IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

Microelectronics: Devices to Circuits

Multistage and Differential Amplifiers

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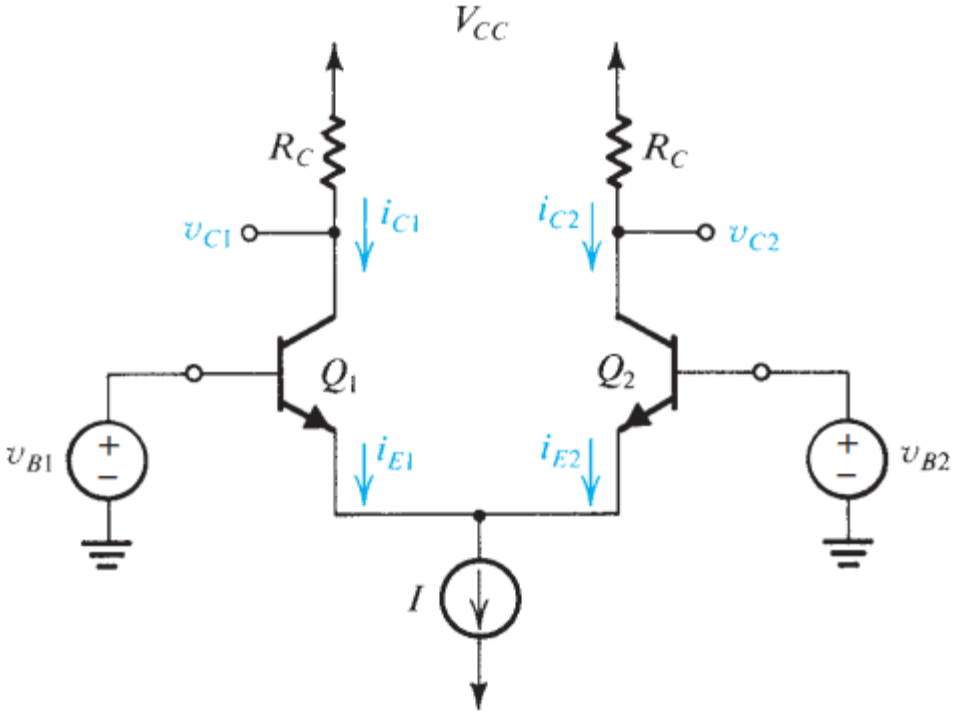
DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING



Outline

- BJT Differential Amplifier
- Basic Operation
- Input common mode range
- Large signal Operation
- Transfer Characteristics of BJT differential pair with emitter resistance Re
- Small signal characteristics
- Differential Half Circuit
- Common mode gain and CMRR
- Common mode input resistance
- Multistage Amplifier
- Two-stage op-amp
- Recapitulation

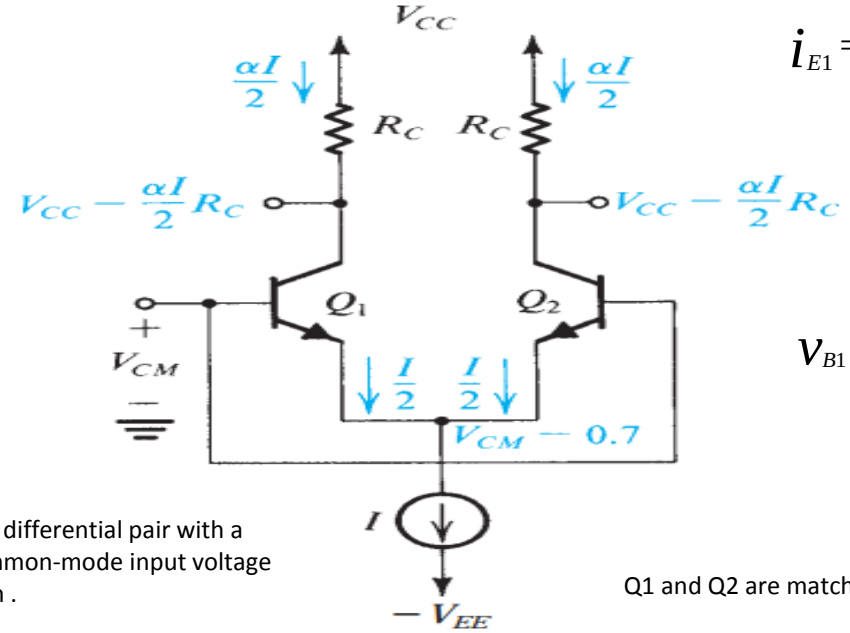
BJT Differential Amplifier



Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Basic Operation

- The two bases joined together and connected to a common-mode V_{CM} voltage.



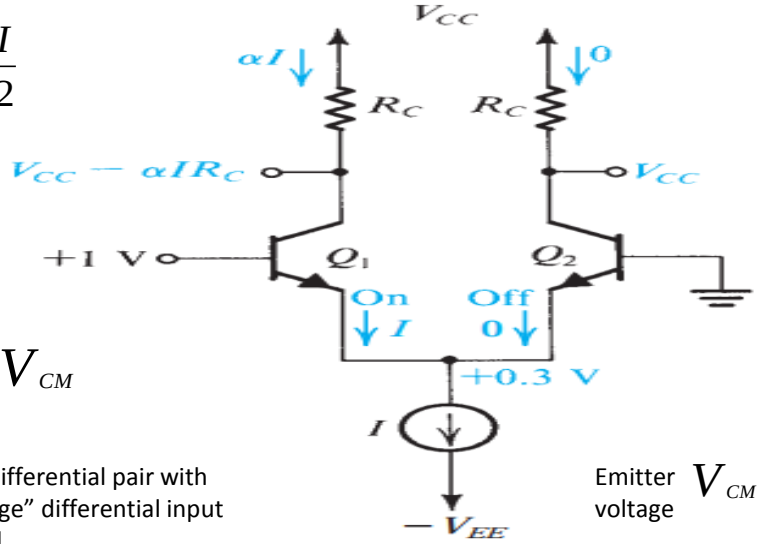
The differential pair with a common-mode input voltage Vcm .

$$i_{E1} = i_{E2} = \frac{I}{2}$$

$$v_{B1} = v_{B2} = V_{CM}$$

Q1 and Q2 are matched

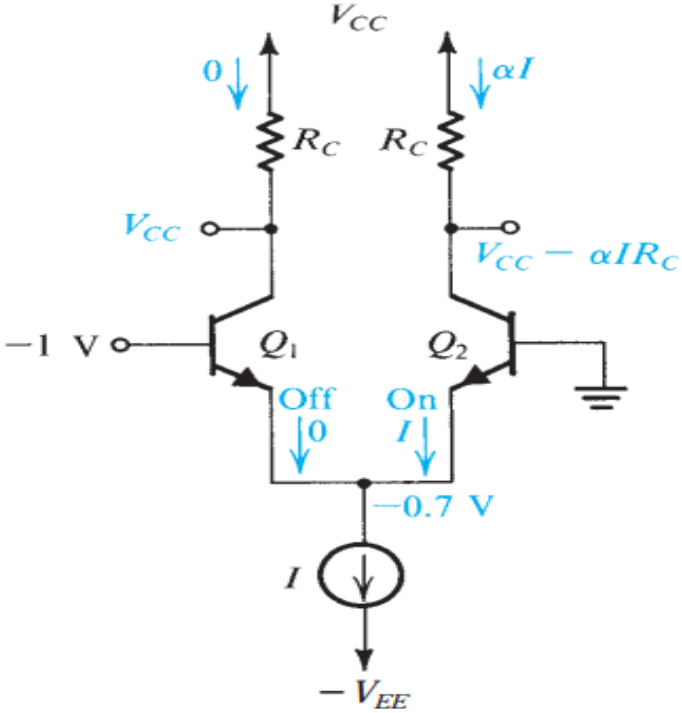
$$V_{BE} = 0.7V$$



The differential pair with a "large" differential input signal

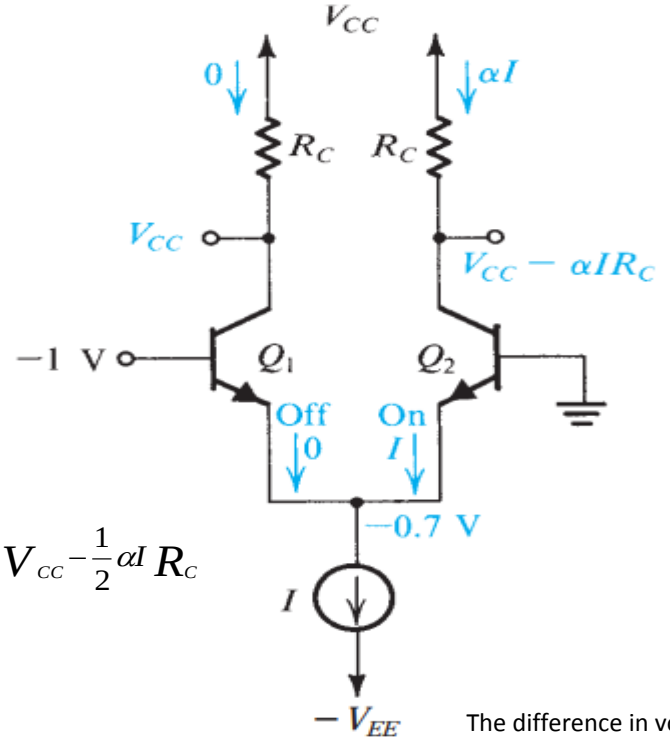
Emitter voltage $V_{CM} - V_{BE}$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition



The differential pair with a large differential input signal of polarity opposite.

Collector voltage $V_{CC} - \frac{1}{2}\alpha I R_C$



The differential pair
with a small differential input signal Vi.

The difference in voltage between the two collectors will be zero.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Case-1 $v_{B2} = 0V$ Q2-off $v_{C1} = V_{CC} - \alpha I R_C$

$v_{B1} = +1V$ Q1-on $v_{C2} = V_{CC}$

Case-2 $v_{B1} = -1V$ Q2-on $v_{C1} = V_{CC}$

$v_{B2} = 0V$ Q1-off $v_{C2} = V_{CC} - \alpha I R_C$

- To use the BJT differential pair as a linear amplifier, we apply a very small differential signal (mV).
- The current flowing through the transistors is $\frac{I}{2} + \Delta I$ and $\frac{I}{2} - \Delta I$.
- The output voltage taken between the two collector will be $2\alpha\Delta I R_C$.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Input common mode range

- The allowable range of Vcm is determined at the upper end by Q1and Q2 leaving the active mode and entering saturation.
- The lower end of the Vcm range is determined by the need to provide a certain minimum voltage Vcs across the current source I to ensure its proper operation.

$$V_{CM\max} \approx V_C + 0.4 = V_{CC} - \alpha \frac{I}{2} R_C + 0.4$$

$$V_{CM\min} \approx -V_{EE} + V_{CS} + V_{BE}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Large signal Operation

- If voltage at emitter is v_{BE} and neglecting the early effect, the exponential relationship applied to each of the two transistor may be written as:

$$I_{E1} = \frac{I_S}{\alpha} e^{(v_{B1} - v_E)/V_T}$$

$$I_{E2} = \frac{I_S}{\alpha} e^{(v_{B2} - v_E)/V_T}$$

$$\frac{I_{E2}}{I_{E2} + I_{E1}} = \frac{1}{1 + e^{(v_{B1} - v_{B2})/v_T}}$$

$$\frac{I_{E1}}{I_{E2}} = e^{(v_{B1} - v_{B2})/V_T}$$

$$\frac{I_{E1}}{I_{E2} + I_{E1}} = \frac{1}{1 + e^{(v_{B2} - v_{B1})/v_T}}$$

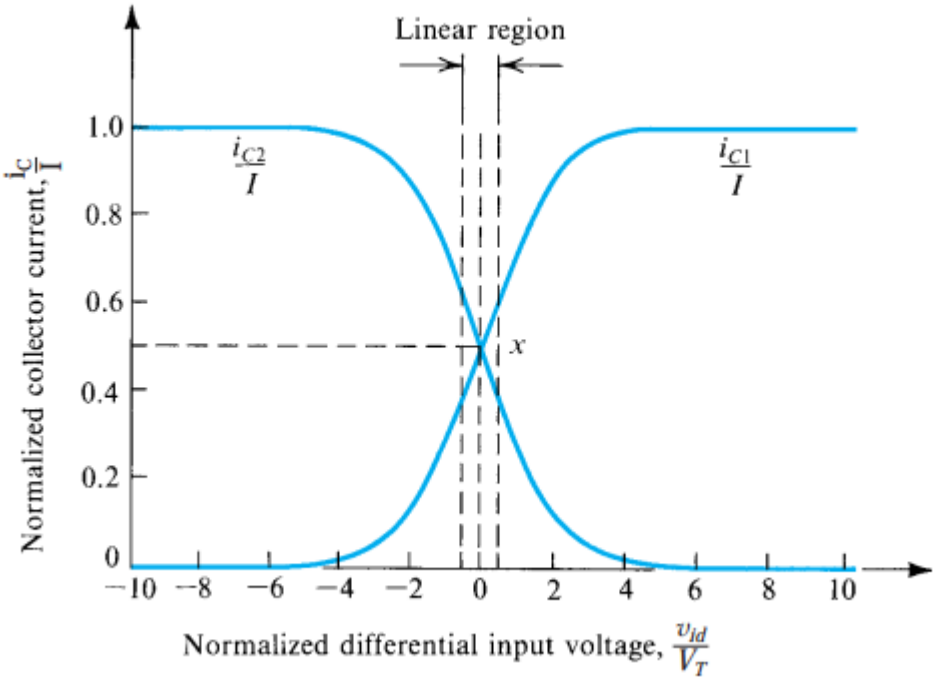
$$I_{E1} + I_{E2} = I$$

$$v_{B1} - v_{B2} = v_{id}$$

$$I_{E1} = \frac{I}{1 + e^{-\frac{v_{id}}{v_T}}}$$

$$I_{E2} = \frac{I}{1 + e^{\frac{v_{id}}{v_T}}}$$

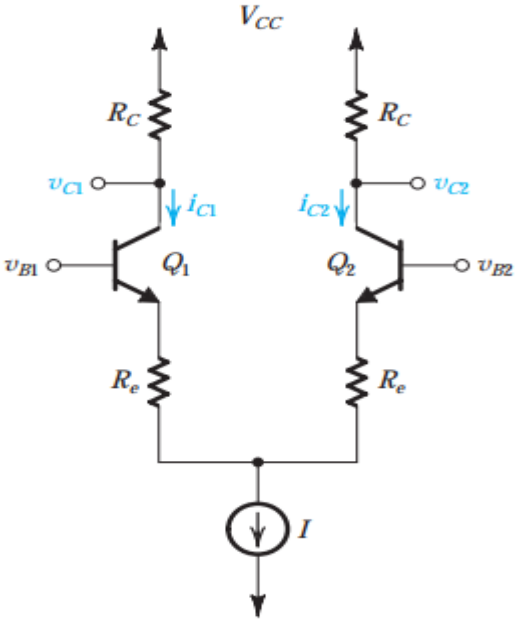
Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

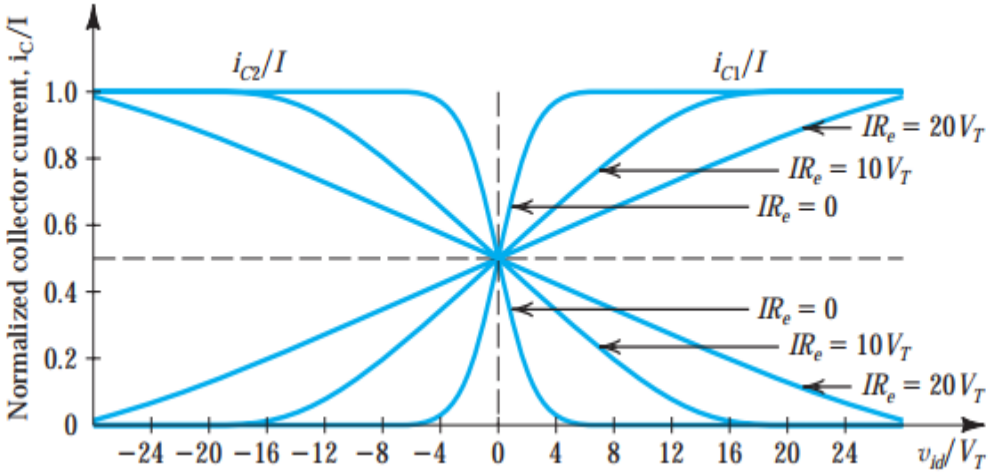


Transfer Characteristics of BJT differential pair assuming α=1.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

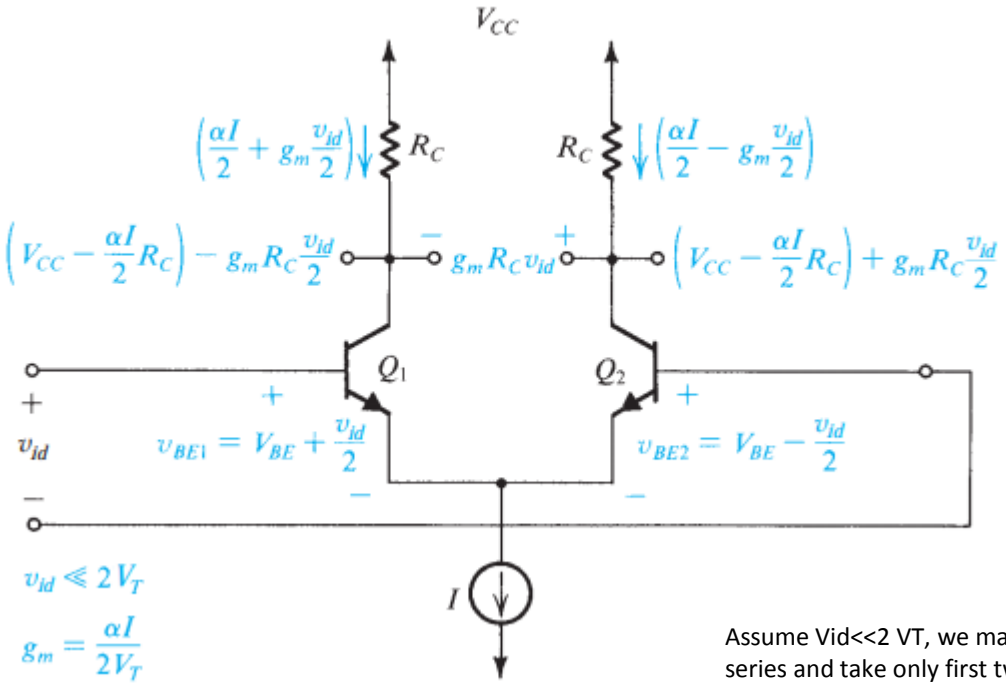
Transfer Characteristics of BJT differential pair with emitter resistance Re





Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Small signal characteristics



Collector current when Vid is applied

$$I_{C1} = \frac{\alpha I}{1 + e^{-\frac{v_{id}}{V_T}}} \qquad I_{C2} = \frac{\alpha I}{1 + e^{\frac{v_{id}}{V_T}}}$$

Multiplying numerator and denominator of the right hand side by $e^{\frac{v_{id}}{2V_T}}$

$$I_{C1} = \frac{\alpha I \, e^{\frac{v_{id}}{2V_T}}}{e^{\frac{v_{id}}{2V_T}} + e^{-\frac{v_{id}}{2V_T}}}$$

Assume Vid<<2 VT, we may expand exponential $e^{\frac{v_{id}}{2V_T}}$ in a series and take only first two terms.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

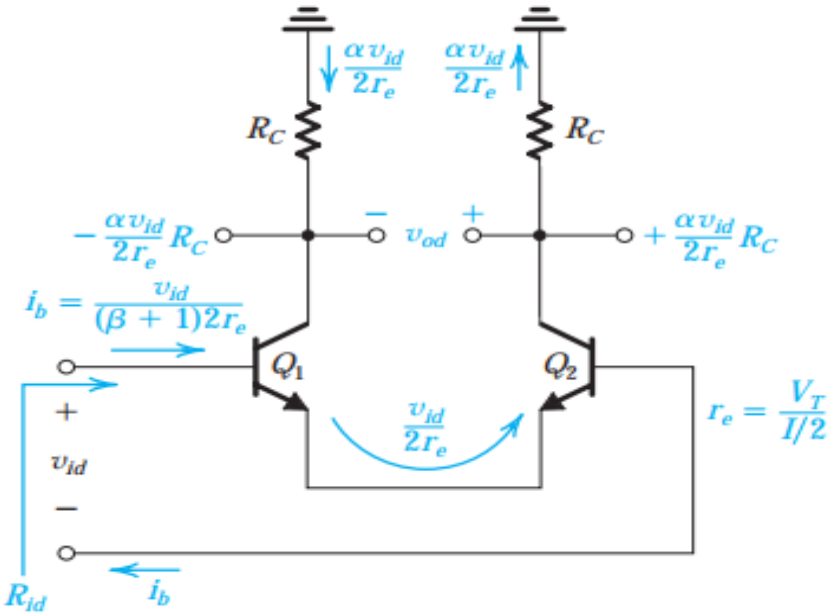
$$I_{C1} = \frac{\alpha I\left(1 + \frac{v_{id}}{2V_T}\right)}{1 + \frac{V_{id}}{V_T} + 1 - \frac{V_{id}}{V_T}}$$

$$I_{C1} = \frac{\alpha I}{2} + \frac{\alpha I}{2V_T}\frac{v_{id}}{2}$$

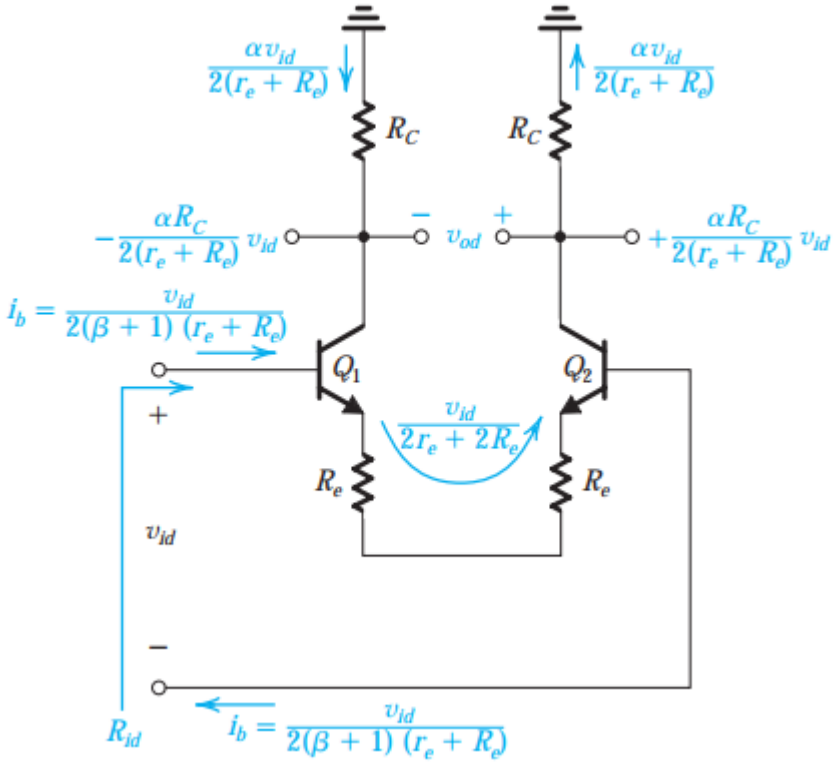
$$I_{C2} = \frac{\alpha I}{2} - \frac{\alpha I}{2V_T}\frac{v_{id}}{2}$$

$$g_m = \frac{I_C}{V_T} \qquad r_e = \frac{V_T}{I_E}$$

A simple technique for determining the signal currents in a differential amplifier excited by a differential voltage signal Vid.



Source: Microelectronics Circuits, Sedra and Smith, Fifth edition



$$i_c = \alpha i_e$$

$$i_e = \frac{v_{id}}{2r_e + 2R_E}$$

Differential input resistance

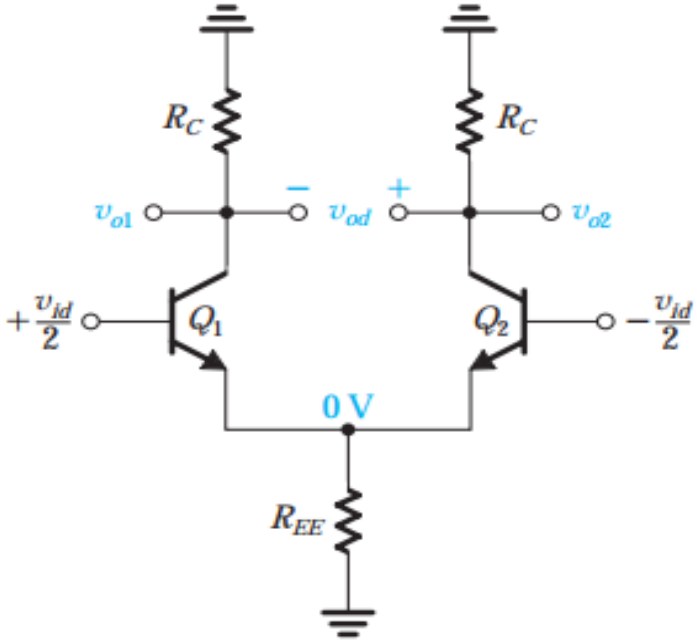
$$R_{id} = (\beta + 1)2r_e = 2r_\pi$$

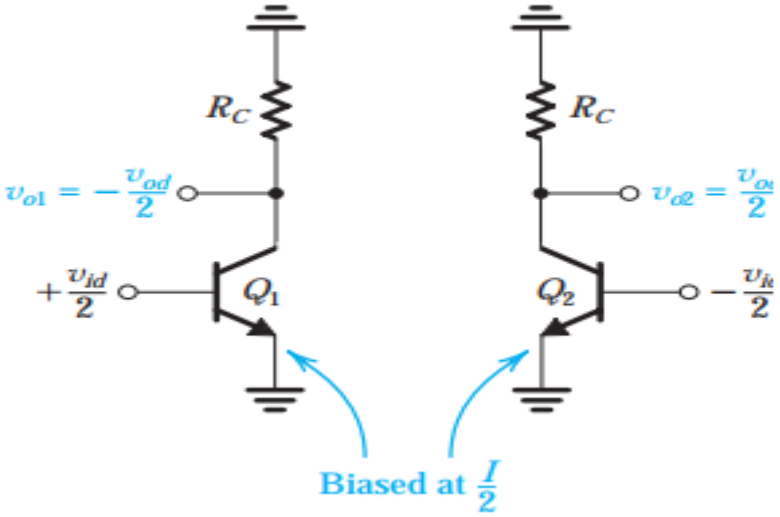
Differential gain

$$A_d = g_m R_C = \frac{R_C}{r_e + R_e}$$

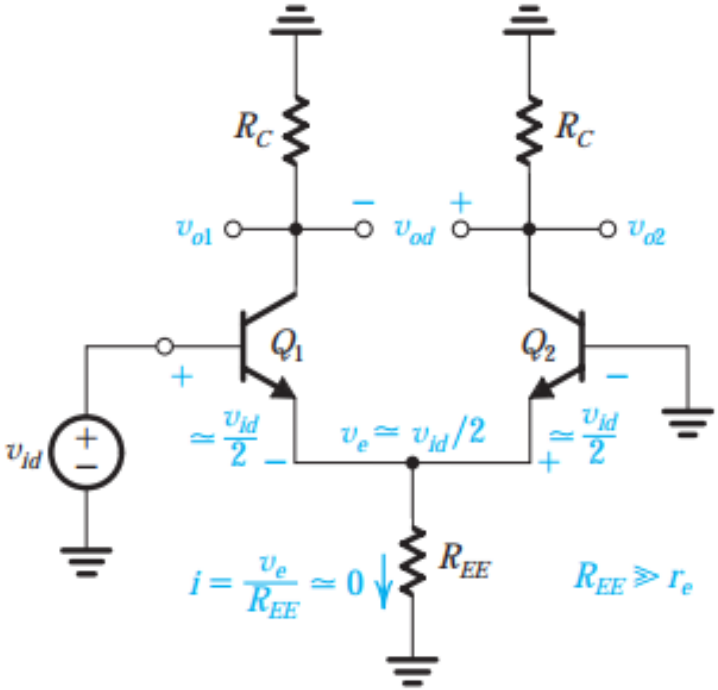
Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

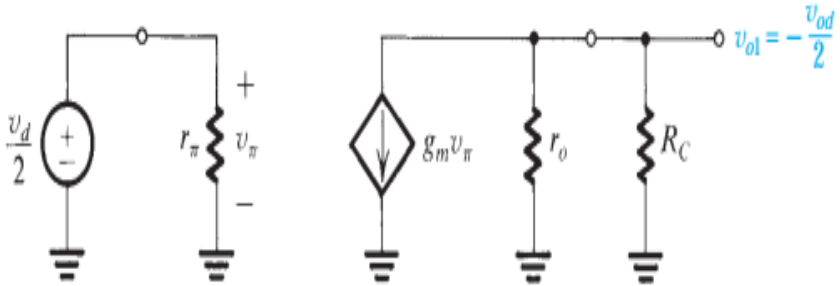
Differential Half Circuit





Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

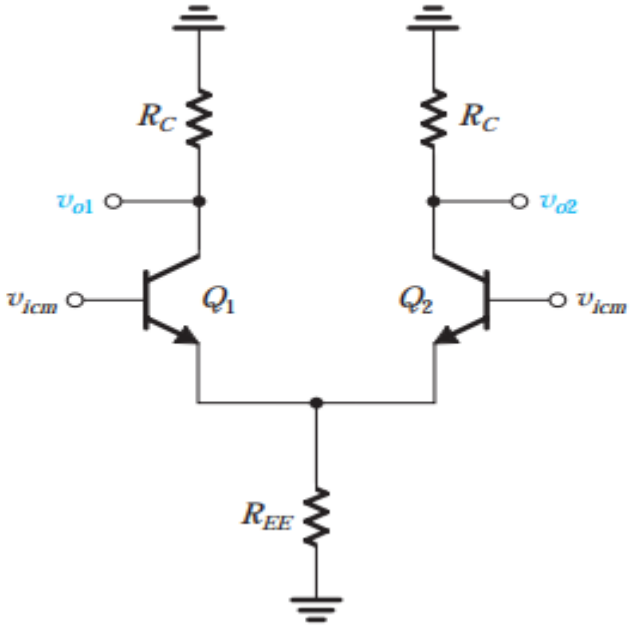


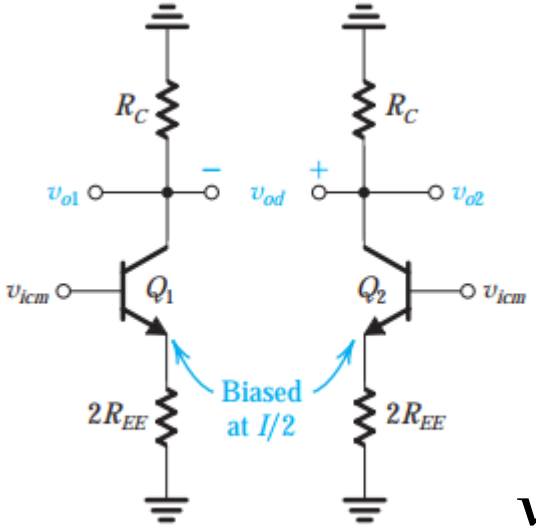


$$A_d = g_m (R_C \parallel r_o)$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Common mode gain and CMRR





$$v_{o1} = -\frac{\alpha R_C}{r_e + 2R_{EE}} v_{icm}$$

$$v_{o2} = -\frac{\alpha R_C}{r_e + 2R_{EE}} v_{icm}$$

$$v_{od} = v_{o2} - v_{o1} = 0$$

$$v_{o2} = -\frac{\alpha(R_C + \Delta R_C)}{2R_{EE} + r_e} v_{icm}$$

Q2 has a collector resistance $(R_C + \Delta R_C)$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

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

$$CMRR = \frac{|A_d|}{|A_{cm}|}$$

$$v_{od} = -\frac{\alpha \Delta R_C}{2R_{EE} + r_e} v_{icm}$$

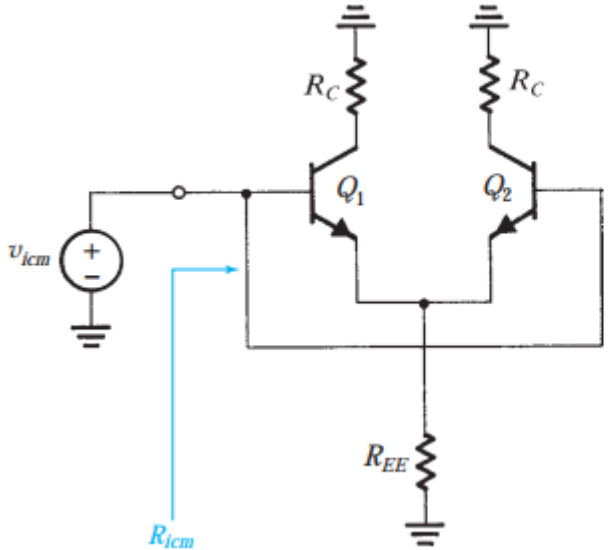
$$A_{cm} = \frac{v_{od}}{v_{icm}} = -\frac{\alpha \Delta R_C}{2R_{EE} + r_e}$$

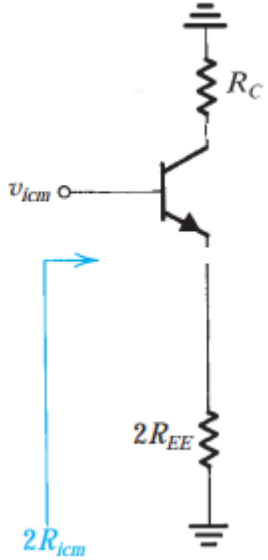
$$CMRR = {2g_m R_{EE}} \Big/ \frac{\Delta R_C}{R_C}$$

$$\alpha = 1 \qquad r_e << 2R_E \qquad A_{cm} \cong -\left(\frac{R_C}{2R_{EE}}\right)\left(\frac{\Delta R_C}{R_C}\right)$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Common mode input resistance





$$R_{incm} = \beta R_{EE} \frac{1 + \frac{R_C}{\beta r_o}}{1 + \frac{R_C + 2R_{EE}}{r_o}}$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Multistage Amplifier

- Practical transistor amplifiers usually consist of a number of stages connected in cascade.
- The first stage is usually required to provide a high input resistance in order to avoid loss of signal level when the amplifier is fed from a high-resistance source.
- In a differential amplifier the input stage must also provide large common mode rejection.
- The function of the middle stage of an amplifier cascade is to provide the bulk of the voltage gain.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

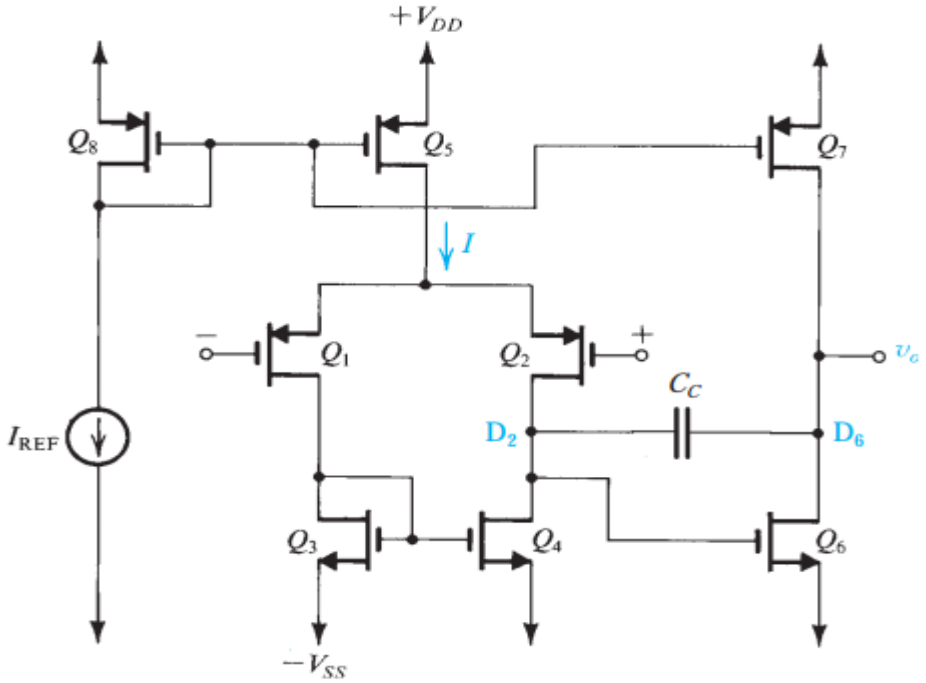
Two-Stage Op-amp

Voltage gain of First stage

$$A_1 = -g_{m1}(r_{o2} \parallel r_{04})$$

Voltage gain of second stage

$$A_2 = -g_{m6}(r_{o6} \parallel r_{07})$$



The dc open loop gain of the op-amp is the product of A_1 and A_2.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Recapitulation

- The input stage of every op-amp is a differential amplifier.
- Differential pairs are insensitive to interference, and they do not need bypass and coupling capacitor.
- For perfect matched differential pair, common mode gain is zero and CMRR is infinite.
- To use the BJT differential pair as a linear amplifier, we apply a very small differential signal (mV).

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

Thank You