Bias Stabilization

Basic Definitions:

The stability of system is a measure of sensitivity of a circuit to variations in its parameters. In any amplifier employing a transistor the ***collector current I_C*** is sensitive to each of the following parameters:

- ***I_{CO} (reverse saturation current): doubles in value for every 10°C increase in temperature.***
- ***$|V_{BE}|$ (base-to-emitter voltage): decrease about 7.5 mV per 1°C increase in temperature.***
- ***β (forward current gain): increase with increase in temperature.***

Any or all of these factors can cause the bias point to drift from the design point of operation.

Stability Factors, $S(I_{CO})$, $S(V_{BE})$, and $S(\beta)$:

A stability factor, *S*, is defined for each of the parameters affecting bias stability as listed below:

$$\boxed{S(I_{CO}) = \frac{\Delta I_C}{\Delta I_{CO}} = \left.\frac{\partial I_C}{\partial I_{CO}}\right|_{V_{BE},\beta=const.}} \qquad [10.1a]$$

$$\boxed{S(V_{BE}) = \frac{\Delta I_C}{\Delta V_{BE}} = \left.\frac{\partial I_C}{\partial V_{BE}}\right|_{I_{CO},\beta=const.}} \qquad [10.1b]$$

$$\boxed{S(\beta) = \frac{\Delta I_C}{\Delta \beta} = \left.\frac{\partial I_C}{\partial \beta}\right|_{I_{CO},V_{BE}=const.}} \qquad [10.1c]$$

Generally, networks that are quite stable and relatively insensitive to temperature variations have low stability factors. In some ways it would seem more appropriate to consider the quantities defined by Eqs. [10.1a - 10.1c] to be sensitivity factors because: the higher the stability factor, the more sensitive the network to variations in that parameter.

The total effect on the collector current can be determined using the following equation:

$$\boxed{\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\Delta V_{BE} + S(\beta)\Delta\beta} \qquad [10.2]$$

Derivation of Stability Factors for Standard Bias Circuits:

For the ***voltage-divider bias circuit***, the exact analysis (using Thevenin theorem) for the input (base-emitter) loop will result in:

$$E_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0,$$

and $I_E = I_C + I_B$ =>

$$I_C R_E + I_B (R_E + R_{Th}) + V_{BE} = E_{Th},$$

and $I_C = \beta I_B + (\beta + 1) I_{CO}$,

or $I_B = \dfrac{I_C}{\beta} - \dfrac{\beta + 1}{\beta} I_{CO}$ =>

$$\boxed{I_C \left[\frac{(\beta+1)R_E + R_{Th}}{\beta} \right] - I_{CO} \left[\frac{(\beta+1)(R_E + R_{Th})}{\beta} \right] + V_{BE} = E_{Th}} \qquad [10.3]$$

The partial derivation of the Eq. [10.3] with respect to I_{CO} will result:

$$\frac{\partial I_C}{\partial I_{CO}} \cdot \frac{(\beta+1)R_E + R_{Th}}{\beta} - \frac{(\beta+1)(R_E + R_{Th})}{\beta} = 0$$

$$\boxed{S(I_{CO}) = \frac{(\beta+1)(R_E + R_{Th})}{(\beta+1)R_E + R_{Th}}} \qquad [10.4a]$$

Also, the partial derivation of the Eq. [10.3] with respect to V_{BE} will result:

$$\frac{\partial I_C}{\partial V_{BE}} \cdot \frac{(\beta+1)R_E + R_{Th}}{\beta} + 1 = 0$$

$$\boxed{S(V_{BE}) = \frac{-\beta}{(\beta+1)R_E + R_{Th}}} \qquad [10.4b]$$

The mathematical development of the last stability factor $S(\beta)$ is more complex than encountered for $S(I_{CO})$ and $S(V_{BE})$. Thus, $S(\beta)$ is suggested by the following equation:

$$\boxed{S(\beta) = \frac{(I_{C_1} / \beta_1)(R_E + R_{Th})}{(\beta_2 + 1)R_E + R_{Th}}} \qquad [10.4c]$$

For the ***emitter-stabilized bias circuit***, the stability factors are the same as these obtained above for the voltage-divider bias circuit except that R_{Th} will replaced by R_B. These are:

$$\boxed{S(I_{CO}) = \frac{(\beta+1)(R_E+R_B)}{(\beta+1)R_E+R_B}} \qquad [10.5a]$$

$$\boxed{S(V_{BE}) = \frac{-\beta}{(\beta+1)R_E+R_B}} \qquad [10.5b]$$

$$\boxed{S(\beta) = \frac{(I_{C_1}/\beta_1)(R_E+R_B)}{(\beta_2+1)R_E+R_B}} \qquad [10.5c]$$

For the ***fixed-bias circuit***, if we plug in $R_E = 0$ the following equation will result:

$$\boxed{S(I_{CO}) = \beta+1} \qquad [10.6a]$$

$$\boxed{S(V_{BE}) = -\frac{\beta}{R_B}} \qquad [10.6b]$$

$$\boxed{S(\beta) = \frac{I_{C_1}}{\beta_1}} \qquad [10.6c]$$

Finally, for the case of the ***voltage-feedback bias circuit***, the following equation will result:

$$\boxed{S(I_{CO}) = \frac{(\beta+1)(R_C+R_E+R_B)}{(\beta+1)(R_C+R_E)+R_B}} \qquad [10.7a]$$

$$\boxed{S(V_{BE}) = \frac{-\beta}{(\beta+1)(R_C+R_E)+R_B}} \qquad [10.7b]$$

$$\boxed{S(\beta) = \frac{(I_{C_1}/\beta_1)(R_C+R_E+R_B)}{(\beta_2+1)(R_C+R_E)+R_B}} \qquad [10.7c]$$

Example 10-1:

1. Design a voltage-divider bias circuit using a V_{CC} supply of +18 V, and an npn silicon transistor with β of 80. Choose R_C = 5R_E, and set I_C at 1 mA and the stability factor $S(I_{CO})$ at 3.8.

2. For the circuit designed in part (1), determine the change in I_C if a change in operating conditions results in I_{CO} increasing from 0.2 to 10 μA, V_{BE} drops from 0.7 to 0.5 V, and β increases 25%.

3. Calculate the change in I_C from 25^o to 75^{o}C for the same circuit designed in part (1), if I_{CO} = 0.2 μA and V_{BE} = 0.7 V.

Solution:

Part 1:

$V_{CE} = V_{CC} / 2 = 18 / 2 = 9V$.

$V_{CE} = V_{CC} - I_C (R_C + R_E)$, $R_C = 5R_E$ =>

$9 = 18 - (1m)(5R_E + R_E)$ => $R_E = 1.5k\Omega$.

$R_C = 5(1.5k) = 7.5k\Omega$.

$I_E \cong I_C = 1mA$, $V_E = I_E R_E = (1m)(1.5k) = 1.5V$.

$V_B = V_E + V_{BE} = 1.5 + 0.7 = 2.2V$.

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} \Rightarrow \boxed{\frac{R_2}{R_1 + R_2} = \frac{V_B}{V_{CC}} = \frac{2.2}{18}} \qquad [10.8a]$$

$$S(I_{CO}) = \frac{(\beta+1)(R_E + R_{Th})}{(\beta+1)R_E + R_{Th}} \Rightarrow$$

$$3.8 = \frac{(81)(1.5k + R_{Th})}{(81)(1.5k) + R_{Th}} \Rightarrow R_{Th} = 4.4k\Omega .$$

$$R_{Th} = \frac{R_1 R_2}{R_1 + R_2} \Rightarrow \boxed{\frac{R_2}{R_1 + R_2} = \frac{R_{Th}}{R_1} = \frac{4.4k}{R_1}} \qquad [10.8b]$$

From Eqs. [10.8a] and [10.8b]:

$$\frac{4.4k}{R_1} = \frac{2.2}{18} \Rightarrow R_1 = 36k\Omega .$$

From Eq. [10.8a]:

$$\frac{R_2}{36k + R_2} = \frac{2.2}{18} \Rightarrow R_2 = 5k\Omega .$$

Fig. 10-1 shows the final circuit.

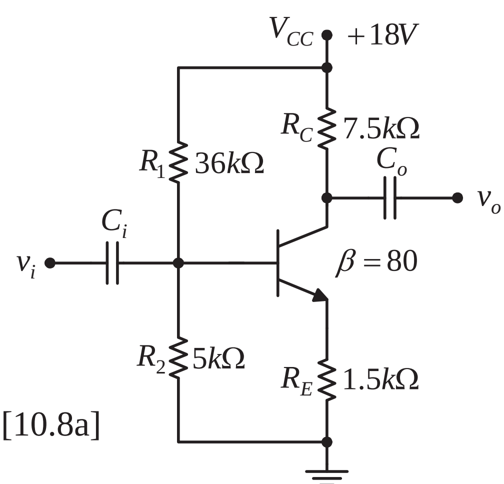

Fig. 10-1

Part 2:

$S(I_{CO}) = 3.8$,

$\Delta I_{CO} = 10\mu - 0.2\mu = 9.8\mu A$.

$$S(V_{BE}) = \frac{-\beta}{(\beta+1)R_E + R_{Th}} = \frac{-80}{(81)(1.5k) + 4.4k} = -0.635mS,$$

$\Delta V_{BE} = 0.5 - 0.7 = -0.2V$.

$\beta_2 = \beta_1(1 + 25/100) = 1.25\beta_1 = 1.25(80) = 100$,

$$S(\beta) = \frac{(I_{C_1}/\beta_1)(R_E + R_{Th})}{(\beta_2+1)R_E + R_{Th}} = \frac{(1m/80)(1.5k + 4.4k)}{(101)(1.5k) + 4.4k} = 0.473\mu A,$$

$\Delta\beta = 100 - 80 = 20$.

$$\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\Delta V_{BE} + S(\beta)\Delta\beta$$
$$= (3.8)(9.8\mu) + (-0.635m)(-0.2) + (0.473\mu)(20) = 0.174mA.$$

Part 3:

Since I_{CO}, doubles in value for every 10^{o}C increase in temperature.

Thus $N = \frac{\Delta T}{10} = \frac{75-25}{10} = 5$, $I_{CO}(75^o C) = 2^N \cdot I_{CO}(25^o C) = (2^5)(0.2\mu) = 6.4\mu A$.

$\Delta I_{CO} = 6.4\mu - 0.2\mu = 6.2\mu A$.

Since V_{BE}, decreases about 7.5 mV per 1^{o}C increase in temperature.

Thus $\Delta T = 75 - 25 = 50^o C$, $V_{BE}(25^o C) = 0.7V$ =>

$V_{BE}(75^o C) = 0.7 - 50(7.5m) = 0.325V$.

$$\Delta I_C = S(I_{CO})\Delta I_{CO} + S(V_{BE})\Delta V_{BE}$$
$$= (3.8)(6.2\mu) + (-0.635m)(-0.375) = 0.262mA.$$

Exercises:

1. Derive a mathematical expression to determine the stability factor $S(V_{CC}) = \Delta I_C / \Delta V_{CC}$ for the emitter-stabilized bias circuit.

2. Discuss and compare (by equations) between the relative levels of stability for the following biasing circuits:
   i. the fixed-bias circuit,
   ii. the emitter-stabilized bias circuit,
   iii. the voltage-divider bias circuit, and
   iv. the voltage-feedback circuit.