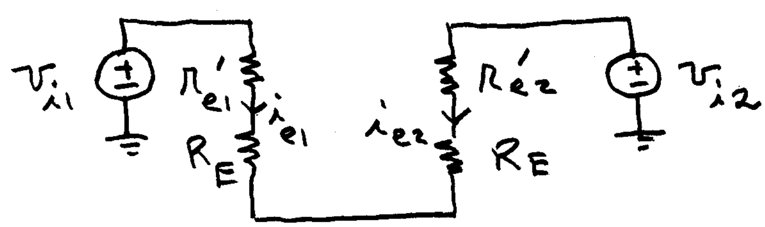
Approximate Analysis of the BJT Diff Amp

Assume $r_0 = \infty$. Use the simplified T model to solve for i_e. Then use $i_c = \alpha i_e$ to solve for i_c.

Looking into the emitter of the two transistors with $r_0 = \infty$, we see r_e' in series with v_{tb}.

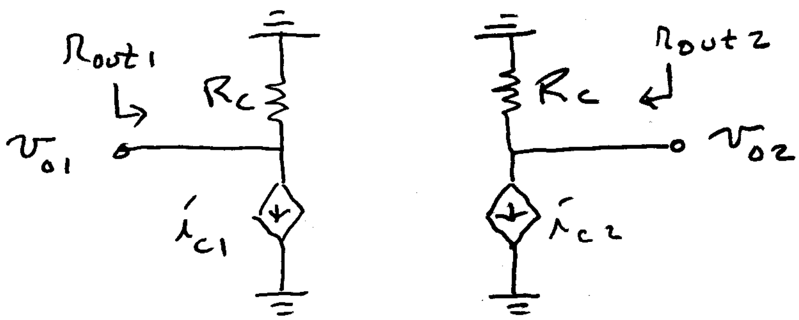


$$r_{e1}' = r_{e2}' = r_e' = \frac{R_B + r_x}{1+\beta} + r_e$$

$$r_e = \frac{V_T}{I_E} = \frac{2V_T}{I_Q}$$

$$i_{e1} = -i_{e2} = \frac{v_{i1} - v_{i2}}{2(r_e' + R_E)}$$

$$i_{c1} = -i_{c2} = \alpha i_{e1} = \frac{\alpha}{2(r_e' + R_E)}(v_{i1} - v_{i2})$$



$$v_{o1} = -v_{o2} = -i_{c1} R_C = \frac{-\alpha R_C}{2(r_e' + R_E)} (v_{i1} - v_{i2})$$

With $v_{i2} = 0$ $\quad r_{in1} = r_{x1} + (1+\beta)(r_{e1}' + R_{te1})$

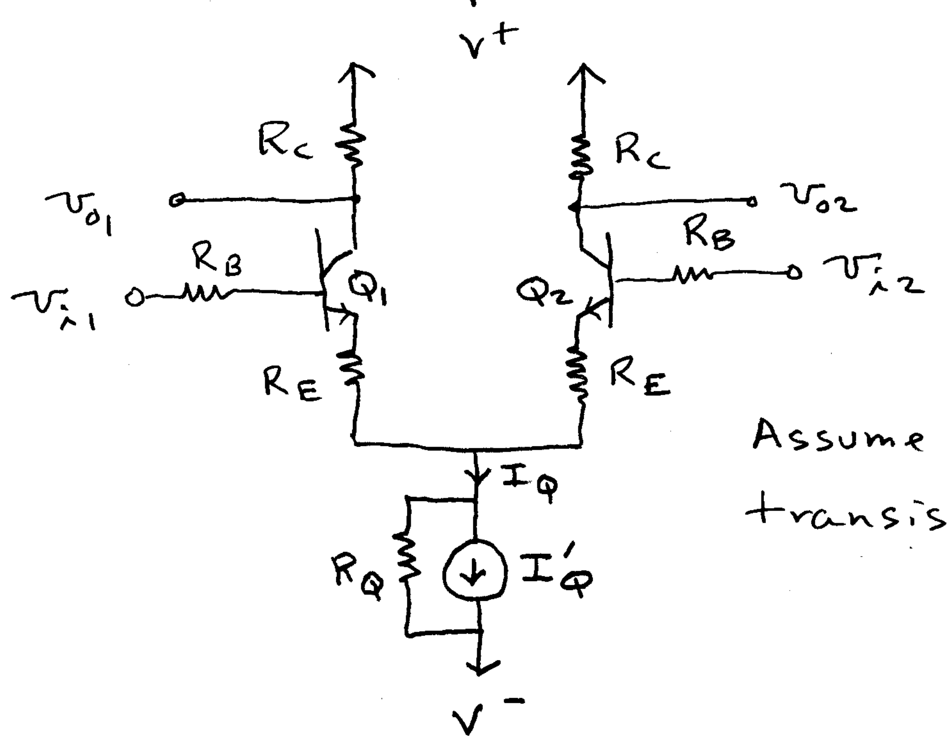
where $R_{te1} = 2R_E + r_{e2}'$

With $v_{i1} = 0$, $r_{in2} = r_{in1}$.

$r_{out1} = r_{out2} = R_C$

Differential and Common-Mode Analysis of the BJT Diff Amp

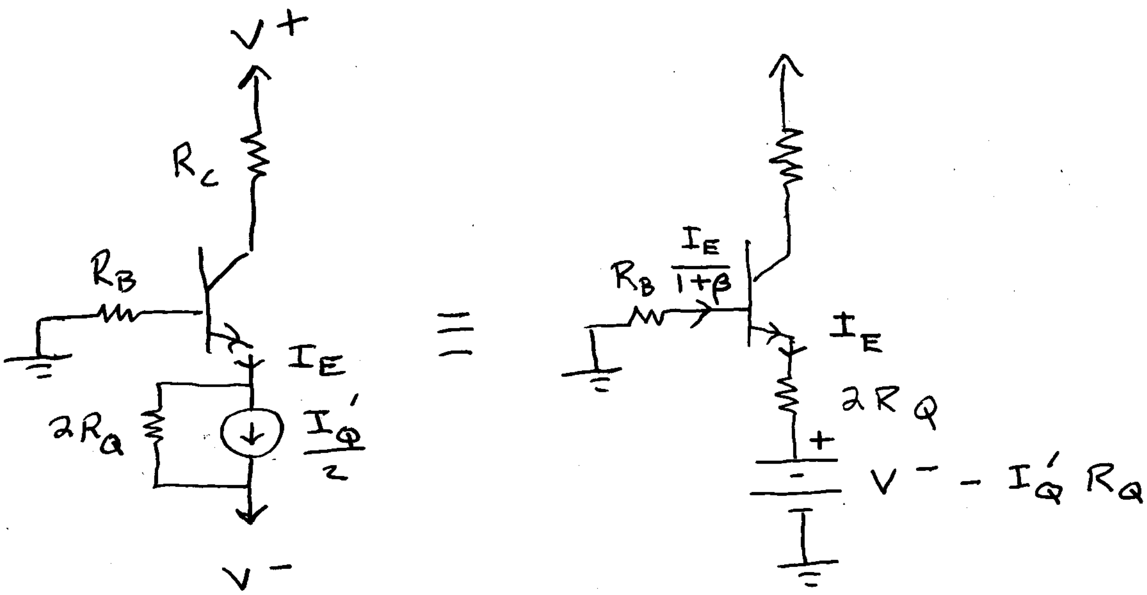
Consider the case where the tail supply is not a perfect current source. Let it exhibit a parallel resistance R_Q.



Assume identical transistors.

For the dc analysis, set $v_{i1} = v_{i2} = 0$. Divide the tail supply into 2 identical current sources ($I_Q'/2$ in parallel with $2R_Q$). By symmetry the circuit for either Q_1 or Q_2

reduces to



The dc bias equation is

$$0 - (V^- - I_Q' R_Q) = \frac{I_E}{1+\beta} R_B + V_{BE} + I_E 2R_Q$$

$$\Rightarrow \quad I_E = \frac{-V^- + I_Q' R_Q - V_{BE}}{\frac{R_B}{1+\beta} + 2R_Q}$$

$$r_{e1} = r_{e2} = r_e = \frac{V_T}{I_E}$$

For the BJT's to be biased in the active mode, $V_{CB} > 0$.

$$V_{CB} = V_C - V_B = (V^+ - \alpha I_E R_C) - \left(-\frac{I_E}{1+\beta} R_B\right)$$

$$= V^+ - I_E \left(\alpha R_C - \frac{R_B}{1+\beta}\right)$$

This must be > 0. Often it is taken to be $\frac{1}{2}V^+$ for a resistively loaded diff amp.

Small-Signal AC Analysis

Let us define the differential and common-mode input voltages as follows:

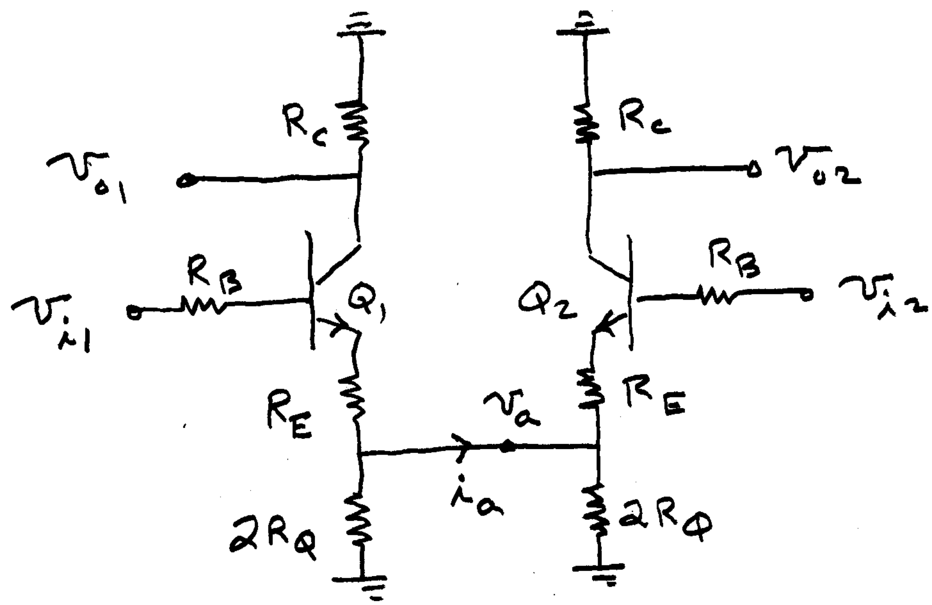
Differential : $v_{id} = v_{i1} - v_{i2}$

Common-Mode : $v_{icm} = \frac{1}{2}(v_{i1} + v_{i})$

It follows from these definitions that

$$v_{i1} = v_{icm} + \frac{1}{2} v_{id}$$
$$v_{i2} = v_{icm} - \frac{1}{2} v_{id}$$

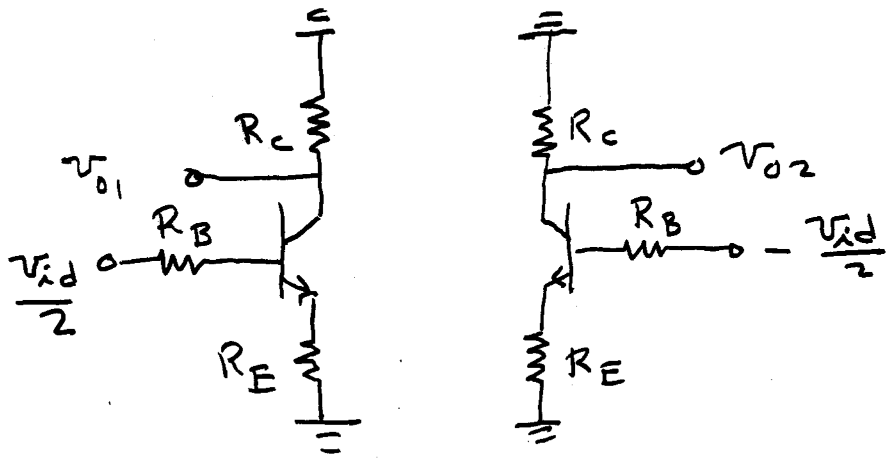
To solve for v_{o1} & v_{o2}, we can use superposition of v_{id} and v_{icm}. The AC signal circuit is



Differential Analysis

Let $v_{i1} = \frac{1}{2} v_{id}$ and $v_{i2} = -\frac{1}{2} v_{id}$

$\Rightarrow$ v_{i1} increases v_a and v_{i2} decreases v_a. The net affect is that $v_a = 0$. Thus we can ground the v_a node. The circuit becomes



Thus the circuit consists of two CE amplifiers. By symmetry, $v_{o2} = -v_{o1}$. From our CE amplifier analysis, we have

$$v_{o1} = -i_{c(sc)}\, r_{ic(d)} \| R_c$$

$$i_{c1(sc)} = G_{mb(d)} \frac{v_{id}}{2}$$

$$\Rightarrow v_{o1} = \left[-\tfrac{1}{2} G_{mb(d)}\, r_{ic(d)} \| R_c\right] v_{id}$$

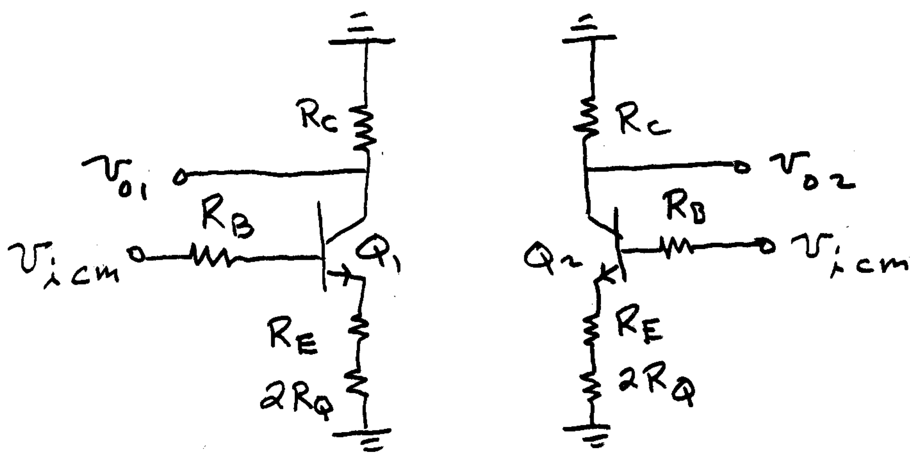
where $G_{mb(d)}$ and $r_{ic(d)}$ are calculated with $R_{tb} = R_B$ and $R_{te} = R_E$. By symmetry

$$v_{o2} = \left[\tfrac{1}{2} G_{mb(d)}\, r_{ic(d)} \| R_c\right] v_{id}$$

Common-Mode Analysis

Let $v_{i1} = v_{i2} = v_{icm}$.

$\Rightarrow$ v_{i1} increases i_a and v_{i2} decreases i_a. The net effect is that $i_a = 0$. Thus we can open the i_a branch. The circuit becomes



Thus the circuit again consists of two CE amplifiers. By symmetry, $v_{o1} = v_{o2}$. From our CE analysis, we have

$$v_{o1} = -i_{c1(sc)} \, R_{ic(cm)} \| R_c$$

$$i_{c1(sc)} = G_{mb(cm)} \, v_{icm}$$

$$\Rightarrow \quad v_{o1} = \left[- G_{mb(cm)}\, r_{ic(cm)} \,\|\, R_c \right] v_{icm}$$

where $G_{mb(cm)}$ and $r_{ic(cm)}$ are calculated with $R_{tb} = R_B$ and $R_{te} = R_E + 2R_Q$. By symmetry

$$v_{o2} = \left[- G_{mb(cm)}\, r_{ic(cm)} \,\|\, R_c \right] v_{icm}$$

Total Solution for v_{o1}:

We add the differential and common-mode solutions to obtain

$$v_{o1} = \left[- \tfrac{1}{2} G_{mb(d)}\, r_{ic(d)} \,\|\, R_c \right] (v_{i1} - v_{i2})$$

$$+ \left[- G_{mb(cm)}\, r_{ic(cm)} \,\|\, R_c \right] \frac{v_{i1} + v_{i2}}{2}$$

$$= A_1 v_{i1} + A_2 v_{i2}$$

where A_1 and A_2 are given by

$$A_1 = -\frac{1}{2}\left[G_{mb(d)}\, r_{ic(d)} \| R_c + G_{mb(cm)}\, r_{ic(cm)} \| R_c\right]$$

$$A_2 = +\frac{1}{2}\left[G_{mb(d)}\, r_{ic(d)} \| R_c - G_{mb(cm)}\, r_{ic(cm)} \| R_c\right]$$

For the case $R_Q \to \infty$, $G_{mb(cm)} \to 0$ and we have

$$A_1 = -A_2 = A = -\frac{1}{2} G_{mb(d)}\, r_{ic(d)} \| R_c$$

In this case, v_{o1} is given by

$$v_{o1} = A\,(v_{i1} - v_{i2})$$

All solutions for v_{o2} can be obtained by interchanging v_{i1} and v_{i2} in the solutions for v_{o1}.

The Common-Mode Rejection Ratio or CMRR

Let the output be taken from

the v_{o1} output. This is given by

$$v_{o1} = -\frac{v_{id}}{2}\left[G_{mb(d)} r_{ic(d)} \| R_c\right]$$

$$- v_{icm}\left[G_{mb(cm)} r_{ic(cm)} \| R_c\right]$$

$$= A_d v_{id} + A_{cm} v_{icm}$$

where A_d and A_{cm} are given by

$$A_d = -\frac{1}{2} G_{mb(d)} r_{ic(d)} \| R_c$$

$$A_{cm} = - G_{mb(cm)} r_{ic(cm)} \| R_c$$

The CMRR is defined by

$$CMRR = \frac{A_d}{A_{cm}} = \frac{\frac{1}{2} G_{mb(d)} r_{ic(d)} \| R_c}{G_{mb(cm)} r_{ic(cm)} \| R_c}$$

For $R_Q \to \infty$, it follows that $CMRR \to \infty$. The larger the CMRR, the lower the common mode gain and the closer the diff amp is to an ideal diff amp with the output $v_{o1} = -A(v_{i1} - v_{i2})$. For CMRR $< \infty$, the gains for the two inputs are not equal. For CMRR $\to \infty$, the gains are equal. In practice a CMRR of 60 to 80 dB ($20 \log (A_d/A_{cm})$) can be achieved.