Differential Amplifier with R_B

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1 Notation

In most electronic circuits both DC and small-signal voltages are applied simultaneously. The DC voltage is applied to set the bias and small-signals are the ones which are generally amplified or processed by electronic circuits. A little attention to notation helps immensely in the analysis of all electronic circuits.

V_{BE} — DC voltage *only* of node B with respect to node E (all upercase letters)
v_{be} — small-signal voltage *only* of node B with respect to node E (all lowercase letters)
v_{BE} — total voltage of node B with respect to node E (v lowercase, subscript uppercase)

Note that the total voltage $v_{BE} = V_{BE} + v_{be}$. When there is just one subscript, as compared to double in the preceding discussion, the uppercase-lowercase notation is the same but all the voltages are referred with respect to ground. The same notation is used for currents. In the following the total current i_C is the sum of the DC current I_C and small-signal current i_c.

$$i_C = I_C + i_c$$

2 Differential Amplifier with Base Resistance

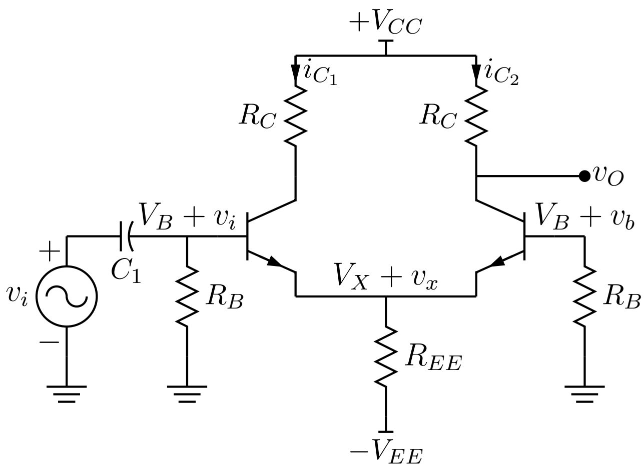

Figure 1: Differential Amplifier with R_{EE}

The bias currents are (assuming that the transistors are identical):

$$I_C = I_{C_1} = I_{C_2} = I_S e^{(V_B - V_X)/V_T} = \frac{V_X + V_{EE}}{2R_{EE}}$$

Equations to work out v_x and v_b

We need two equations to work out v_x and v_b.

The first equation We first write the KCL at the node where R_{EE} and both the emitters meet,

$$I_S e^{(V_B+v_i-V_X-v_x)/V_T} + I_S e^{(V_B+v_b-V_X-v_x)/V_T} = 2I_C + \frac{v_x}{R_{EE}}. \tag{1}$$

Equation (1) can be rewritten as:

$$\begin{aligned} I_C e^{(v_i-v_x)/V_T} + I_C e^{(v_b-v_x)/V_T} &= 2I_C + \frac{v_x}{R_{EE}} \quad (2)\\ I_C\left(1+\frac{v_i-v_x}{V_T}+\cdots\right) + I_C\left(1+\frac{v_b-v_x}{V_T}+\cdots\right) &= 2I_C + \frac{v_x}{R_{EE}} \quad (3)\\ I_C\left(\frac{v_i-2v_x+v_b}{V_T}\right) &= \frac{v_x}{R_{EE}} \quad (4) \end{aligned}$$

The step from equation (3) to equation (4) is valid when $|v_i - v_x| << V_T$ and $|v_b - v_x| << V_T$.

The second equation Next we see that the collector and base currents in the right hand side transistor are related as:

$$\begin{aligned} I_S e^{(V_B+v_b-V_X-v_x)/V_T} &= -\beta\frac{V_B+v_b}{R_B} \quad (5)\\ I_C e^{(v_b-v_x)/V_T} &= -\beta\frac{V_B+v_b}{R_B} \quad (6)\\ I_C(1+\frac{v_b-v_x}{V_T}) &= -\beta\frac{V_B+v_b}{R_B} \quad (7) \end{aligned}$$

Note that $I_C = -\beta\frac{V_B}{R_B}$ and defining $g_m = \frac{I_C}{V_T}$ we obtain from (7)

$$v_b = \frac{g_m R_B}{\beta + g_m R_B} v_x \tag{8}$$

Putting them together Substituting the above expression (8) of v_b in equation (4), we get

$$v_x = \frac{v_i}{2 - \frac{g_m R_B}{\beta+g_m R_B} + \frac{1}{g_m R_{EE}}} \tag{9}$$

For $\beta << g_m R_B$ and $R_{EE} \to \infty$,

$$v_b = v_x \text{ and } v_x = v_i$$

and when $\beta \to \infty$ and $R_{EE} \to \infty$,

$$v_b = 0 \text{ and } v_x = \frac{v_i}{2}.$$