The BJT Bias Equation

Basic Bias Equation

(a) Look out of the 3 terminals of the BJT and make Thévenin equivalent circuits as shown in Fig. 1.

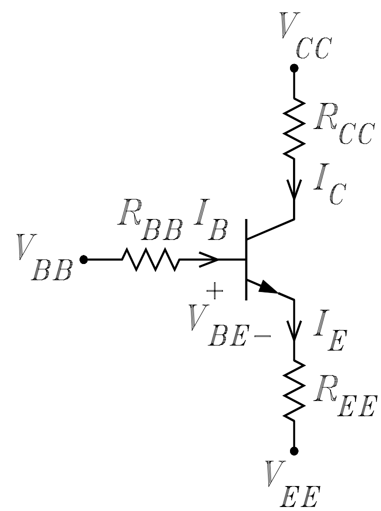

Figure 1: Basic bias circuit.

(b) Write a loop equation for the base-emitter loop.

$$V_{BB} - V_{EE} = I_B R_{BB} + V_{BE} + I_E R_{EE}$$

(c) Use the relation $I_C = \beta I_B = \alpha I_E$ to express I_B and I_E as functions of the current desired. Let I_C be the current.

$$V_{BB} - V_{EE} = \frac{I_C}{\beta} R_{BB} + V_{BE} + \frac{I_C}{\alpha} R_{EE}$$

(d) Solve for I_C.

$$I_C = \frac{V_{BB} - V_{EE} - V_{BE}}{\dfrac{R_{BB}}{\beta} + \dfrac{R_{EE}}{\alpha}}$$

An "educated guess" of the value of V_{BE} must be made to evaluate this. Typical values are 0.7 V for IC transistors, 0.6−0.65 V for low-power discrete transistors, and 0.5−0.6 V for higher-power discrete transistors.

(e) Check for the active mode. For the active mode, $V_{CB} > 0$.

$$V_{CB} = V_C - V_B = (V_{CC} - I_C R_{CC}) - (V_{BB} - I_B R_{BB}) \overset{\text{or}}{=} (V_{CC} - I_C R_{CC}) - (V_{EE} + I_E R_{EE} + V_{BE})$$

Example 1

$$V_{BB} = \frac{V^+ R_2 + V^- R_1}{R_1 + R_2} \qquad R_{BB} = R_1 \| R_2$$

$$V_{EE} = V^- \qquad R_{EE} = R_E \qquad V_{CC} = V^+ \qquad R_{CC} = R_C$$

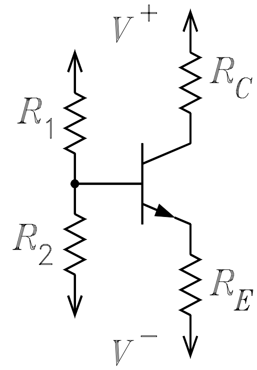

Figure 2: Circuit for Example 1.

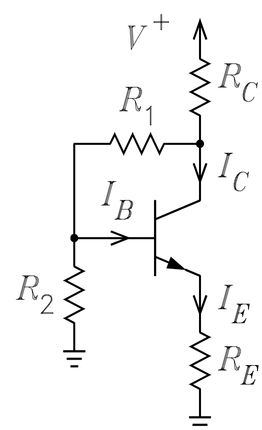

Figure 3: Circuit for Example 2.

Example 2

$$V_{BB} = V^{+}\frac{R_2}{R_C + R_1 + R_2} - I_C\frac{R_C}{R_C + R_1 + R_2}R_2 \qquad R_{BB} = (R_1 + R_C)\,\|R_2$$

$$V_{CC} = V^{+}\frac{R_1 + R_2}{R_C + R_1 + R_2} - I_B\frac{R_2}{R_C + R_1 + R_2}R_C \qquad R_{CC} = R_C\|\,(R_1 + R_2)$$

$$V_{EE} = 0 \qquad R_{EE} = R_E$$

The base-emitter loop equation for I_C is

$$V^{+}\frac{R_2}{R_C + R_1 + R_2} - I_C\frac{R_C}{R_C + R_1 + R_2}R_2 = \frac{I_C}{\beta}R_{BB} + V_{BE} + \frac{I_C}{\alpha}R_E$$

This can be solved for I_C and it can be determined if the BJT is in the active mode.

Example 3

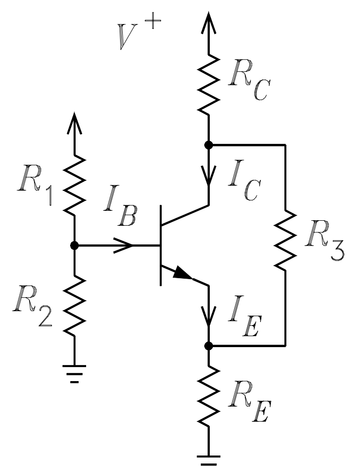

Figure 4: Circuit for Example 3.

$$V_{BB} = \frac{V^{+}R_2 + V^{-}R_1}{R_1 + R_2} \qquad R_{BB} = R_1\|R_2$$

$$V_{EE} = V^{+}\frac{R_E}{R_C + R_3 + R_E} - I_C\frac{R_C}{R_C + R_3 + R_E}R_E \qquad R_{EE} = R_E\|\,(R_C + R_3)$$

$$V_{CC} = V^{+}\frac{R_3 + R_E}{R_C + R_3 + R_E} + I_E\frac{R_E}{R_C + R_3 + R_E}R_C \qquad R_{CC} = R_C\|\,(R_3 + R_E)$$

The base-emitter loop equation for I_C is

$$\frac{V^{+}R_2 + V^{-}R_1}{R_1 + R_2} - \left(V^{+}\frac{R_E}{R_C + R_3 + R_E} - I_C\frac{R_C}{R_C + R_3 + R_E}R_E\right) = \frac{I_C}{\beta}R_{BB} + V_{BE} + \frac{I_C}{\alpha}R_{EE}$$

This can be solved for I_C and it can be determined if the BJT is in the active mode.

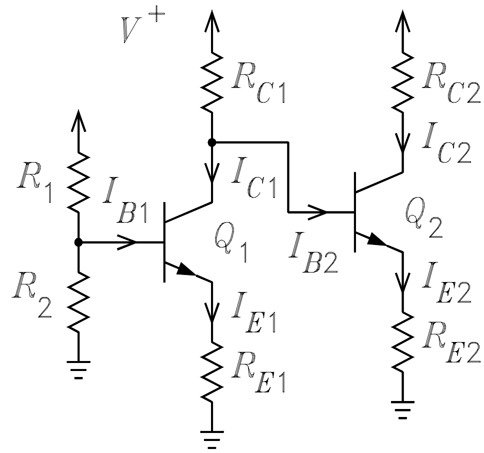

Figure 5: Circuit for Example 4.

Example 4

$$V_{BB1} = V^+ \frac{R_2}{R_1 + R_2} \qquad R_{BB1} = R_1 \| R_2 \qquad V_{EE1} = 0 \qquad R_{EE1} = R_{E1}$$

$$V_{CC1} = V^+ - I_{B2} R_{C1} \qquad R_{CC1} = R_{C1}$$

The base-emitter loop equation for I_{C1} is

$$V^+ \frac{R_2}{R_1 + R_2} = \frac{I_{C1}}{\beta_1} R_{BB1} + V_{BE1} + \frac{I_{C1}}{\alpha_1} R_E$$

This can be solved for I_{C1}.

For Q_2

$$V_{BB2} = V^+ - I_{C1} R_{C1} \qquad R_{BB2} = R_{C1}$$

$$V_{EE2} = 0 \qquad R_{EE2} = R_{E2} \qquad V_{CC2} = V^+ \qquad R_{CC2} = R_{C2}$$

The base-emitter loop equation for I_{C2} is

$$V^+ - I_{C1} R_{C1} = \frac{I_{C2}}{\beta_2} R_{C1} + V_{BE2} + \frac{I_{C2}}{\alpha_2} R_{E2}$$

This can be solve for I_{C2}.

Given I_{C1} and I_{C2}, it can be determined if the two BJTs are in the active mode.

Example 5

$$V_{BB1} = V^+ \frac{R_2}{R_1 + R_2} \qquad R_{BB1} = R_1 \| R_2 \qquad V_{EE1} = -I_{B2} R_{E1} = -\frac{I_{C2}}{\beta_2} R_{E1} \qquad R_{EE1} = R_{E1}$$

$$V_{BB2} = I_{E1} R_{E1} = \frac{I_{C1}}{\alpha_1} R_{E1} \qquad R_{BB2} = R_{E1} \qquad V_{EE2} = 0 \qquad R_{EE2} = R_{E2} \qquad V_{CC2} = V^+ \qquad R_{CC2} = R_{C2}$$

Let the currents to be solved for be I_{C1} and I_{C2}. The two base-emitter loop equations are

$$V^+ \frac{R_2}{R_1 + R_2} - \left(-\frac{I_{C2}}{\beta_2} R_{E1} \right) = \frac{I_{C1}}{\beta_1} R_1 \| R_2 + V_{BE1} + \frac{I_{C1}}{\alpha_1} R_{E1}$$

$$\frac{I_{C1}}{\alpha_1} R_{E1} = \frac{I_{C2}}{\beta_2} R_{E1} + V_{BE2} + \frac{I_{C2}}{\alpha_2} R_{E2}$$

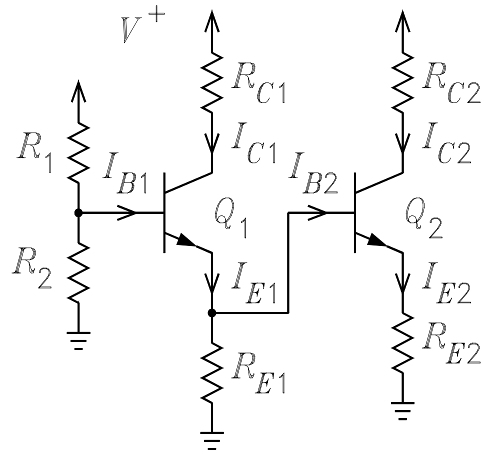

Figure 6: Circuit for Example 5.

These can be rewritten as follows:

$$I_{C1}\left(\frac{R_1\|R_2}{\beta_1}+\frac{R_{E1}}{\alpha_1}\right)-I_{C2}\left(\frac{R_{E1}}{\beta_2}\right)=V^+\frac{R_2}{R_1+R_2}-V_{BE1}$$

$$-I_{C1}\left(\frac{R_{E1}}{\alpha_1}\right)+I_{C2}\left(\frac{R_{E1}}{\beta_2}+\frac{R_{E2}}{\alpha_2}\right)=-V_{BE2}$$

The above two equations require simultaneous solution. The determinant solutions are

$$I_{C1}=\frac{1}{\Delta}\left[\left(V^+\frac{R_2}{R_1+R_2}-V_{BE1}\right)\left(\frac{R_{E1}}{\beta_2}+\frac{R_{E2}}{\alpha_2}\right)-V_{BE2}\frac{R_{E1}}{\beta_2}\right]$$

$$I_{C2}=\frac{1}{\Delta}\left[-\left(\frac{R_1\|R_2}{\beta_1}+\frac{R_{E1}}{\alpha_1}\right)V_{BE2}+\frac{R_{E1}}{\alpha_1}\left(V^+\frac{R_2}{R_1+R_2}-V_{BE1}\right)\right]$$

where Δ is the determinant given by

$$\Delta=\left(\frac{R_1\|R_2}{\beta_1}+\frac{R_{E1}}{\alpha_1}\right)\left(\frac{R_{E1}}{\beta_2}+\frac{R_{E2}}{\alpha_2}\right)-\left(\frac{R_{E1}}{\alpha_1}\right)\left(\frac{R_{E1}}{\beta_2}\right)$$

In the event that $I_{E1}\gg I_{B2}$, the I_{C2}/β_2 term in the first equation can be neglected so that the first equation becomes

$$V^+\frac{R_2}{R_1+R_2}=\frac{I_{C1}}{\beta_1}R_1\|R_2+V_{BE1}+\frac{I_{C1}}{\alpha_1}R_{E1}$$

In this case, the approximate solutions are

$$I_{C1}\simeq\frac{V^+\dfrac{R_2}{R_1+R_2}-V_{BE1}}{\dfrac{R_1\|R_2}{\beta_1}+\dfrac{R_{E1}}{\alpha_1}}$$

$$I_{C2}=\frac{I_{C1}\left(\dfrac{R_{E1}}{\alpha_1}\right)-V_{BE2}}{\dfrac{R_1\|R_2}{\beta_1}+\dfrac{R_{E1}}{\alpha_1}}$$