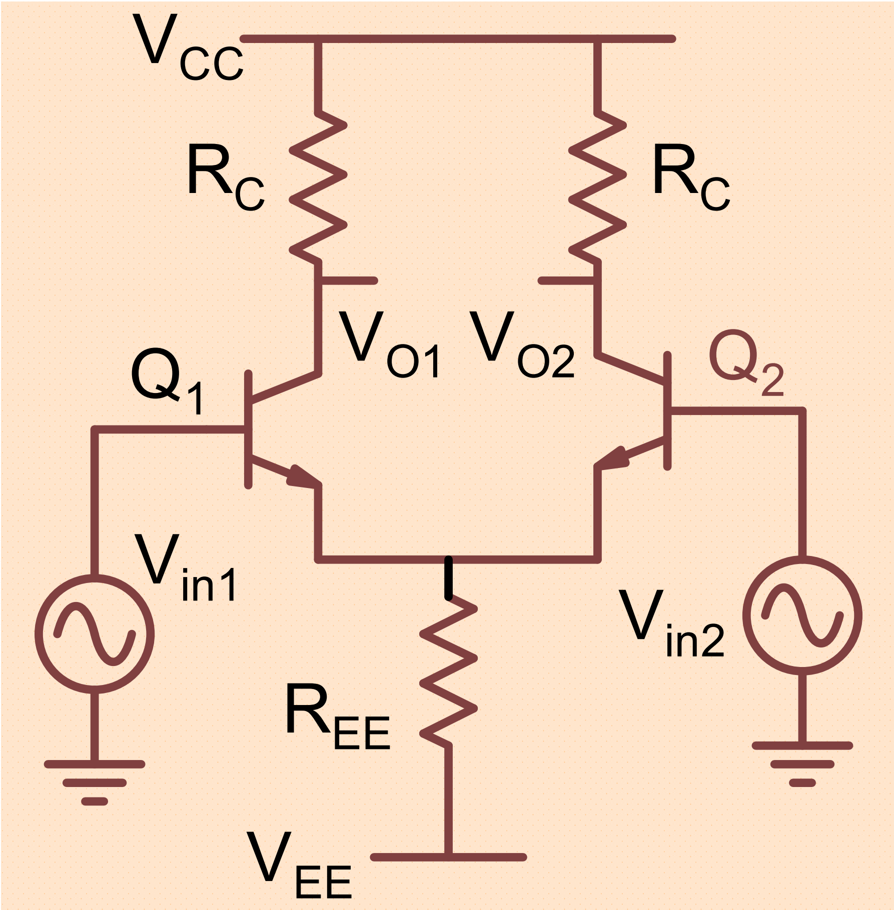
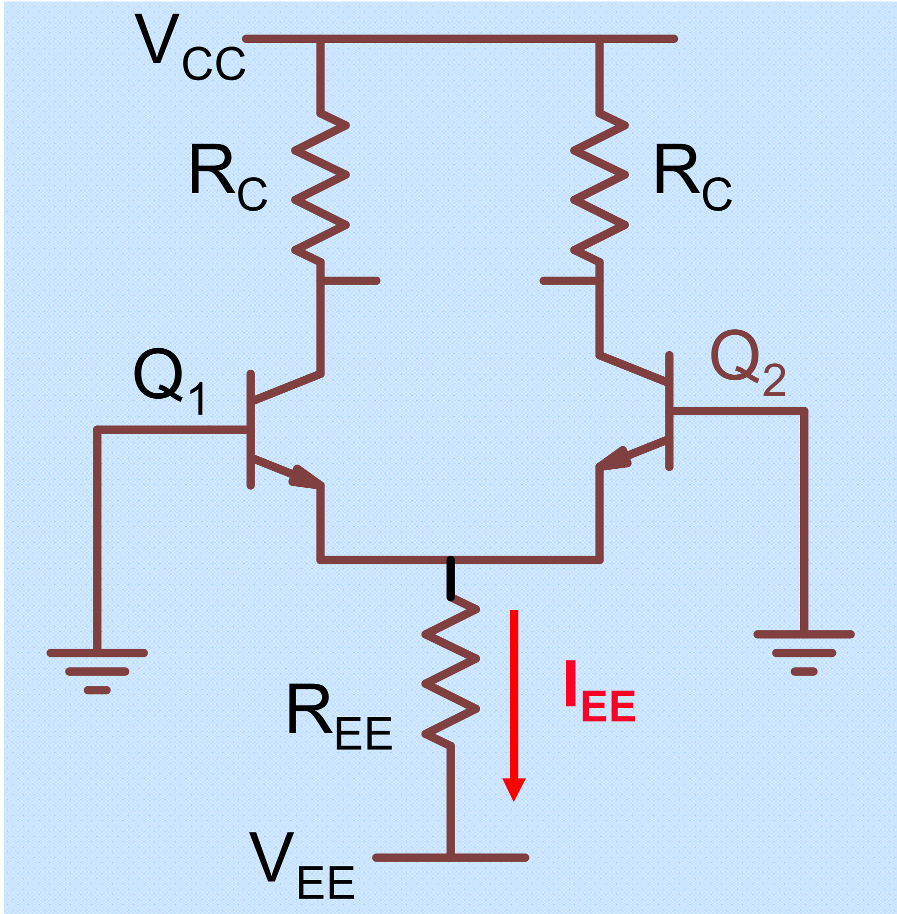
Bias or Quiescent point analysis

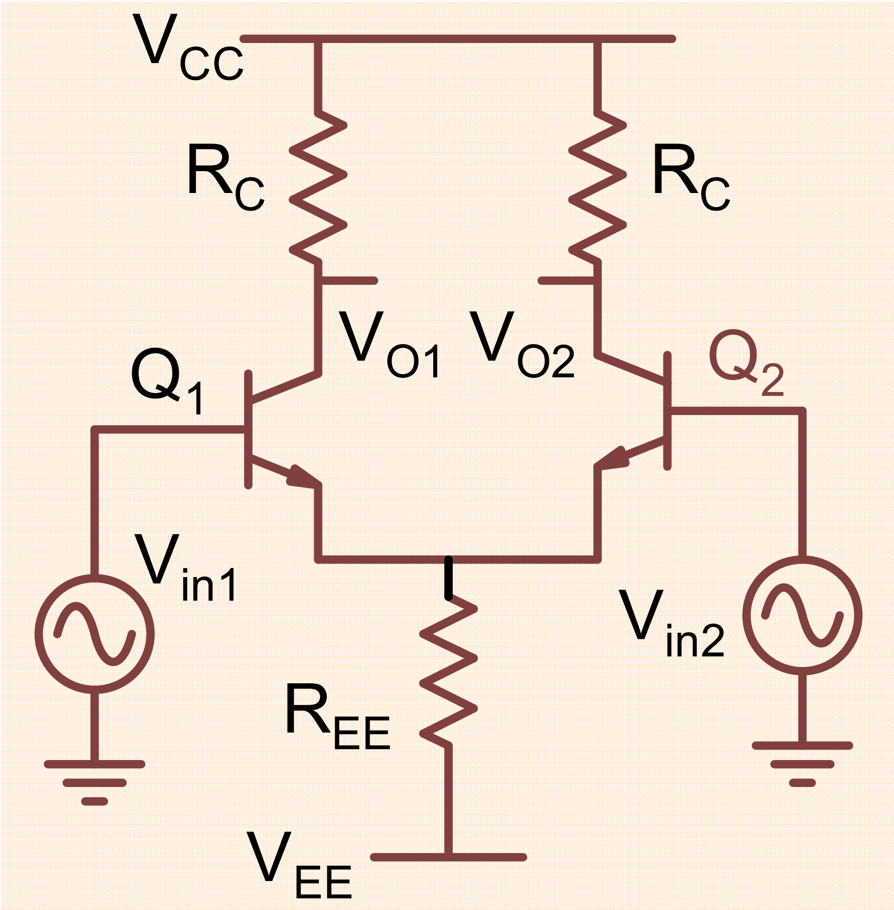




$$I_{EE} = \frac{-0.7 - V_{EE}}{R_E} \ ; \ I_{CQ1} = I_{CQ2} = 0.5 I_{EE}$$

Small Signal Analysis

Small signal can be dc, ac,…



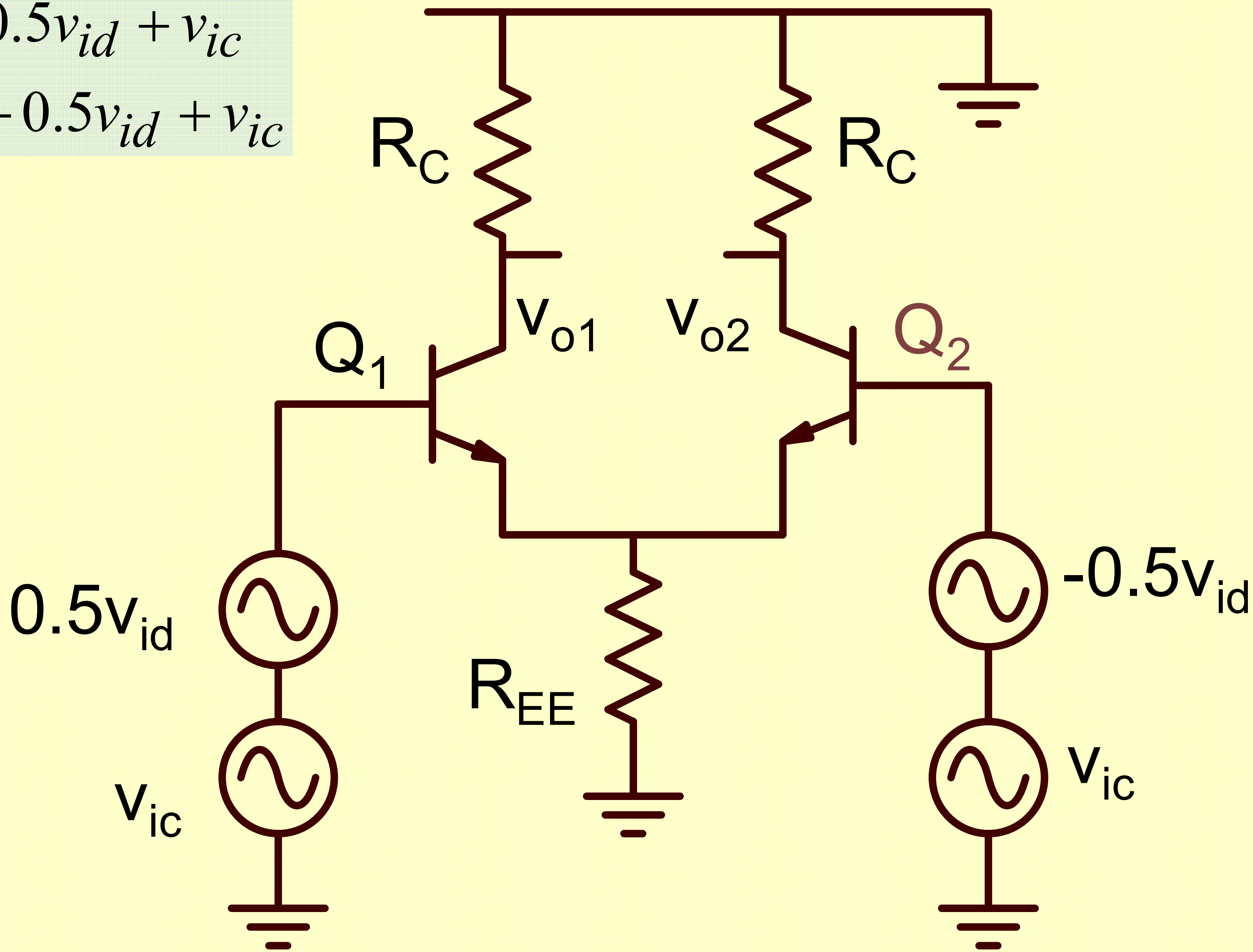
$$v_{id} = v_{in1} - v_{in2};$$

$$v_{ic} = \frac{v_{in1} + v_{in2}}{2}$$

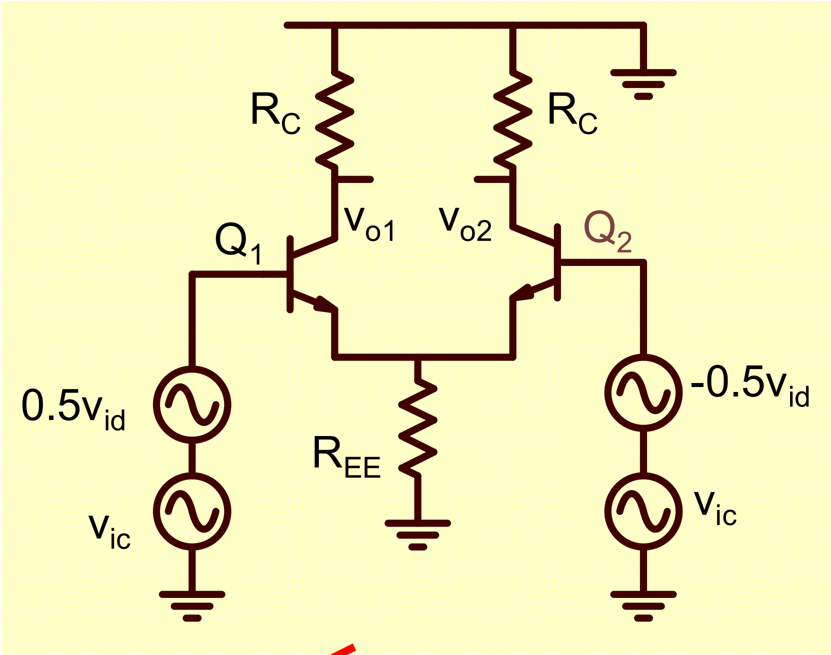
$$v_{in1} = 0.5v_{id} + v_{ic}$$

$$v_{in2} = -0.5v_{id} + v_{ic}$$

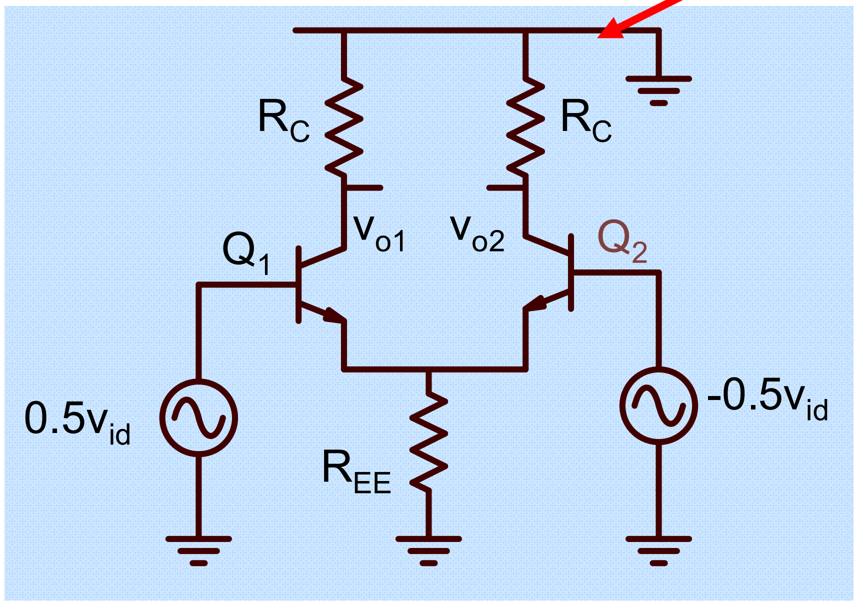
$$v_{in1} = 0.5v_{id} + v_{ic}$$
$$v_{in2} = -0.5v_{id} + v_{ic}$$



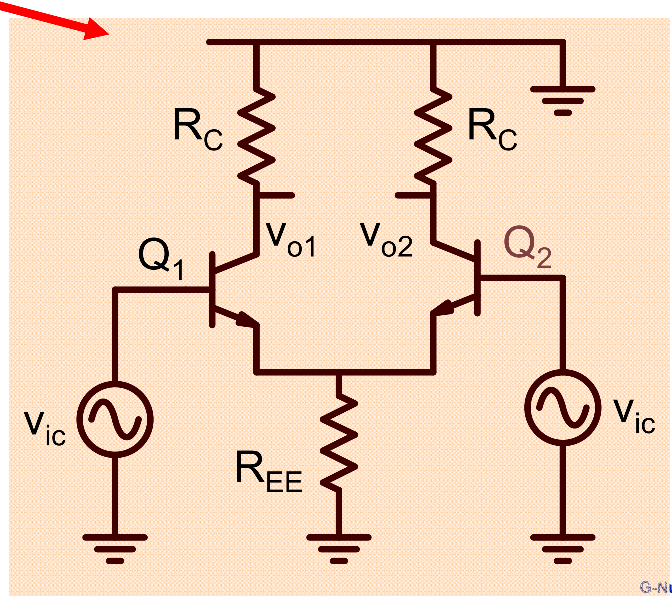
Use superposition to break analysis into two parts:



Differential mode



Common mode



G-Number

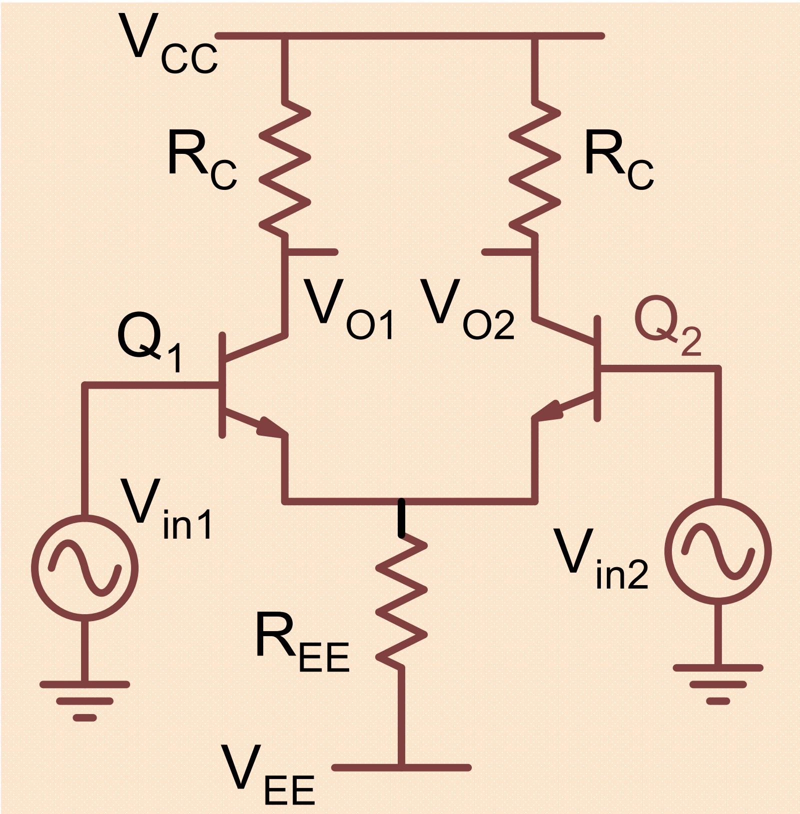
Signal at any point in the circuit:

$$X_j = X_{JQ} + x_j$$

$$x_j = x_{jd} + x_{jc}$$

$$x_{jd} = K_{jd} \times v_{id}$$

$$x_{jc} = K_{jc} \times v_{ic}$$

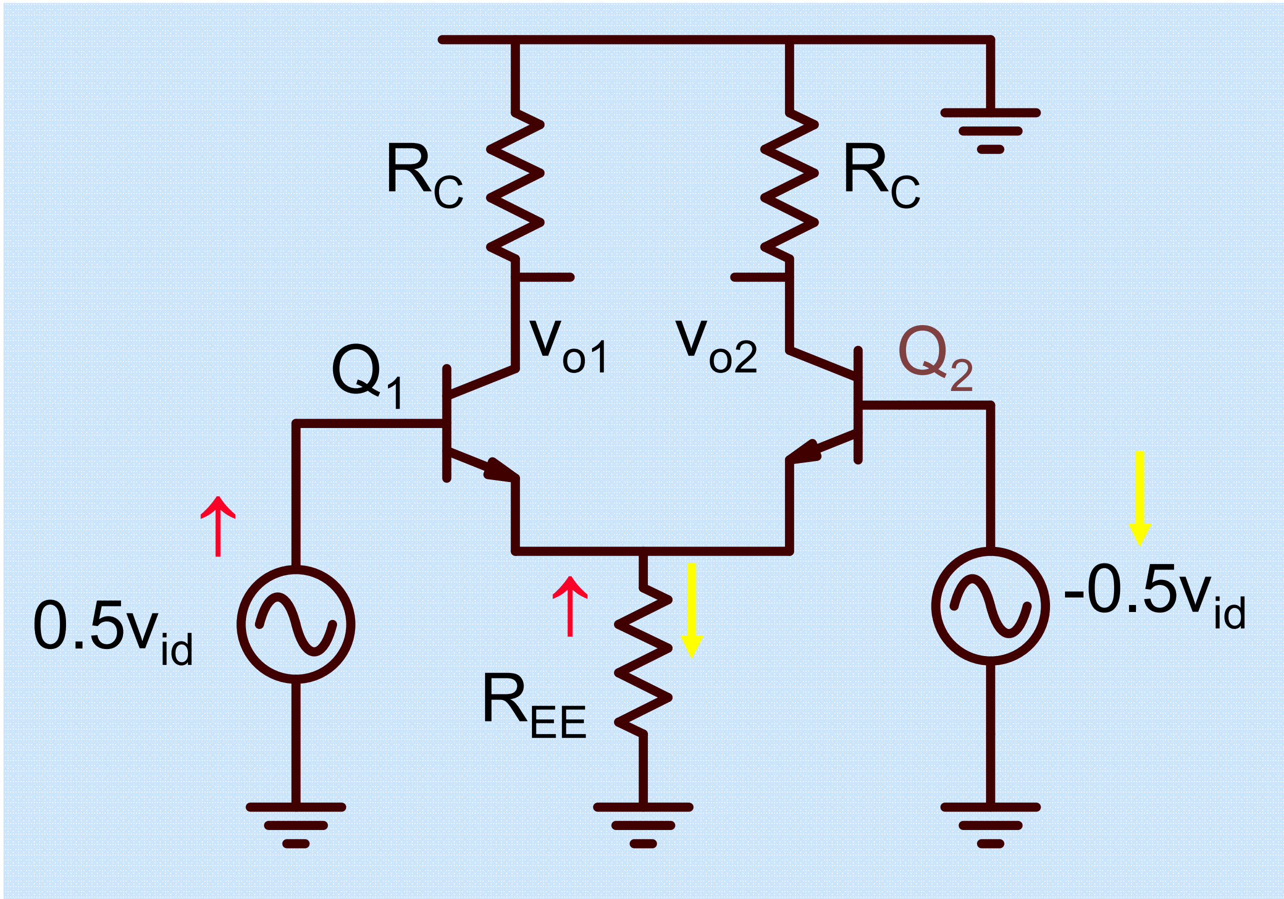


$$V_{o1} = V_{o1Q} + v_{o1d} + v_{o1c}$$

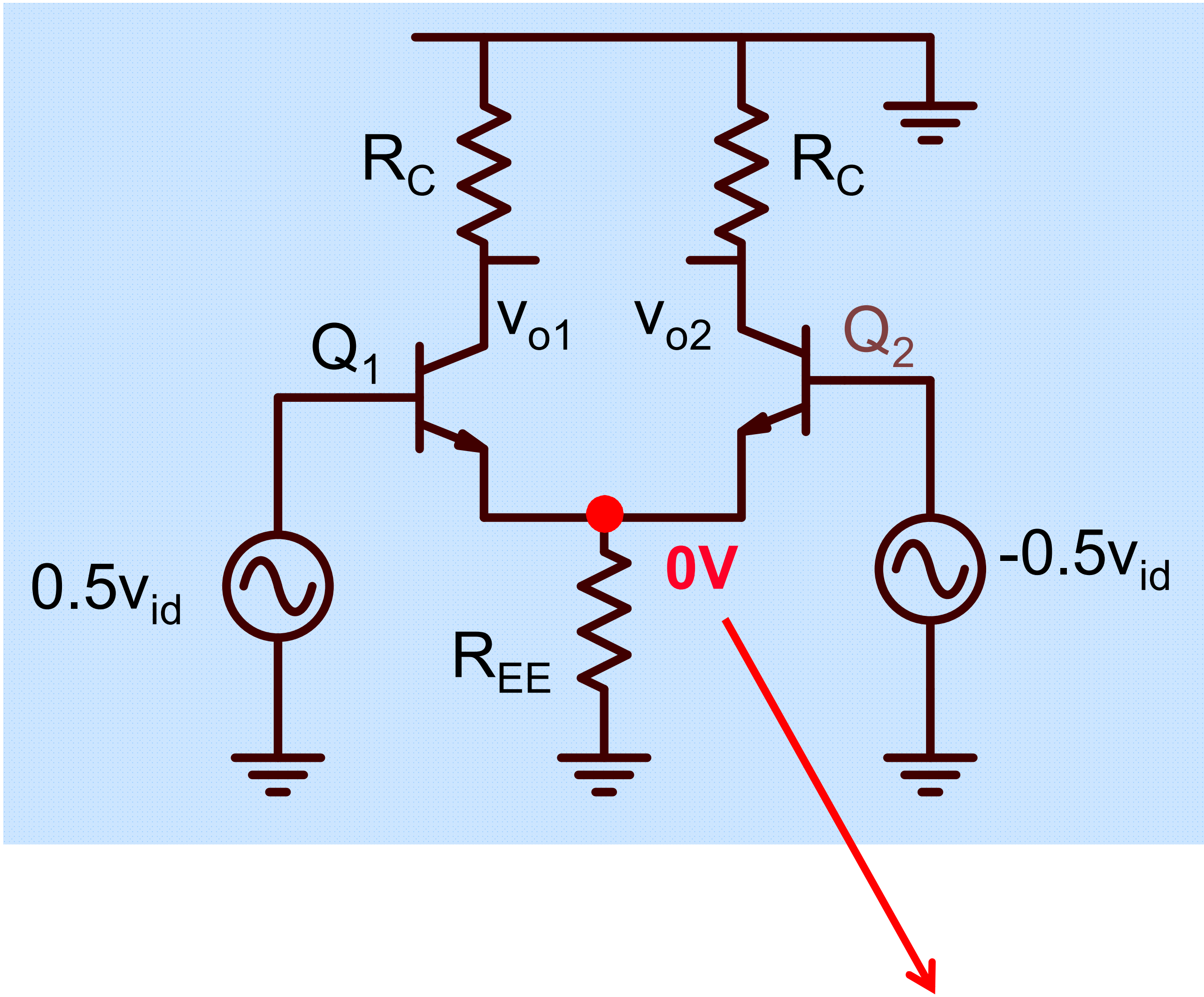
$$v_{o1d} = A_{dm} v_{id} \ ; \ v_{o1c} = A_{cm} v_{ic}$$

Analysis : Bias point
small signal: differential mode
common mode

Differential Mode Analysis

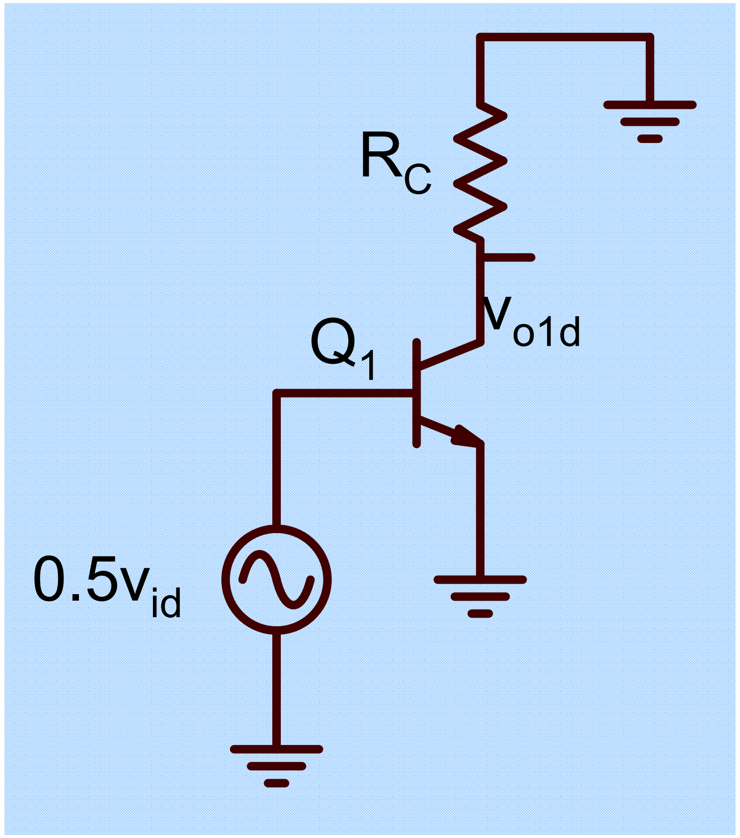


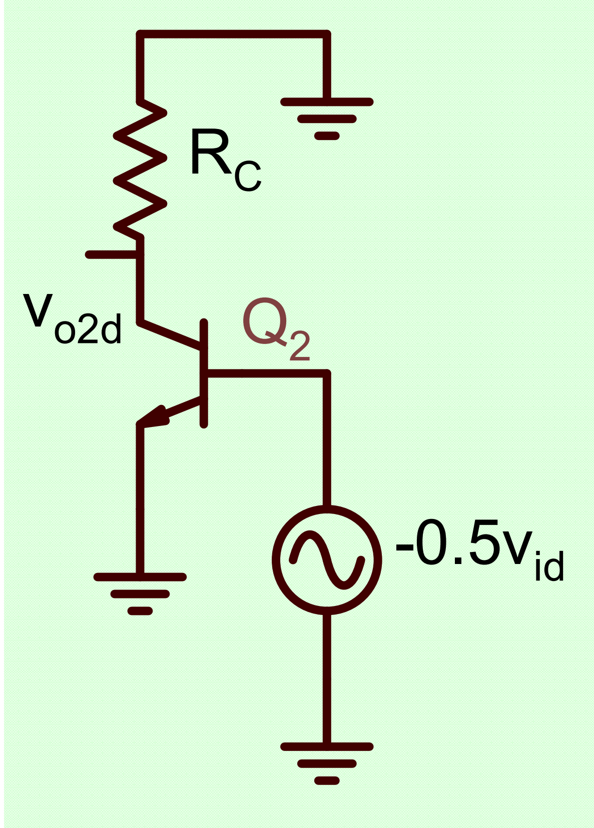
Differential Mode Analysis



Small signal ground

Differential Mode Analysis



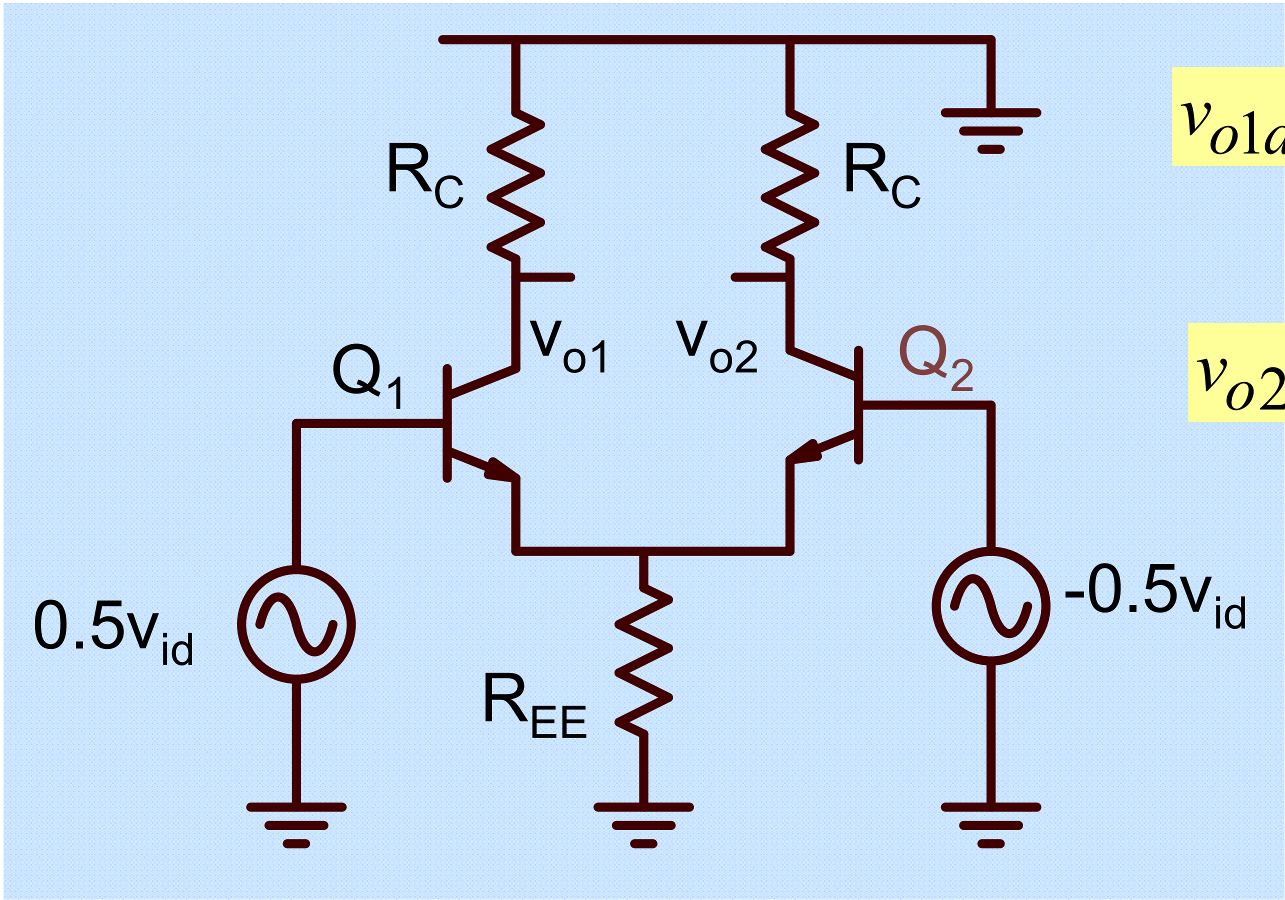


$$v_{o1d} = -0.5 g_m R_C v_{id}$$

$$v_{o2d} = 0.5 g_m R_C v_{id}$$

$$A_{dm} = \frac{v_{o1d}}{v_{id}} = -0.5 g_m R_C$$

Differential output Voltage

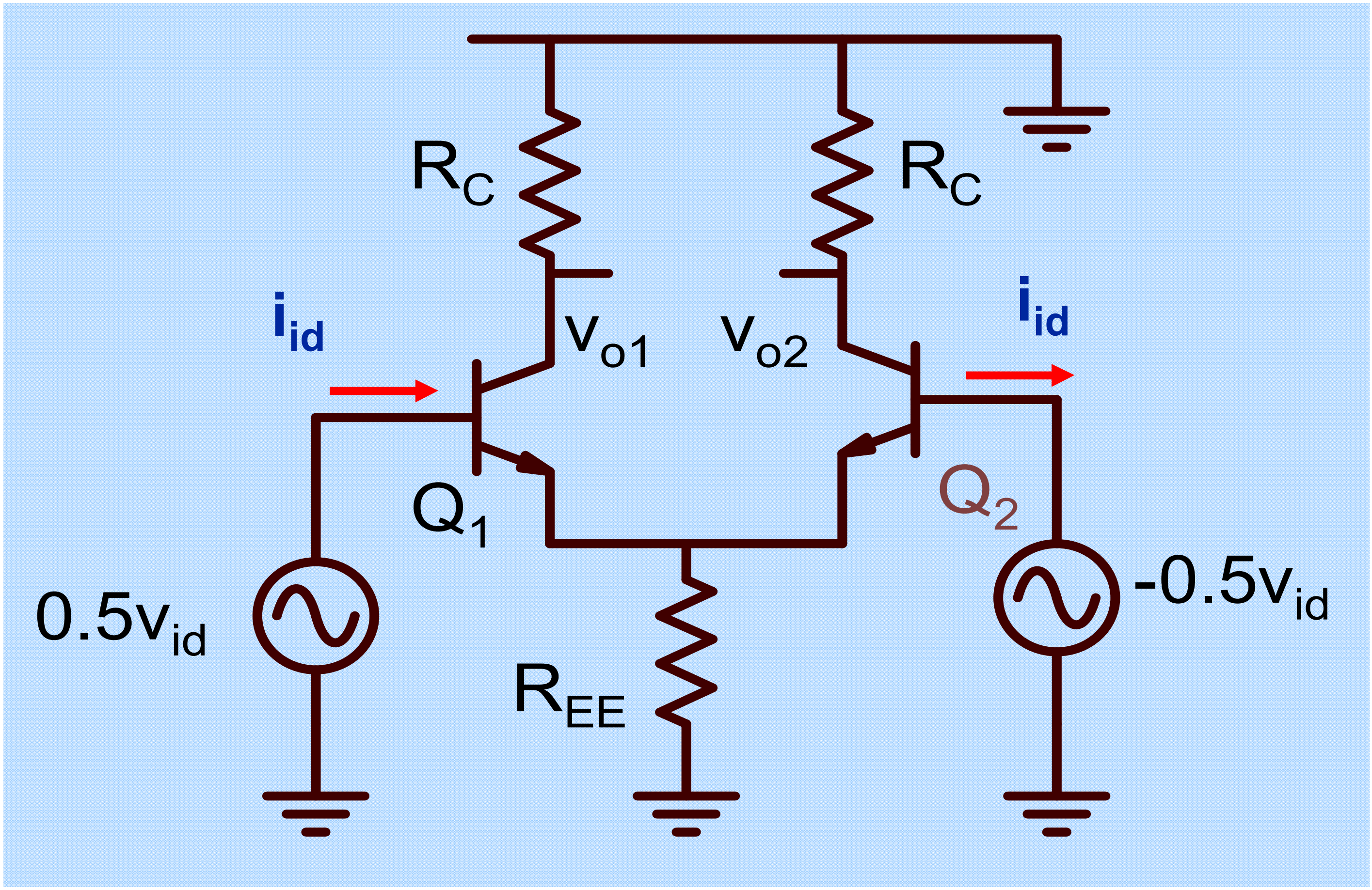


$$v_{o1d} = -0.5 g_m R_C v_{id}$$

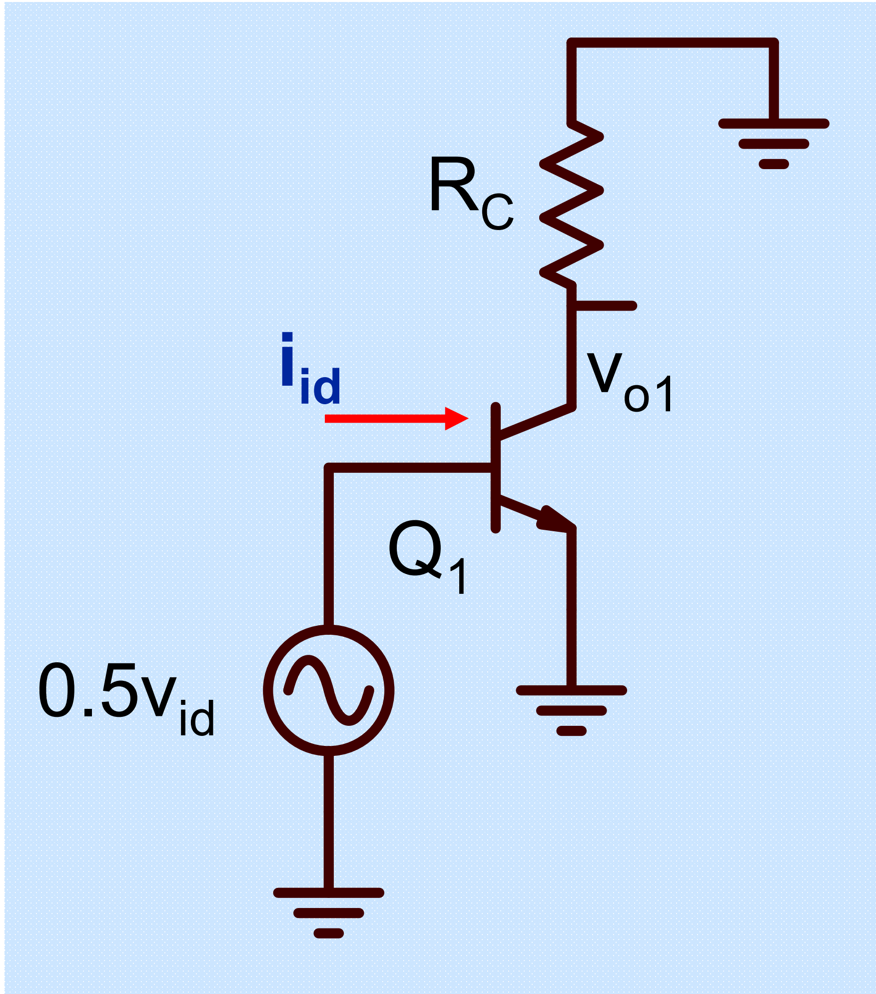
$$v_{o2d} = 0.5 g_m R_C v_{id}$$

$$v_{od} = v_{o2d} - v_{o1d} = g_m \times R_C$$

Differential Input Resistance



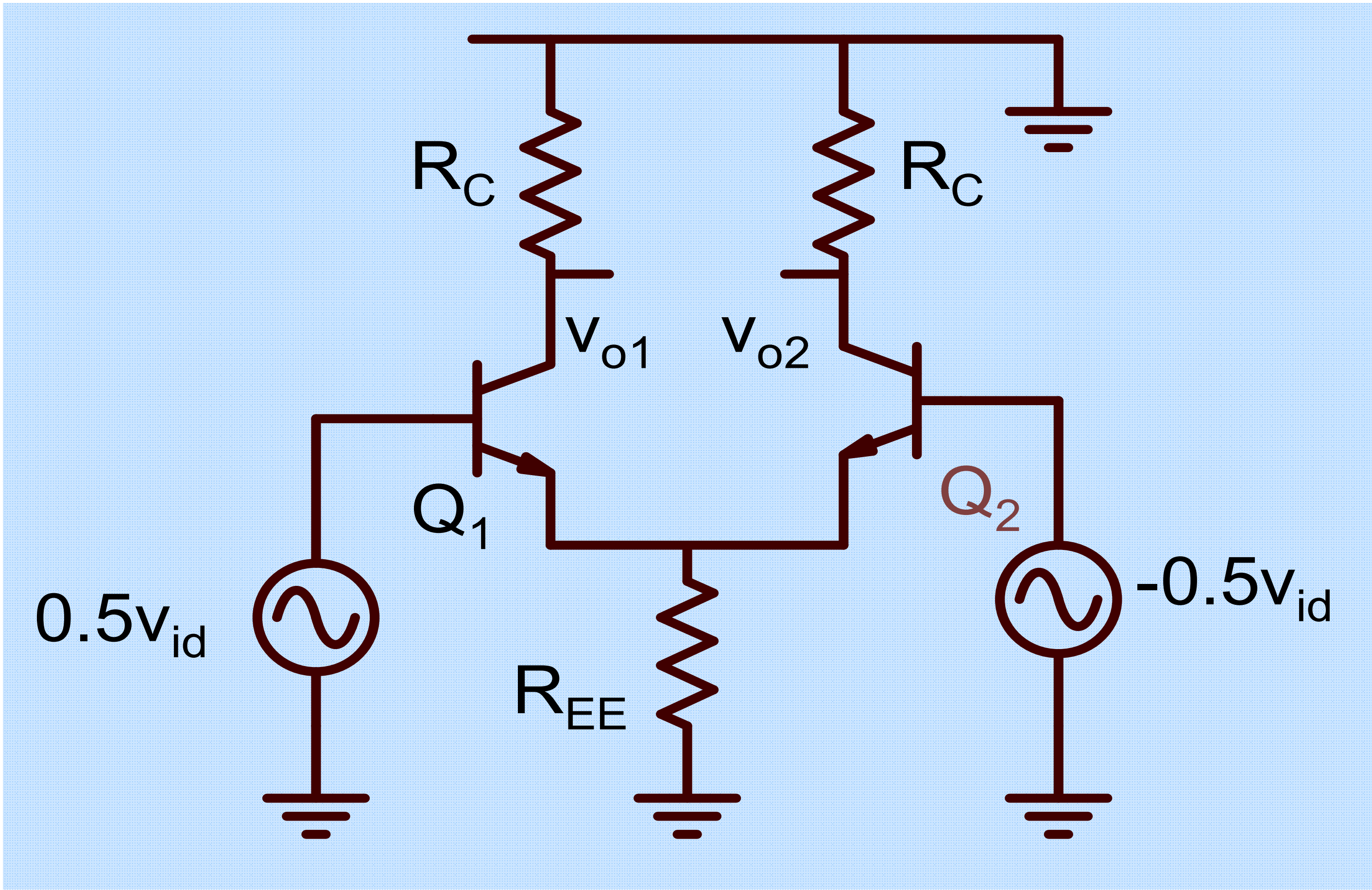
$$R_{id} = \frac{v_{id}}{i_{id}}$$



$$i_{id} = \frac{0.5 v_{id}}{r_\pi}$$

$$R_{id} = 2 r_\pi$$

Output Resistance



Single ended output: R_C

Summary

Single ended output

$$A_{dm} = -0.5 g_m R_C$$

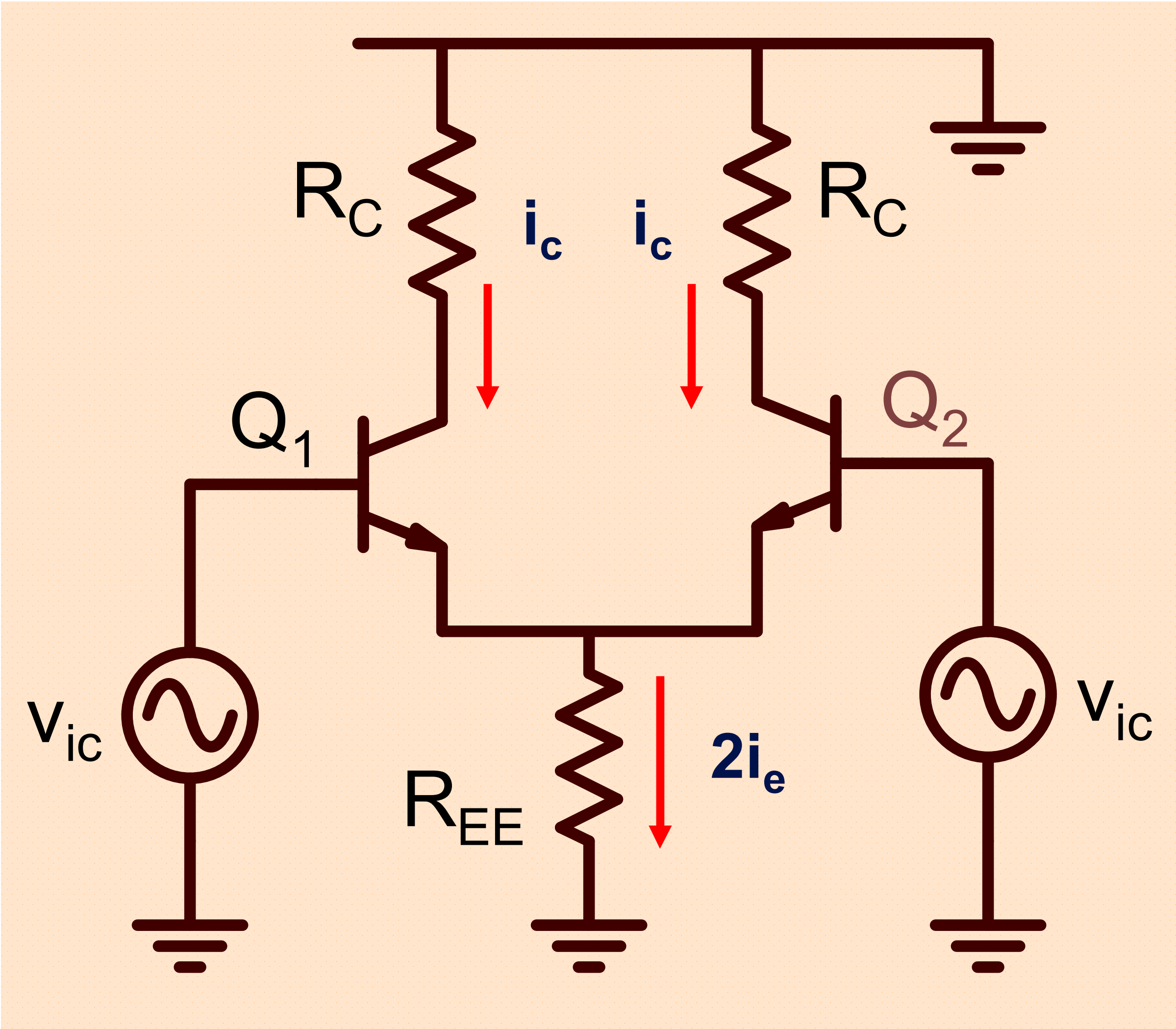
$$R_o = R_C$$

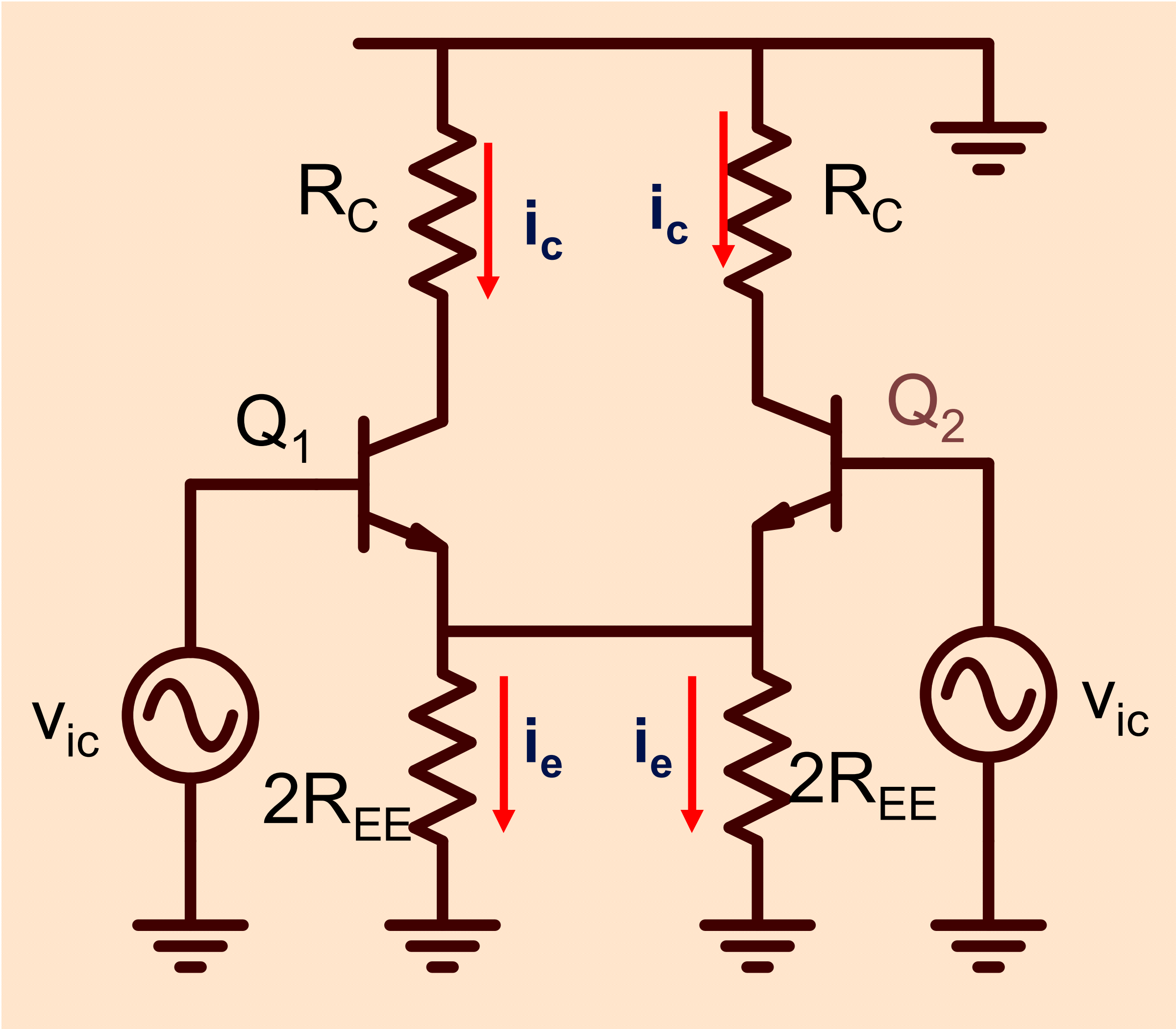
$$R_{id} = 2r_\pi$$

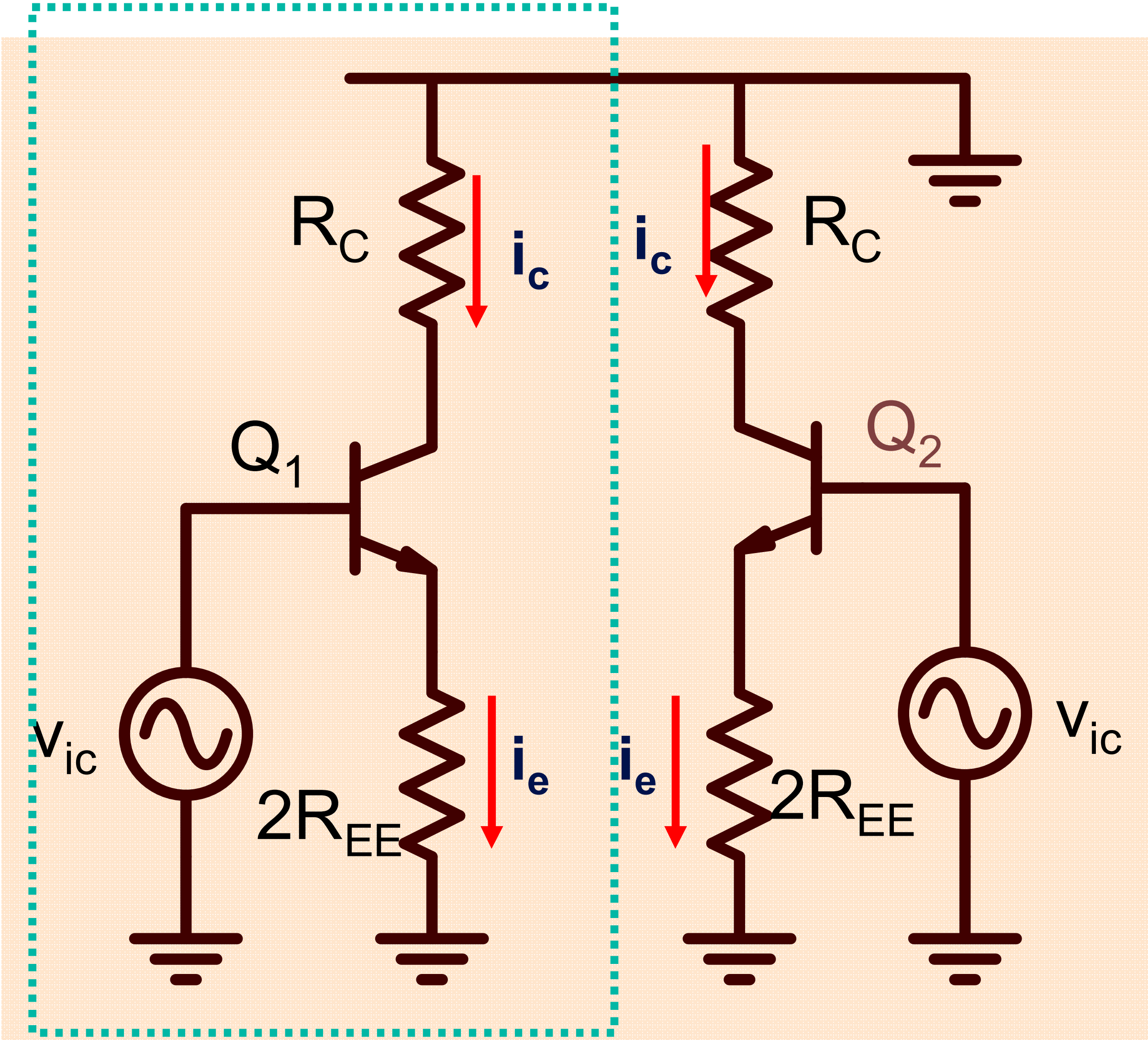
$$\frac{A_{dm} \times R_{id}}{R_O} = \beta$$

Like CE amplifier

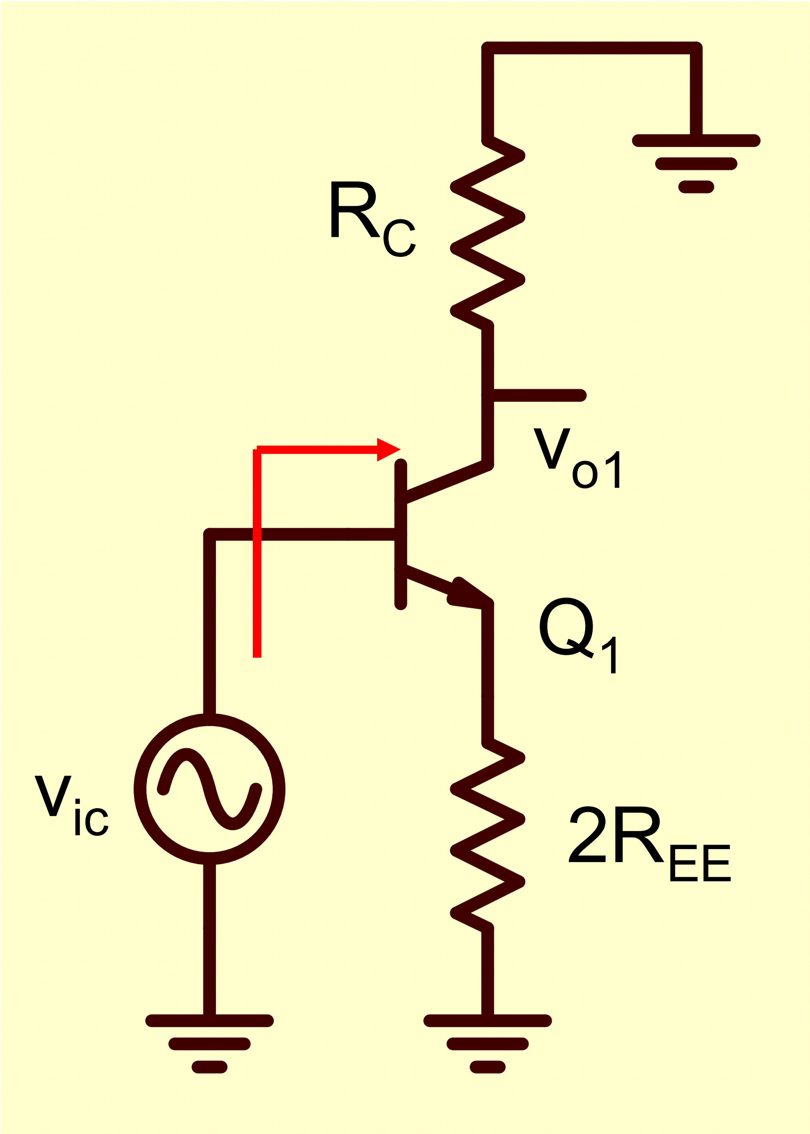
Common Mode Analysis




R_C
i_c
i_c
R_C
Q_1
Q_2
v_ic
v_ic
2R_EE
i_e
i_e
2R_EE


R_C
i_c
i_c
R_C
Q_1
Q_2
v_ic
i_e
i_e
2R_EE
2R_EE
v_ic

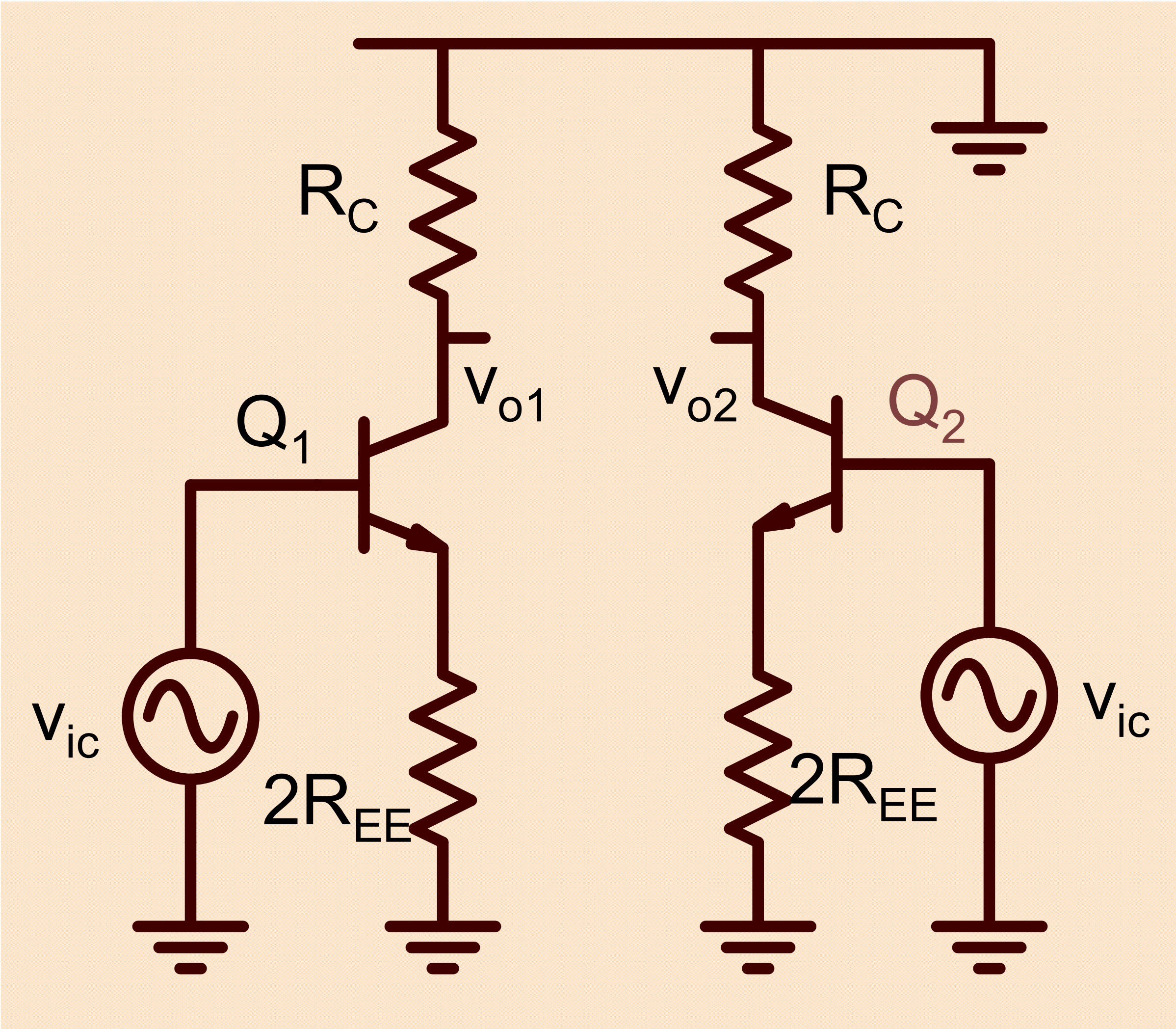
Single ended common mode gain



$$A_{cm} = \frac{v_{o1}}{v_{ic}} = -\frac{g_m}{1+2g_m R_{EE}} R_C$$

$$R_{ic} = r_\pi + (1+\beta) \times 2R_{EE}$$

Differential Output



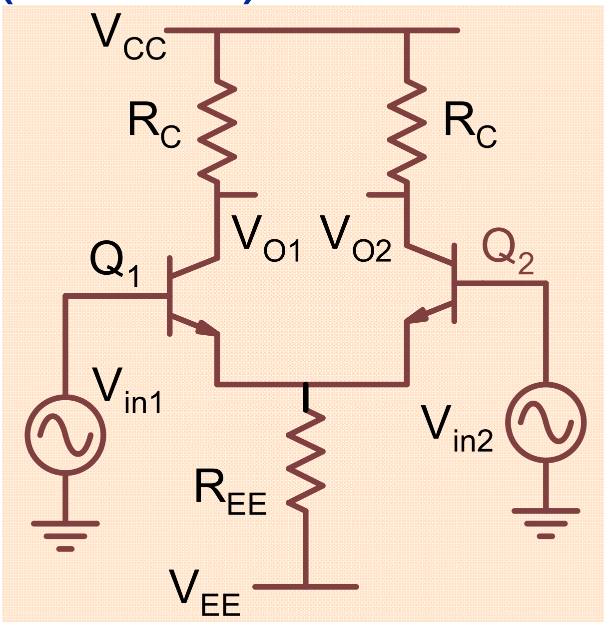
$$v_{o1} = v_{o2} \Rightarrow v_{od} = 0$$

Mismatches result in non-zero common mode gain

Common Mode Rejection Ratio (CMRR)

$$A_{dm} = -0.5 g_m R_C$$

$$A_{cm} = -\frac{g_m}{1+2g_m R_{EE}} R_C$$



$$CMRR = \frac{A_{dm}}{A_{cm}} = 0.5 + g_m R_{EE}$$

A high cmrr is required to reject unwanted common mode signals

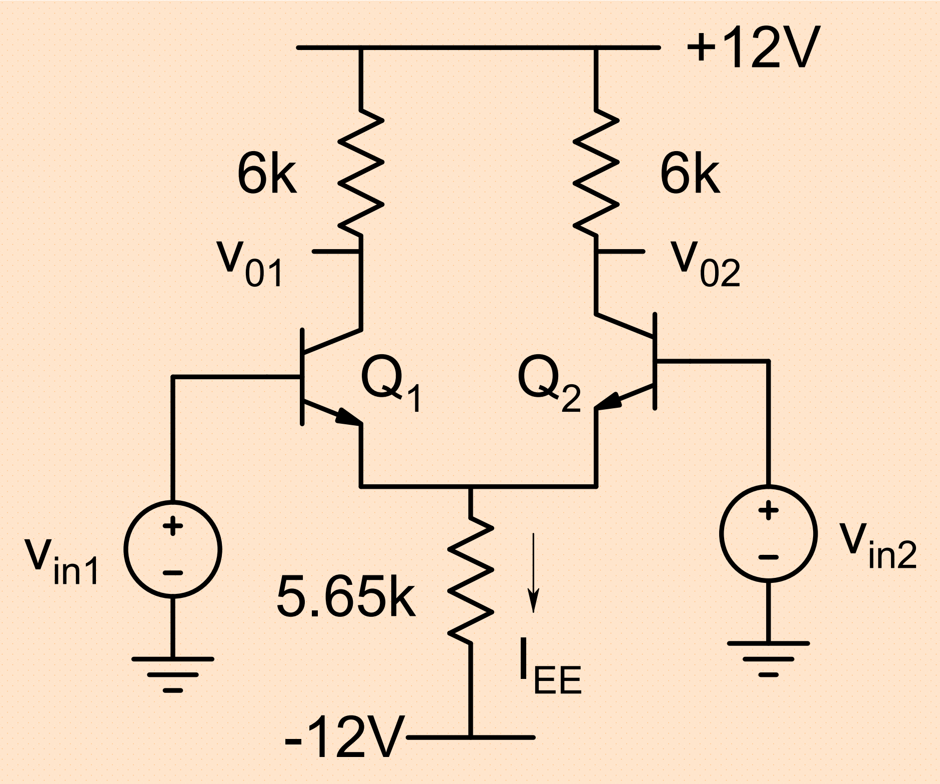
$$g_m = \frac{I_{CQ}}{V_T} = \frac{I_{EE}}{2V_T}$$

$$CMRR = 0.5 + \frac{I_{EE} R_{EE}}{2V_T} \cong 0.5 + \frac{-0.7 - V_{EE}}{2V_T}$$

For a V_{EE} of -12V , $CMRR = 217.8$

G-Number

Example



$$I_{EE} = \frac{-0.7 - V_{EE}}{R_{EE}} = 2mA$$

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

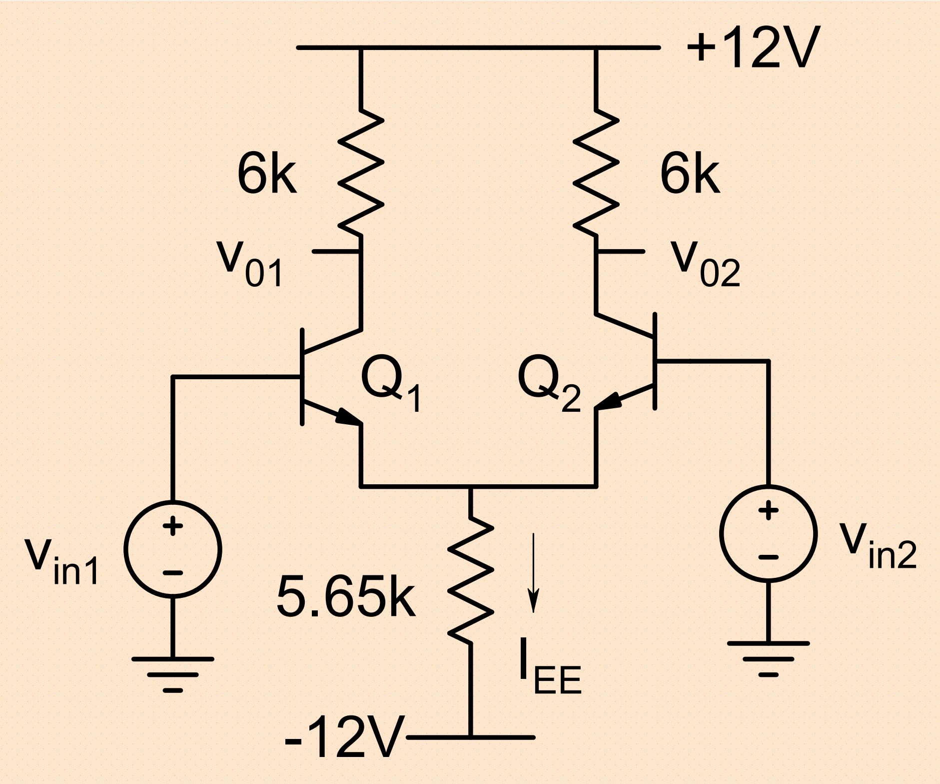
$$g_m = 38.46m\Omega^{-1}$$

$$A_{dm} = ?;\ R_{id} = ?$$

$$A_{cm} = ?;\ R_{ic} = ?$$

$$CMRR = ?$$

Example



$$I_{EE} = \frac{-0.7 - V_{EE}}{R_{EE}} = 2mA$$

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

$$g_m = 38.46m\Omega^{-1}$$

$$A_{dm} = -0.5 g_m R_C$$

$$A_{cm} = -\frac{g_m}{1 + 2 g_m R_{EE}} R_C$$

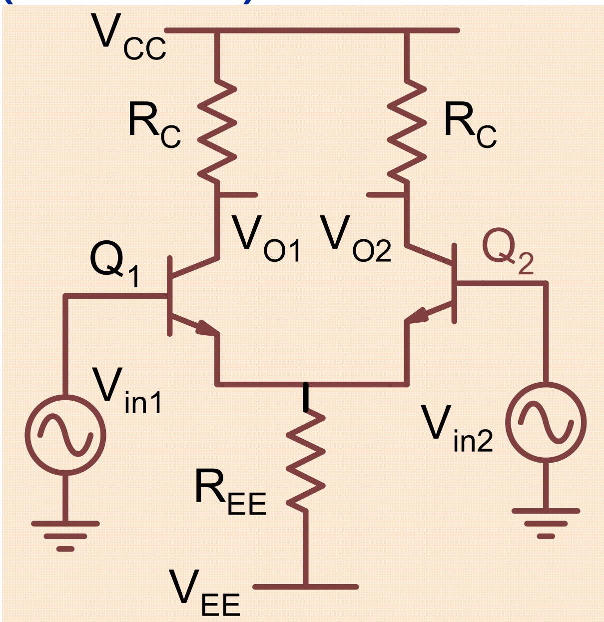
$$A_{dm} = -115.38;\ R_{id} = 5.2K\Omega$$

$$A_{cm} = -0.53;\ R_{ic} = 1.14M\Omega \qquad CMRR = 217.81$$

Common Mode Rejection Ratio (CMRR)

$$A_{dm} = -0.5 g_m R_C$$

$$A_{cm} = -\frac{g_m}{1+2g_m R_{EE}} R_C$$



$$CMRR = \frac{A_{dm}}{A_{cm}} = 0.5 + g_m R_{EE}$$

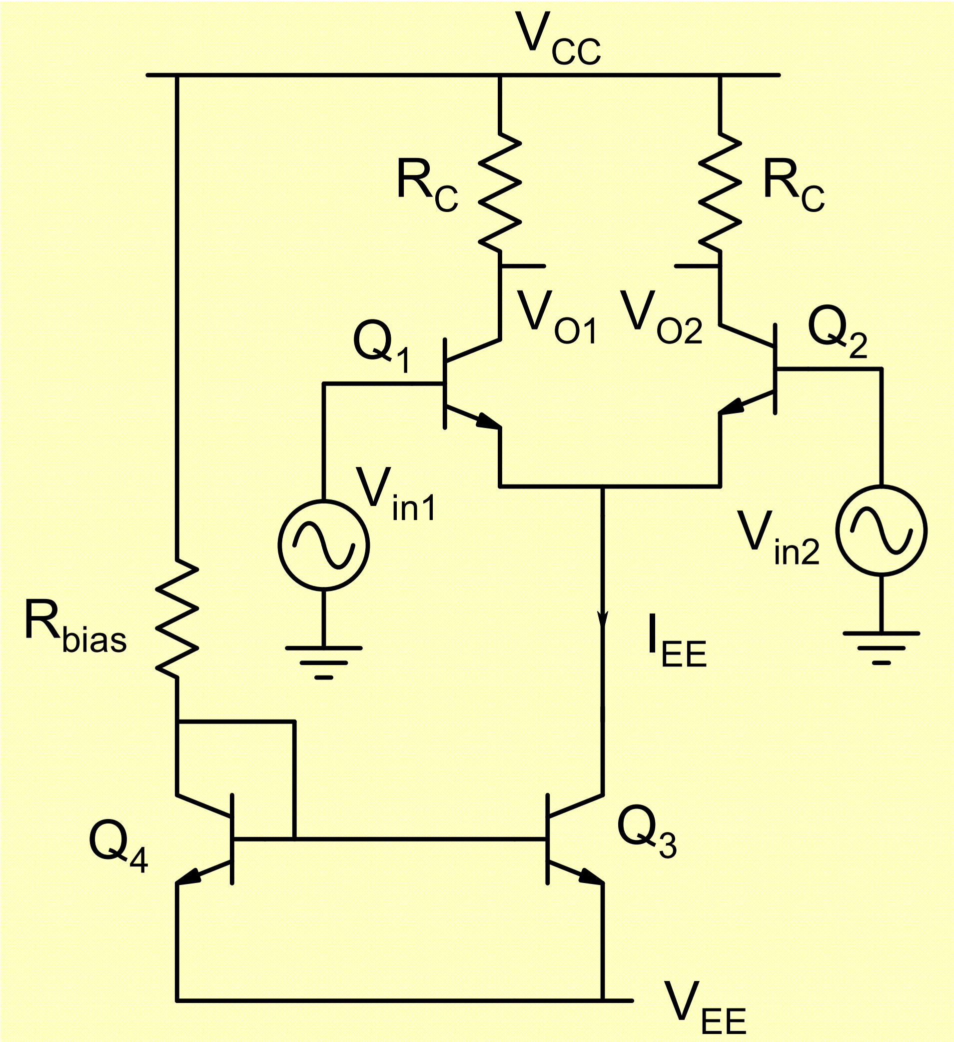
A high cmrr is required to reject unwanted common mode signals

$$g_m = \frac{I_{CQ}}{V_T} = \frac{I_{EE}}{2V_T}$$

$$CMRR = 0.5 + \frac{I_{EE} R_{EE}}{2V_T} \cong 0.5 + \frac{-0.7 - V_{EE}}{2V_T}$$

For a V_{EE} of -12V , $CMRR = 217.8$

Differential amplifier with current source biasing



$$I_{EE} = \frac{V_{CC} - 0.7 - V_{EE}}{R_{bias}}$$

Small signal analysis:

$$R_{EE} = r_{o3} = \frac{V_A}{I_{EE}}$$

All results same with this value of R_{EE}

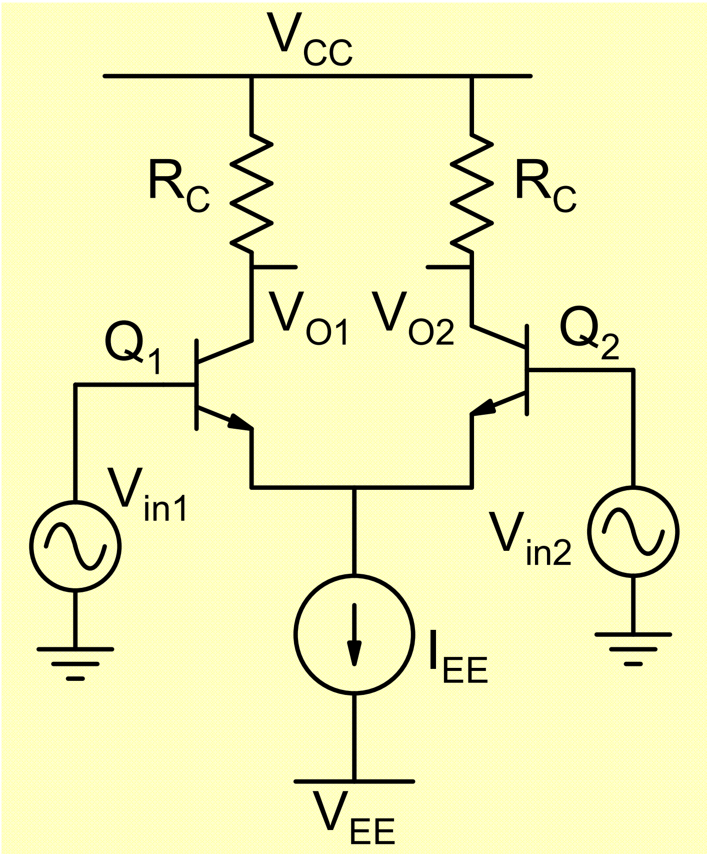
$$A_{dm} = -0.5 g_m R_C$$

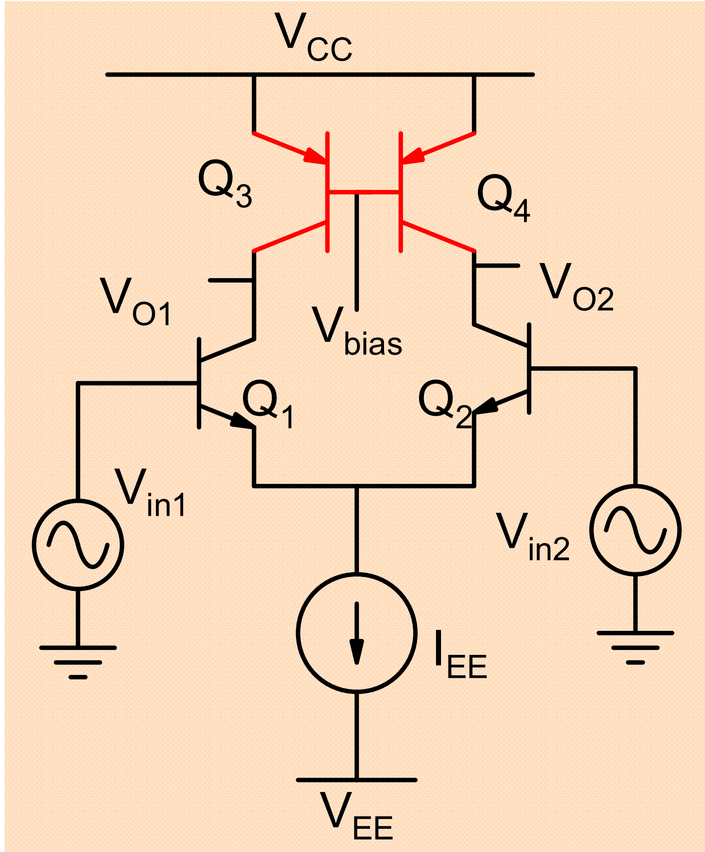
$$A_{cm} = -\frac{g_m}{1 + 2 g_m R_{EE}} R_C$$

$$CMRR = \frac{A_{dm}}{A_{cm}} = 0.5 + g_m R_{EE}$$

G-Number

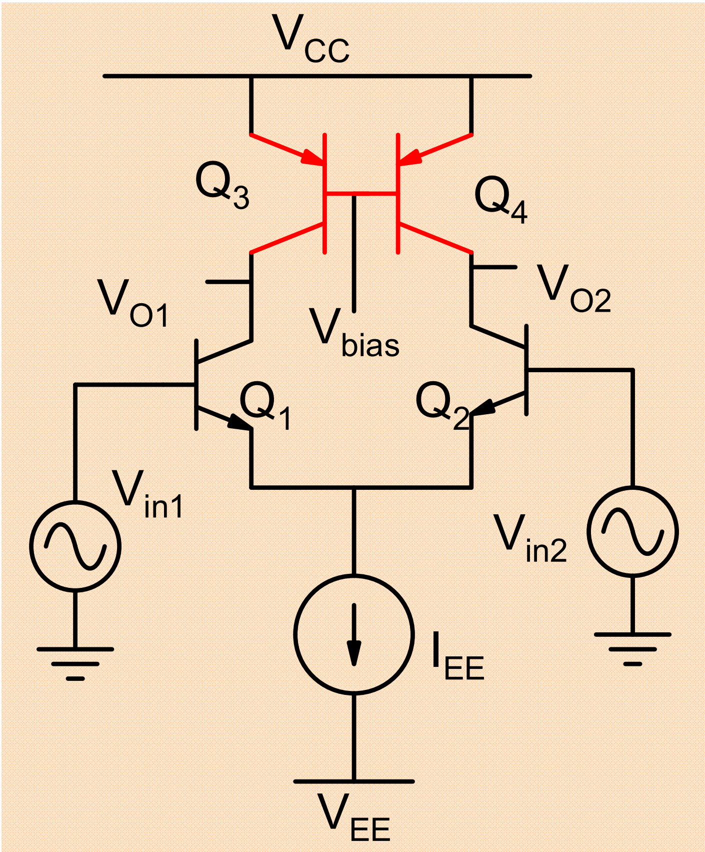
Differential amplifier with Active load

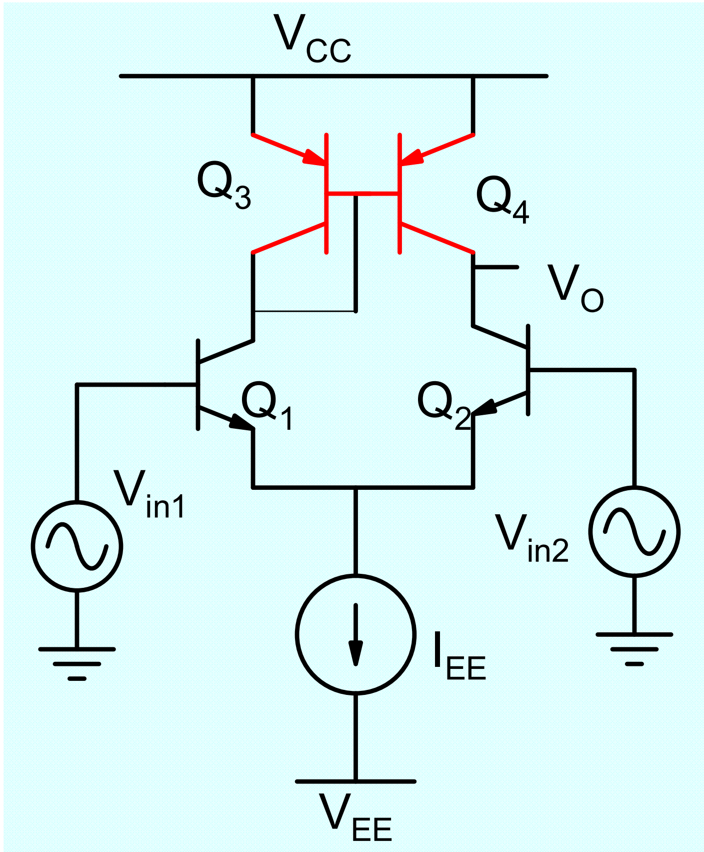




Although higher voltage gain is obtained, the bias point is very sensitive to Vbias of pnp transistors

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