ELECTRONICA APLICADA I

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- ESTABILIDAD DE LA POLARIZACION(1)

Estas diapositivas están basadas en las clases dictadas por el Profesor Ing. Alberto Muhana.

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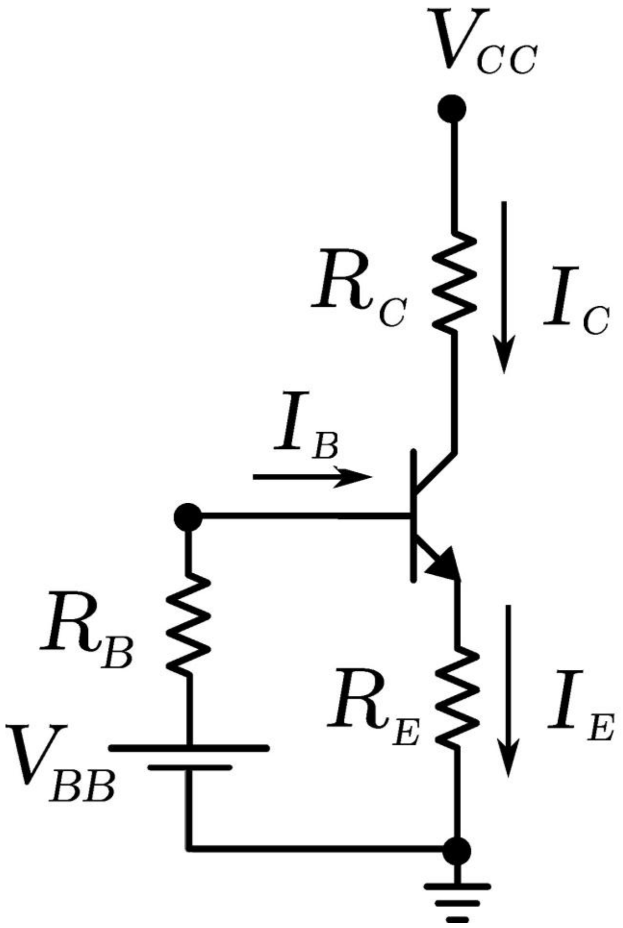
Estabilidad de la Polarización



$$I_C = \alpha I_E + I_{CBO} \qquad (1)$$

$$I_B = (1-\alpha)I_E - I_{CBO} \qquad (2)$$

$$\beta = \frac{\alpha}{1-\alpha} \qquad \alpha = \frac{\beta}{\beta+1}$$

$$V_{BB} = I_B R_B + V_{BE} + I_E R_E \quad (3)$$

Reemplazamos (2) *en* (3)

$$\begin{aligned} V_{BB} &= \left[(1-\alpha)I_E - I_{CBO}\right]R_B + V_{BE} + I_E R_E \\ &= (1-\alpha)I_E R_B - I_{CBO}R_B + V_{BE} + I_E R_E \\ &= I_E\left[(1-\alpha)R_B + R_E\right] - I_{CBO}R_B + V_{BE} \qquad (4) \end{aligned}$$

Estabilidad de la Polarización (Cont.)

$De\ (1)$

$$I_E = \frac{I_C - I_{CBO}}{\alpha} \qquad (5)$$

$Reemplazamos\ (5)\ en\ (4)\ y\ ordenamos$

$$V_{BB} - V_{BE} = \left(\frac{I_C - I_{CBO}}{\alpha}\right)\left[(1-\alpha)R_B + R_E\right] - I_{CBO}R_B$$

$$= \left(\frac{I_C}{\alpha} - \frac{I_{CBO}}{\alpha}\right)\left[(1-\alpha)R_B + R_E\right] - I_{CBO}R_B$$

$$= \frac{I_C}{\alpha}\left[(1-\alpha)R_B + R_E\right] - \frac{I_{CBO}}{\alpha}\left[(1-\alpha)R_B + R_E\right] - I_{CBO}R_B$$

$$= \frac{I_C}{\alpha}\left[(1-\alpha)R_B + R_E\right] - \frac{I_{CBO}}{\alpha}\left[(1-\alpha)R_B + R_E + \alpha R_B\right]$$

Estabilidad de la Polarización (Cont.)

$$V_{BB} - V_{BE} = \frac{I_C}{\alpha}\left[(1-\alpha)R_B + R_E\right] - \frac{I_{CBO}}{\alpha}\left[+R_B - \cancel{\alpha}\cancel{R}_B + R_E + \cancel{\alpha}\cancel{R}_B\right]$$

$$= \frac{I_C}{\alpha}\left[(1-\alpha)R_B + R_E\right] - \frac{I_{CBO}}{\alpha}\left[R_E + R_B\right]$$

$$V_{BB} - V_{BE} + \frac{I_{CBO}}{\alpha}\left[R_E + R_B\right] = \frac{I_C}{\alpha}\left[(1-\alpha)R_B + R_E\right]$$

$$\alpha(V_{BB} - V_{BE}) + I_{CBO}\left[R_E + R_B\right] = I_C\left[(1-\alpha)R_B + R_E\right]$$

$$I_{CQ} \quad = \frac{\alpha\left[V_{BB} - V_{BE}\right] + I_{CBO}\left[R_E + R_B\right]}{(1-\alpha)R_B + R_E} \quad \textit{ecuacion general}$$

$Si \ \alpha \cong 1$

$$I_{CQ} = \frac{V_{BB} - V_{BE}}{R_E} + I_{CBO}\left(1 + \frac{R_B}{R_E}\right) \qquad (6)$$

$Si \ \mathrm{I}_{CBO} \cong 0$

$$I_{CQ} = \frac{V_{BB} - V_{BE}}{R_E}$$

Estabilidad de la Polarización (Cont.)

$$De\ la\ ecuacion\ general\ si\ I_{CBO} \cong 0$$

$$I_{CQ} = \frac{\alpha\left[V_{BB} - V_{BE}\right]}{\left(1-\alpha\right)R_B + R_E}$$

$$I_{CQ} = \frac{V_{BB} - V_{BE}}{\frac{\left(1-\alpha\right)}{\alpha}R_B + \frac{R_E}{\alpha}} = \frac{V_{BB} - V_{BE}}{\frac{R_B}{\beta} + \frac{R_E}{\alpha}}$$

$$I_{CQ} = f\,(\underbrace{V_{BE}, I_{CBO}, \beta}_{Son\ f\,(T)}, \ldots)$$

$$\Delta V_{BE} = V_{BE2} - V_{BE1} = -k\left(T_2 - T_1\right) = -k\Delta T$$

$$donde\ \mathrm{k} = 2{,}5\,{}^{mV}\!/_{{}^\circ C}$$

$$I_{CBO(2)} = I_{CBO(1)}e^{K\Delta T} \qquad donde\ K = 0{,}07\ {}^{1}\!/_{{}^\circ C}$$

$$\Delta I_{CBO} = \Delta I_{CBO(2)} - \Delta I_{CBO(1)} = I_{CBO}(e^{K\Delta T} - 1)$$

Estabilidad de la Polarización (Cont.)

$$\frac{\Delta I_{CQ}}{\Delta T} = \frac{\Delta I_{CQ}}{\Delta V_{BE}} \cdot \frac{\Delta V_{BE}}{\Delta T} + \frac{\Delta I_{CQ}}{\Delta I_{CBO}} \cdot \frac{\Delta I_{CBO}}{\Delta T} + \frac{\Delta I_{CQ}}{\Delta \beta} \cdot \frac{\Delta \beta}{\Delta T}$$

$$\Delta I_{CQ} = \frac{\Delta I_{CQ}}{\Delta V_{BE}} \Delta V_{BE} + \frac{\Delta I_{CQ}}{\Delta I_{CBO}} . \Delta I_{CBO} + \frac{\Delta I_{CQ}}{\Delta \beta} \Delta \beta$$

$Si\ tengo\ \Delta T;\ tengo\ \Delta V_{BE}\ ,\ \Delta I_{CBO}\ y\ \Delta \beta$

$Factores\ de\ estabilidad:$

$$S_V = \frac{\Delta I_{CQ}}{\Delta V_{BE}}$$

$$S_I = \frac{\Delta I_{CQ}}{\Delta I_{CBO}}$$

$$S_\beta = \frac{\Delta I_{CQ}}{\Delta \beta}$$

$Entonces:$

$$\boxed{\Delta I_{CQ} = S_V \Delta V_{BE} + S_I \Delta I_{CBO} + S_\beta \Delta \beta}$$

Estabilidad de la Polarización (Cont.)

$$Partiendo\ de\ (6):\ I_{CQ} = \frac{V_{BB} - V_{BE}}{R_E} + I_{CBO}\left(1 + \frac{R_B}{R_E}\right)$$

$$S_V = \frac{\Delta I_{CQ}}{\Delta V_{BE}} = -\frac{1}{R_E}$$

$$S_I = \frac{\Delta I_{CQ}}{\Delta I_{CBO}} = 1 + \frac{R_B}{R_E}$$

$$\Delta I_{CQ} = -\frac{1}{R_E}\left(-k\Delta T\right) + \left(1 + \frac{R_B}{R_E}\right) I_{CBO}\left(e^{K\Delta T} - 1\right) + \ldots$$

$$= \frac{k\Delta T}{R_E} + \left(1 + \frac{R_B}{R_E}\right) I_{CBO}\left(e^{K\Delta T} - 1\right) + \ldots$$

$$S_\beta = \frac{\Delta I_{CQ}}{\Delta \beta}$$

Estabilidad de la Polarización (Cont.)

$$I_{CQ} = \frac{\alpha\left[V_{BB} - V_{BE}\right]}{\left(1-\alpha\right)R_B + R_E} =$$

$$Como\ \ \alpha = \frac{\beta}{\beta+1}$$

$$I_{CQ} = \frac{\beta(V_{BB} - V_{BE})}{(\beta+1)(1-\alpha)R_B + (\beta+1)R_E}$$

$$Como\ \ \alpha = \frac{\beta}{\beta+1} \Rightarrow \beta+1 = \frac{\beta}{\alpha}$$

$$Como\ \ \beta = \frac{\alpha}{1-\alpha} \Rightarrow 1-\alpha = \frac{\alpha}{\beta}$$

$$Entonces\ \ \left(\beta+1\right)\left(1-\alpha\right) = \frac{\cancel{\beta}}{\cancel{\alpha}}\frac{\cancel{\alpha}}{\cancel{\beta}} = 1$$

$$I_{CQ} = \frac{\beta(V_{BB} - V_{BE})}{R_B + (\beta+1)R_E}$$

Estabilidad de la Polarización (Cont.)

$$Si\ \beta_1 = inicial\ y\ \beta_2 = final$$

$$I_{CQ1} = \frac{\beta_1 (V_{BB} - V_{BE})}{R_B + (\beta_1 + 1) R_E} \qquad I_{CQ2} = \frac{\beta_2 (V_{BB} - V_{BE})}{R_B + (\beta_2 + 1) R_E}$$

$$\frac{I_{CQ2}}{I_{CQ1}} = \frac{\beta_2 \left[R_B + (\beta_1 + 1) R_E \right]}{\beta_1 \left[R_B + (\beta_2 + 1) R_E \right]}$$

$$\frac{\Delta I_{CQ}}{I_{CQ1}} = \frac{I_{CQ2} - I_{CQ1}}{I_{CQ1}} = \frac{I_{CQ2}}{I_{CQ1}} - 1$$

Estabilidad de la Polarización (Cont.)

$$\frac{\Delta I_{CQ}}{I_{CQ1}} = \frac{\beta_2}{\beta_1}\frac{\left[R_B + (\beta_1 + 1)R_E\right]}{\left[R_B + (\beta_2 + 1)R_E\right]} - 1$$

$$= \frac{\beta_2\left[R_B + (\beta_1 + 1)R_E\right] - \beta_1\left[R_B + (\beta_2 + 1)R_E\right]}{\beta_1\left[R_B + (\beta_2 + 1)R_E\right]}$$

$$= \frac{\beta_2 R_B + \beta_2\beta_1 R_E + \beta_2 R_E - \beta_1 R_B - \beta_1\beta_2 R_E - \beta_1 R_E}{\beta_1\left[R_B + (\beta_2 + 1)R_E\right]}$$

$$= \frac{R_B(\beta_2 - \beta_1) + R_E(\beta_2 - \beta_1)}{\beta_1\left[R_B + (\beta_2 + 1)R_E\right]}$$

$$= \frac{\Delta\beta(R_B + R_E)}{\beta_1\left[R_B + (\beta_2 + 1)R_E\right]} \Rightarrow$$

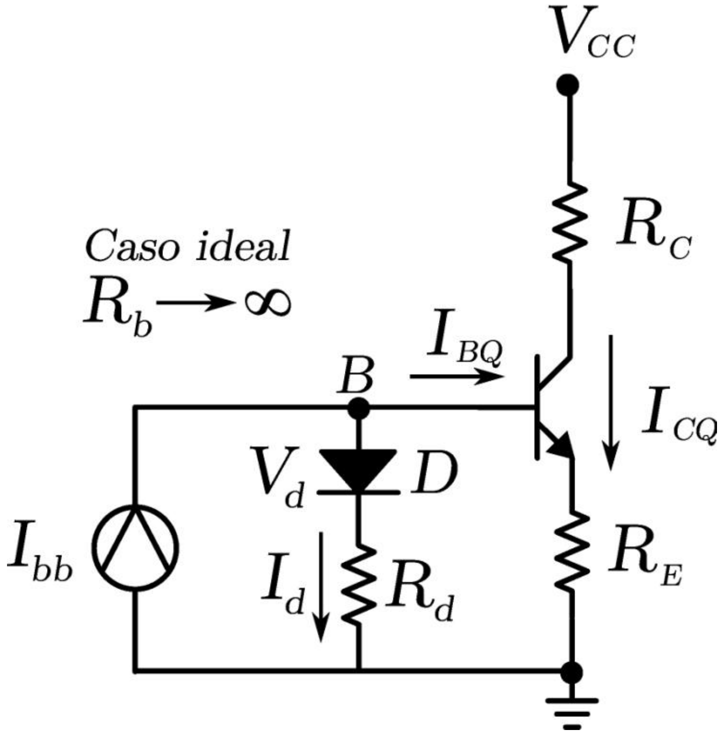
$$S_\beta = \frac{\Delta I_{CQ}}{\Delta\beta} = \frac{I_{CQ1}(R_B + R_E)}{\beta_1\left[R_B + (\beta_2 + 1)R_E\right]}$$

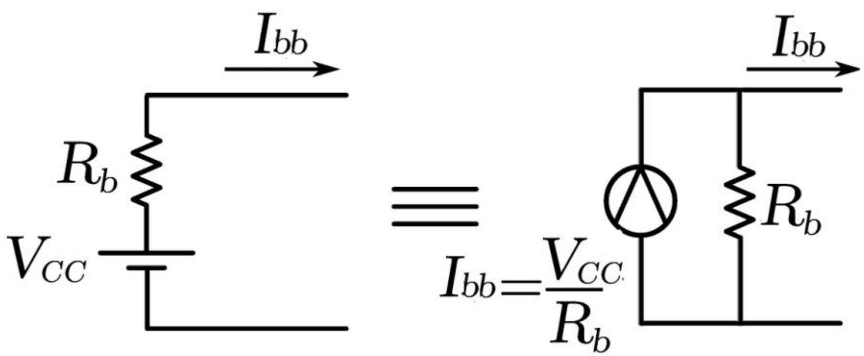
Finalmenete

$$\Delta I_{CQ} = S_V \Delta V_{BE} + S_I \Delta I_{CBO} + S_\beta \Delta\beta + \ldots$$

$$\Delta I_{CQ} = \left(-\frac{1}{R_E}\right)\Delta V_{BE} + \left(1 + \frac{R_B}{R_E}\right)\Delta I_{CBO} + \frac{I_{CQ1}(R_B + R_E)}{\beta_1\left[R_B + (\beta_2 + 1)R_E\right]}\Delta\beta + \ldots$$

Estabilidad Mediante la Compensación ΔT Mediante Polarización por Diodo.





Estabilidad Mediante la Compensación ΔT Mediante Polarización por Diodo.

$$Para\ este\ circuito: \ \frac{\Delta V_D}{\Delta T} = \frac{\Delta V_{BE}}{\Delta T}$$

$$Del\ circuito\ ideal: I_{bb} = I_d + I_{BQ} = I_d + \frac{I_{EQ}}{\beta+1}$$

$$I_{EQ} = (I_{bb} - I_d)(\beta+1) \qquad (1)$$

$$V_B = V_d + I_d R_d = V_{BEQ} + I_{EQ} R_E$$

$$I_d = \frac{V_{BEQ} + I_{EQ} R_E - V_d}{R_d} \qquad (2)$$

$$reemplazamos\ (2)\ en\ (1)$$

$$I_{EQ} = \left(\frac{I_{bb} R_d}{R_d} + \frac{-V_{BEQ} - I_{EQ} R_E + V_d}{R_d} \right)(\beta+1)$$

$$I_{EQ} R_d = \left(I_{bb} R_d - V_{BEQ} + V_d \right)(\beta+1) - I_{EQ} R_E (\beta+1)$$

$$I_{EQ} \left[\frac{R_d + R_E(\beta+1)}{(\beta+1)} \right] = I_{bb} R_d - V_{BEQ} + V_d$$

Estabilidad Mediante la Compensación ΔT Mediante Polarización por Diodo.

$$I_{EQ} = \frac{I_{bb}R_d + V_d - V_{BEQ}}{\frac{R_d}{\beta+1} + R_e} \cong I_{CQ}$$

$$\frac{\Delta I_{CQ}}{\Delta T} = \frac{\frac{\Delta V_d}{\Delta T} - \frac{\Delta V_{BEQ}}{\Delta T}}{\frac{R_d}{\beta+1} + R_e} = 0$$

Por lo tanto, la I_{CQ} *es insensible a las variaciones de temperatura.*

Estabilidad Mediante la Compensación ΔT Mediante Polarización por Diodo o Transistor

$$Ahora\ le\ agregamos\ R_b \neq \infty$$

$$I_{bb} = \frac{V_b}{R_b} + \frac{V_b - V_d}{R_d} + \underbrace{\cancel{I}_{BQ}}_{se\ desprecia}$$

$$Elegimos \begin{cases} R_b \Rightarrow I_{BQ} << V_b/R_b \\ R_d \Rightarrow I_{BQ} << \dfrac{V_b - V_d}{R_d} \end{cases}$$

$$I_{bb} = \frac{V_b}{R_b} + \frac{V_b}{R_d} - \frac{V_d}{R_d} = V_b\left(\frac{1}{R_b} + \frac{1}{R_d}\right) - \frac{V_d}{R_d} = V_b\left(\frac{R_d + R_b}{R_b R_d}\right) - \frac{V_d}{R_d}$$

$$I_{bb} + \frac{V_d}{R_d} = V_b\left(\frac{R_d + R_b}{R_b R_d}\right)$$

$$V_b = \left(I_{bb} + \frac{V_d}{R_d}\right)\left(\frac{R_d R_b}{R_b + R_d}\right) = \frac{\overbrace{I_{bb} R_b}^{V_{cc}} R_d}{R_b + R_d} + V_d\,\frac{R_b}{R_b + R_d}$$

$$I_{EQ} = \frac{V_b - V_{BE}}{R_e} = \frac{1}{R_e}\left(\frac{V_{cc} R_d}{R_b + R_d} + V_d\,\frac{R_b}{R_b + R_d} - V_{BE}\right) \cong I_{CQ}$$

Estabilidad Mediante la Compensación ΔT Mediante Polarización por Diodo o Transistor

$Tenemos\ que:$

$$\frac{\Delta V_d}{\Delta T} = \frac{\Delta V_{BE}}{\Delta T} = -k$$

$$\frac{\Delta I_{CQ}}{\Delta T} = \frac{1}{R_e}\left(\frac{R_b}{R_d + R_b}\frac{\Delta V_d}{\Delta T} - \frac{\Delta V_{BE}}{\Delta T}\right) = \frac{1}{R_e}\left(k - \frac{R_b}{R_d + R_b}k\right)$$

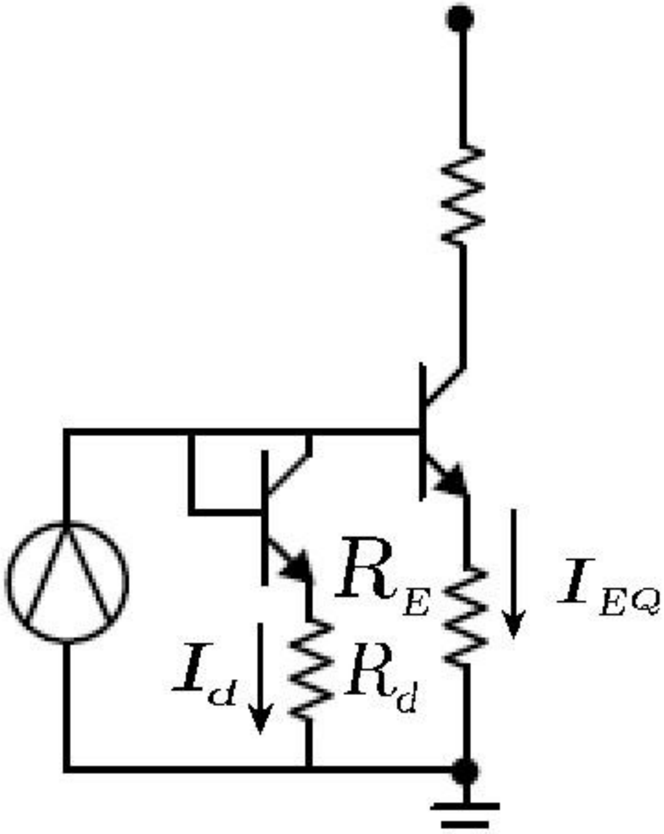
$$= \frac{k}{R_e}\left(\frac{\cancel{R_b} + R_d - \cancel{R_b}}{R_b + R_d}\right)$$

$$\frac{\Delta I_{CQ}}{\Delta T} = \frac{k}{R_e}\left(\frac{1}{1 + \frac{R_b}{R_d}}\right)$$

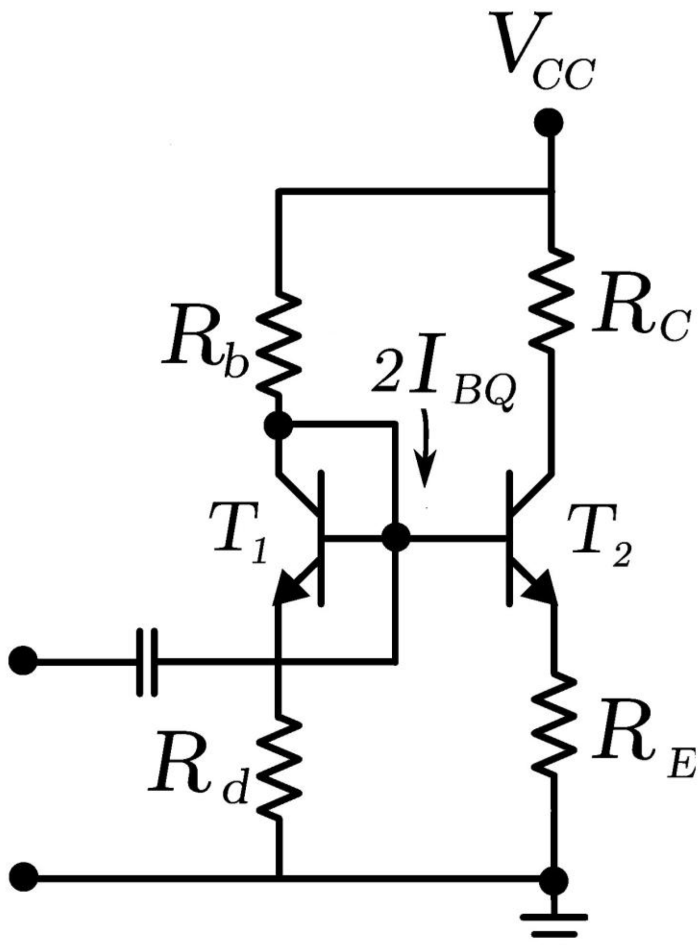
Estabilidad Mediante la Compensación ΔT Mediante Polarización por Diodo o Transistor

Podemos reemplazar el diodo por un transistor.

Se usa en circuitos integrados.



Polarización Balanceada- Polarización por Diodo o Transistor- “Espejo de Corriente”.



Condicion de espejo de corriente:

$$\boxed{R_d = R_E}$$

Iguales transistores, igual β.

Polarización Balanceada- Polarización por Diodo o Transistor- “Espejo de Corriente”.(Cont.)

$$V_{CC} = \left(I_{CQ} + 2\frac{I_{CQ}}{\beta} \right) R_b + V_{BE} + I_{CQ} R_E$$

$$I_{CQ} = \frac{V_{CC} - V_{BE}}{\left(1 + \frac{2}{\beta}\right) R_b + R_E}$$

$$= \frac{V_{CC} - V_{BE}}{\left(\frac{\beta + 2}{\beta}\right) R_b + R_E}$$

$Para\ \beta >> 2$

$$I_{CQ} = \frac{V_{CC} - V_{BE}}{R_b + R_E}$$

$$\frac{\Delta I_{CQ}}{\Delta T} = \frac{k}{R_b + R_E}$$

Ahora con $R_d = R_e = 0$ (*es comun para los CI, evita el capacitor de desacople*).

$$I_{CQ} = \frac{V_{CC} - V_{BE}}{R_b} \qquad \frac{\Delta I_{CQ}}{\Delta T} = \frac{k}{R_b}$$