STABILITY

Stability of a system is a measure of the sensitivity of a network to variation in its parameters.

Collector current depends on:

β : increases with increase in temperature

$|V_{BE}|$: decreases by about 7.5 mV/°C increase in temperature

I_{co} : doubles in value for every 10°C increase in temperature.

Stability Factors:

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

$$\boxed{S_{(I_{co})} = \frac{\Delta I_C}{\Delta I_{CO}}}$$

$$\boxed{S_{(V_{BE})} = \frac{\Delta I_C}{\Delta V_{BE}}}$$

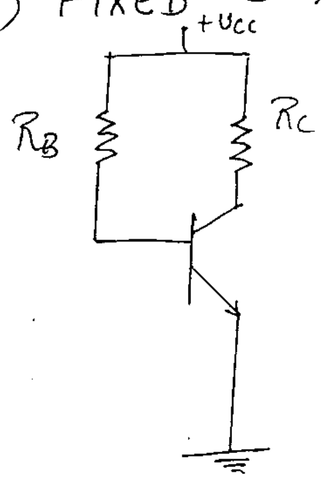
$$\boxed{S_{(\beta)} = \frac{\Delta I_C}{\Delta \beta}}$$

Networks that are quite stable & relatively insensitive to temperature variations have low stability factors.

Thus stability is nothing but sensitivity. Higher the stability factor, the more sensitive the network to variations in the parameters.

$S(I_{CO})$

(I) FIXED - BIAS



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

Diff w.r.t. I_C we get

$$1 = \beta \frac{dI_B}{dI_C} + (1+\beta)\frac{dI_{CO}}{dI_C}$$

$$1 = \beta \frac{dI_B}{dI_C} + \frac{(1+\beta)}{S_{(I_{CO})}} \quad \text{—— (1)}$$

Applying KVL to B-E loop

$$V_{CC} - I_B R_B - V_{BE} = 0$$

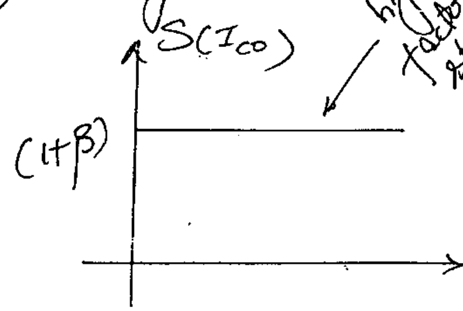
Diff. wrt I_C we get

$$\frac{dI_B}{dI_C} = 0 \quad \text{—— (2)}$$

substituting (2) in (1) we get

$$1 = 0 + \frac{(1+\beta)}{S_{(I_{CO})}}$$

$$\therefore S_{(I_{CO})} = (1+\beta)$$

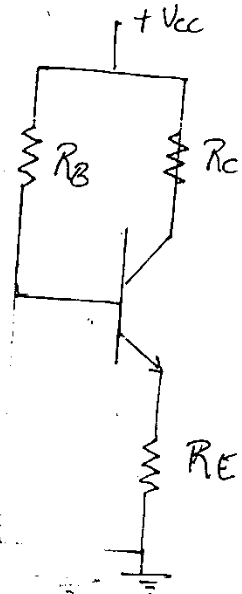


high stability factor ⇒ poor stability

In the next derivation we will see that the worst case of emitter - bias matches with that of fixed - bias.

$S_{(I_{CO})}$

(II) Emitter-Stabilized Bias



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

Diff. w.r.t. I_C we get

$$1 = \beta \frac{dI_B}{dI_C} + (1+\beta)\frac{dI_{CO}}{dI_C}$$

$$1 = \beta \frac{dI_B}{dI_C} + \frac{1+\beta}{S} \quad \text{——— (1)}$$

Applying KVL to the base-emitter loop

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{CC} - I_B R_B - V_{BE} - (I_C + I_B) R_E = 0$$

$$V_{CC} - I_B [R_B + R_E] - I_C R_E - V_{BE} = 0$$

Diff. w.r.t. I_C we get

$$\frac{dI_B}{dI_C} = \frac{-R_E}{R_E + R_B} \quad \text{——— (2)}$$

Substituting (2) in (1) we get

$$1 = \beta \left[\frac{-R_E}{R_E + R_B}\right] + \frac{1+\beta}{S_{(I_{CO})}}$$

$$\frac{1+\beta}{S(I_{co})} = 1 + \frac{\beta R_E}{R_E + R_B}$$

$$\frac{1+\beta}{S(I_{co})} = \frac{R_E(1+\beta) + R_B}{R_E + R_B}$$

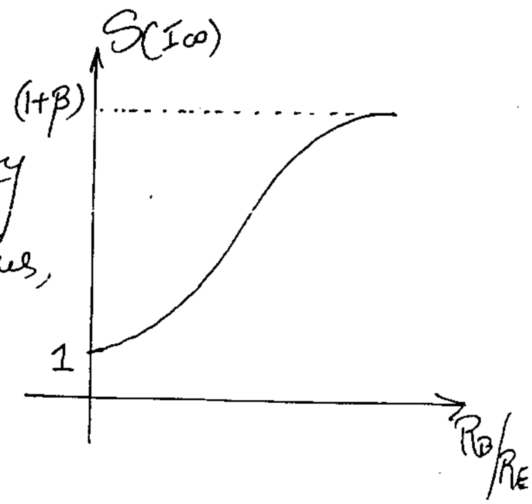
$$\boxed{S(I_{co}) = (1+\beta)\frac{R_E + R_B}{(1+\beta)R_E + R_B}}$$

$$S(I_{co}) = (1+\beta)\frac{1 + R_B/R_E}{(1+\beta) + R_B/R_E}$$

If $R_B/R_E >> (1+\beta)$ then $S(I_{co}) \cong \beta + 1$

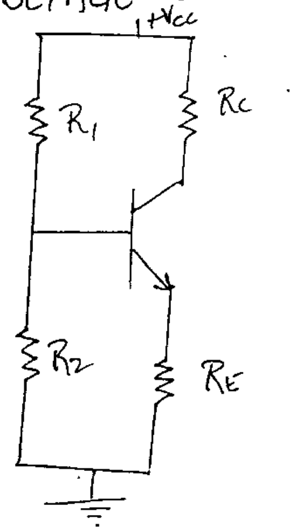
If $R_B/R_E << 1$ then $S(I_{co}) \cong 1$

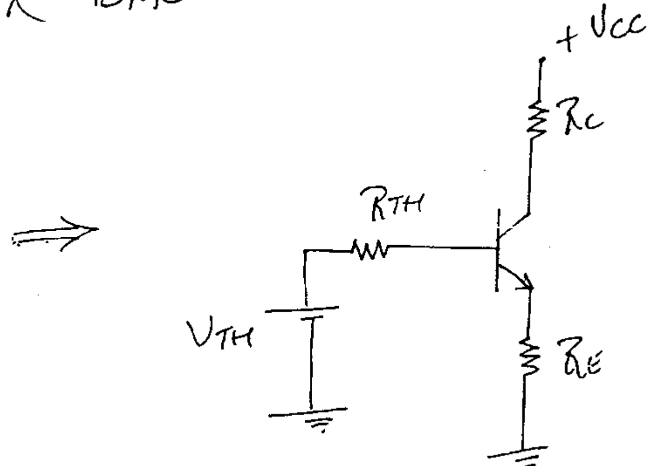
Thus stability factor approaches its lowest (best case) level as R_E becomes sufficiently large. But for good stability control we need $R_B > R_E$. Thus, a trade-off must be achieved between best stability & good design.



$S(I_{CO})$:

(III) VOLTAGE DIVIDER BIAS:





where $R_{TH} = R_1 || R_2$

$V_{TH} = \frac{R_2}{R_1 + R_2} \cdot V_{CC}$

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

Diff. w.r.t. I_C we get

$$1 = \beta \frac{dI_B}{dI_C} + (1+\beta)\frac{dI_{CO}}{dI_C}$$

$$1 = \beta \frac{dI_B}{I_C} + \frac{(1+\beta)}{S_{(I_{CO})}} \quad \text{———} \; (1)$$

Applying KVL to B-E loop we get

$$V_{TH} - I_B R_{TH} - V_{BE} - I_E R_E = 0$$

$$V_{TH} - I_B R_{TH} - V_{BE} - (I_B + I_C) R_E = 0$$

$$V_{TH} - I_B R_{TH} - V_{BE} -$$

$$V_{TH} - I_B(R_{TH} + R_E) - V_{BE} - I_C R_E = 0$$

Diff w.r.t. I_C

$$\frac{dI_B}{dI_C} = \frac{-R_E}{R_E + R_{TH}} \quad \text{—} \ (2)$$

Substituting (2) in (1) we get

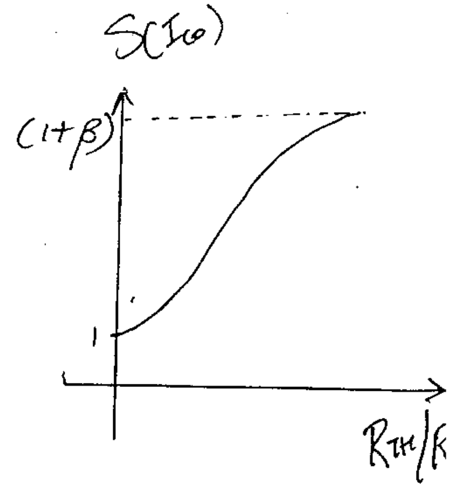
$$1 = \beta\left[\frac{-R_E}{R_E + R_{TH}}\right] + \frac{(1+\beta)}{S_{(I_{co})}}$$

$$\frac{1+\beta}{S_{(I_{co})}} = 1 + \frac{\beta R_E}{R_E + R_{TH}}$$

$$\frac{1+\beta}{S_{(I_{co})}} = \frac{R_E(1+\beta) + R_{TH}}{R_E + R_{TH}}$$

$$\frac{S_{(I_{co})}}{1+\beta} = \frac{R_E + R_{TH}}{(1+\beta)R_E + R_{TH}}$$

$$\boxed{S_{(I_{co})} = (1+\beta)\frac{R_E + R_{TH}}{(1+\beta)R_E + R_{TH}}}$$



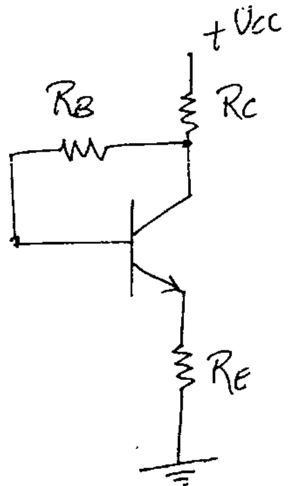
$$S_{(I_{co})} = (1+\beta)\frac{1 + R_{TH}/R_E}{(1+\beta) + R_{TH}/R_E}$$

If $R_{TH}/R_E >> (1+\beta)$ then $S_{(I_{co})} \cong 1+\beta$

If $R_{TH}/R_E << 1$ then $S_{(I_{co})} \cong 1$

$S(I_{CO})$

(IV) COLLECTOR FEEDBACK BIAS:



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

Diff. w.r.t. I_C

$$1 = \beta \frac{dI_B}{dI_C} + (1+\beta)\frac{dI_{CO}}{dI_C}$$

$$1 = \beta \frac{dI_B}{dI_C} + \frac{(1+\beta)}{S_{(I_{CO})}} \quad \text{—(1)}$$

Applying KVL to B-E loop

$$V_{CC} - I_C' R_C - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{CC} - (I_C + I_B) R_C - I_B R_B - V_{BE} - (I_C + I_B) R_E = 0$$

$$V_{CC} - I_B(R_C + R_B + R_E) - I_C(R_C + R_E) - V_{BE} = 0$$

Diff. w.r.t. I_C

$$\frac{dI_B}{dI_C} = -\frac{R_C + R_E}{R_C + R_E + R_B} \quad \text{—(2)}$$

Substituting (2) in (1) we get

$$1 = \beta \left[\frac{-(R_C + R_E)}{R_C + R_E + R_B} \right] + \frac{1+\beta}{S(I_{CO})}$$

$$\frac{1+\beta}{S(I_{co})} = 1 + \frac{\beta(R_C+R_E)}{R_C+R_E+R_B}$$

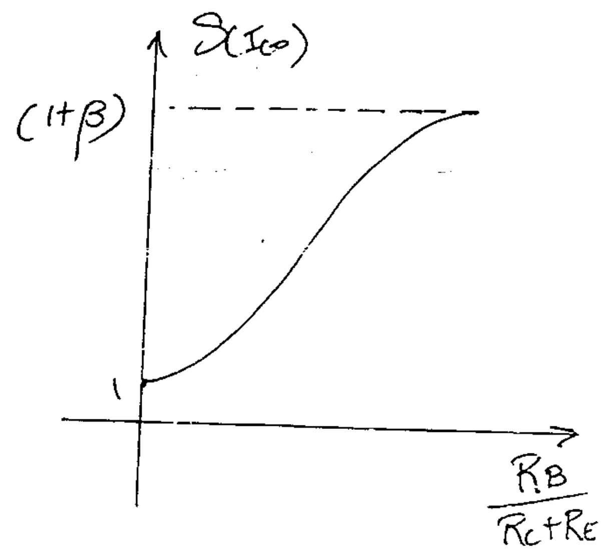
$$\frac{1+\beta}{S(I_{co})} = \frac{(1+\beta)(R_C+R_E)+R_B}{(R_C+R_E)+R_B}$$

$$\boxed{S(I_{co}) = (1+\beta)\,\frac{R_C+R_E+R_B}{(1+\beta)(R_C+R_E)+R_B}}$$

$$S(I_{co}) = (1+\beta)\,\frac{1+R_B/(R_C+R_E)}{(1+\beta)+R_B/(R_C+R_E)}$$

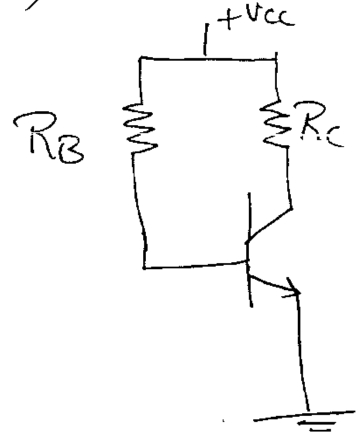
If $R_B/(R_C+R_E) >> (1+\beta)$ then $S(I_{co}) \simeq 1+\beta$

If $R_B/(R_C+R_E) << 1$ then $S(I_{co}) \simeq 1$.



$S(V_{BE})$:

(I) Fixed-Bias



Applying KVL to B-E loop

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{I_C}{\beta}$$

$$\therefore V_{CC} - \frac{I_C}{\beta} R_B - V_{BE} = 0$$

Dif w.r.t to I_C

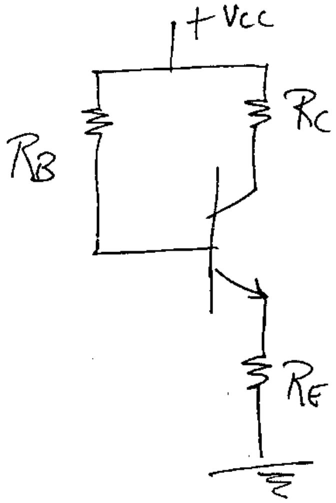
$$0 - \frac{R_B}{\beta}\frac{dI_C}{dI_C} - \frac{dV_{BE}}{dI_C} = 0$$

$$\therefore \frac{dI_C}{dV_{BE}} = \frac{-\beta}{R_B}$$

$$\boxed{S(V_{BE}) = \frac{-\beta}{R_B}}$$

$S_{(V_{BE})}$:

(II) EMITTER STABILIZED BIAS:



Applying KVL to B-E loop

$$V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0$$

$$V_{CC} - I_B R_B - V_{BE} - (I_C + I_B) R_E = 0$$

$$V_{CC} - \frac{I_C}{\beta} R_B - V_{BE} - I_C R_E - \frac{I_C}{\beta} R_E = 0$$

Diff wrt I_C.

$$0 - \frac{R_B}{\beta} - \frac{dV_{BE}}{dI_C} - R_E - \frac{R_E}{\beta} = 0$$

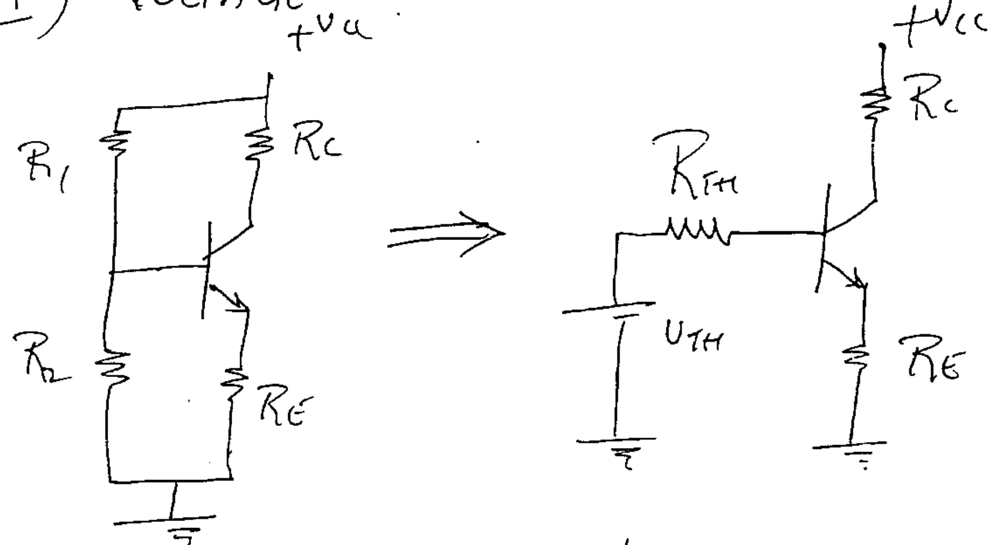
$$\frac{dV_{BE}}{dI_C} = -\frac{R_E + R_B + \beta R_E}{\beta}$$

$$\frac{dI_C}{dV_{BE}} = \frac{-\beta}{R_B + (1+\beta) R_E}$$

$$\boxed{S_{(V_{BE})} = \frac{-\beta}{R_B + (1+\beta) R_E}}$$

$S(V_{BE})$:

(III) VOLTAGE DIVIDER BIAS:



Applying KVL to B-E loop

$$V_{TH} - I_B R_{TH} - V_{BE} - I_E R_E = 0$$

$$V_{TH} - I_B R_{TH} - V_{BE} - (I_C + I_B) R_E = 0$$

$$V_{TH} - \frac{I_C}{\beta} R_{TH} - V_{BE} - I_C R_E - \frac{I_C}{\beta} R_E = 0$$

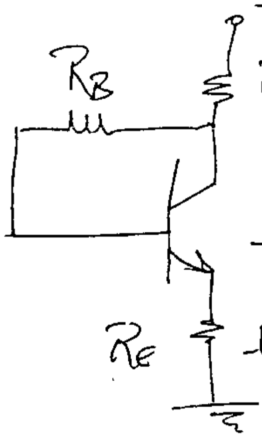
Diff. w.r.t I_C

$$0 - \frac{R_{TH}}{\beta} - \frac{dV_{BE}}{dI_C} - R_E - \frac{R_E}{\beta} = 0$$

$$\boxed{S(V_{BE}) = \frac{-\beta}{(1+\beta) R_E + R_{TH}}}$$

$S_{(V_{BE})}$:

(IV) Collector-feedback bias:



Applying KVL to B-E loop

$$-V_{BE} + V_{CC} - I_C' R_C - I_B R_B - I_E R_E = 0$$

$$-V_{BE} + V_{CC} - (I_C + I_B) R_C - I_B R_B - (I_C + I_B) R_E = 0$$

$$-V_{BE} + V_{CC} - I_C R_C - \frac{I_C}{\beta} R_C - \frac{I_C}{\beta} R_B - I_C R_E - \frac{I_C}{\beta} R_E =$$

Diff w.r.t. I_C

$$0 - R_C - \frac{R_C}{\beta} - \frac{R_B}{\beta} - R_E - \frac{R_E}{\beta} - \frac{dV_{BE}}{dI_C} = 0$$

$$\frac{dV_{BE}}{dI_C} = -\left[\frac{(1+\beta)(R_C + R_E) + R_B}{\beta}\right]$$

$$\boxed{S_{(V_{BE})} = \frac{-\beta}{(1+\beta)(R_C + R_E) + R_B}}$$