Circuitos de RadioFrecuencia

Fundamentos de amplificación

Amplificadores Monoetapa

Clasificación I

Señal pequeña (P_D<500mW)
Gran señal (P_D>500mW)

Clasificación II

- Lineales
  - Clase A
  - Clase B
  - Clase AB
- Clase C (<180°)
- Amplificadores conmutados

Amplificadores lineales clase A

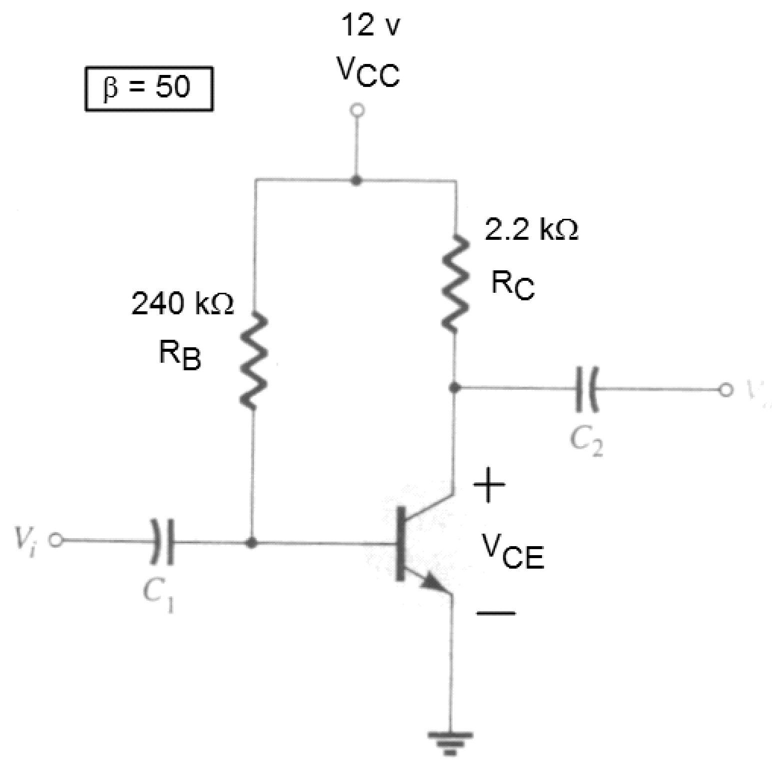
Características

- Conduce sobre los 360° de la señal
- Alta disipación de potencia (P_D)
- Potencia de salida limitada (Po)
- Eficiencia < 50%

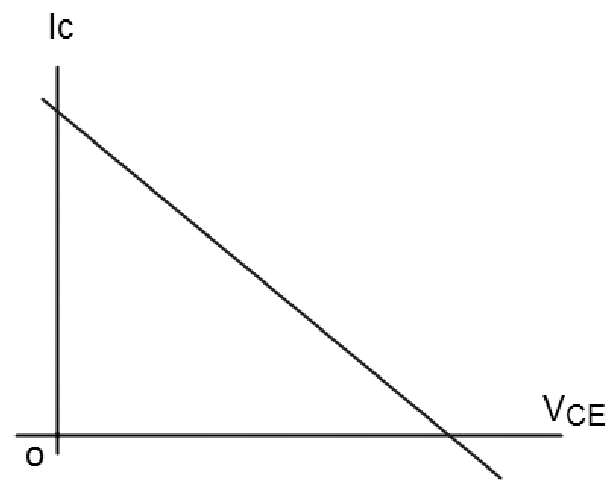
$$\eta = \frac{Po}{P_{DC}} \times 100$$

Amplificadores monoetapa con TBJ

Polarización fija



Recta de carga de DC



Diseño

Polarización fija

1. Fuente de alimentación (V_{CC})
2. Elección del transistor

- $I_{C_{sat_t}}$
- β_{DC}

3. $1/4\ I_{C_{sat_t}} \leq I_{C_{sat_C}} \leq 1/2\ I_{C_{sat_t}}$

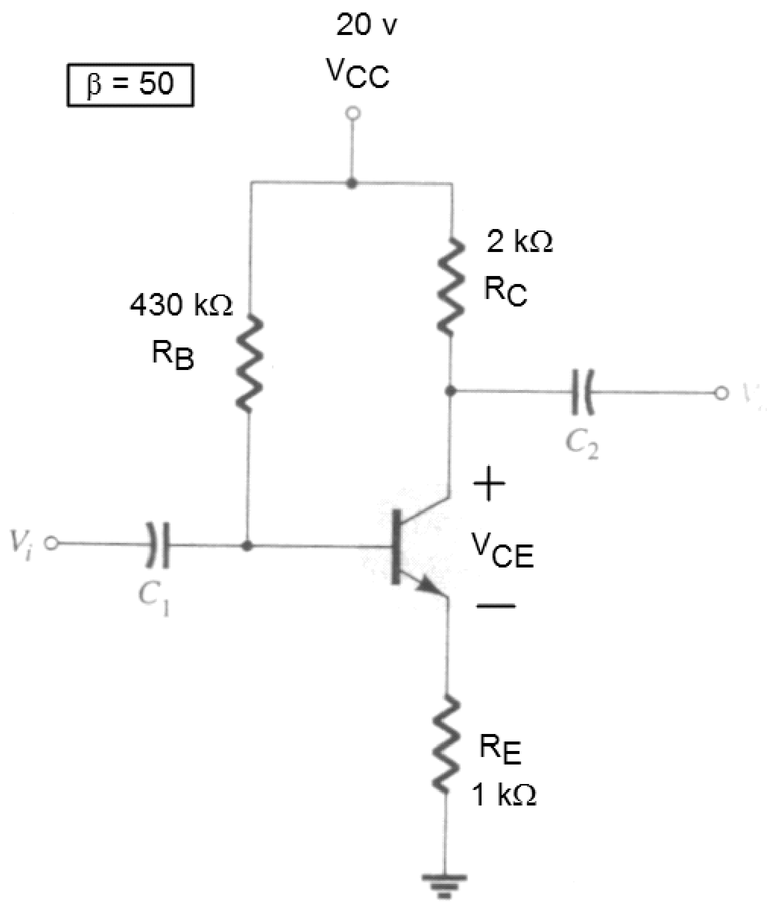
- $I_{C_{sat_C}} = \dfrac{V_{CC}}{R_C}$

4. $I_{C_Q} = 1/2\ I_{C_{sat_C}}$; $V_{CE_Q} = 1/2\ V_{CC}$

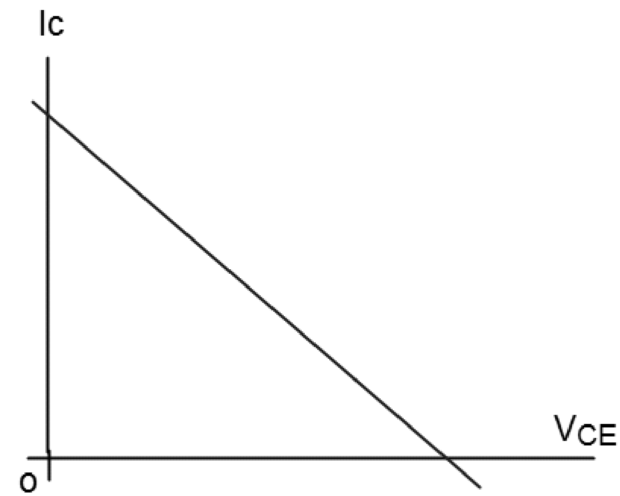
5. $\beta = \dfrac{I_{C_Q}}{I_B}$

6. $R_B = \dfrac{V_{CC} - V_{BE}}{I_{BQ}}$

Polarización estabilizada en emisor



Recta de carga de DC

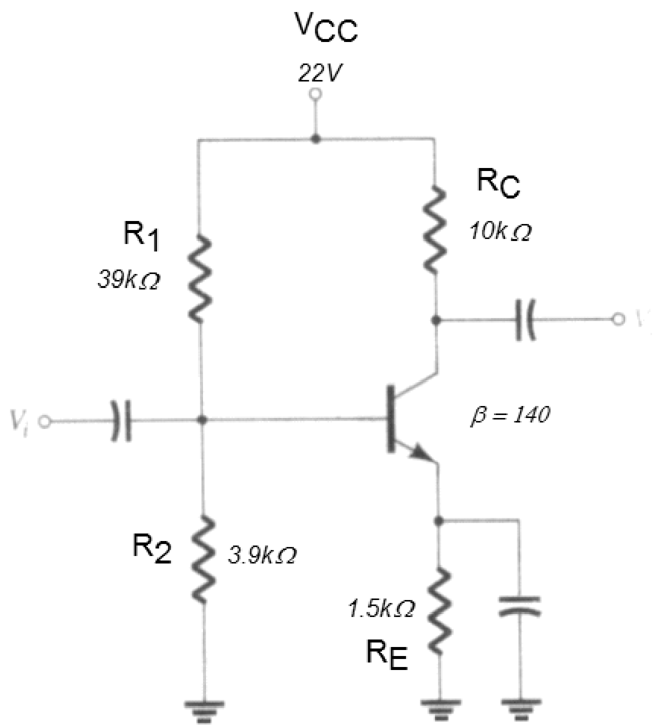


Diseño

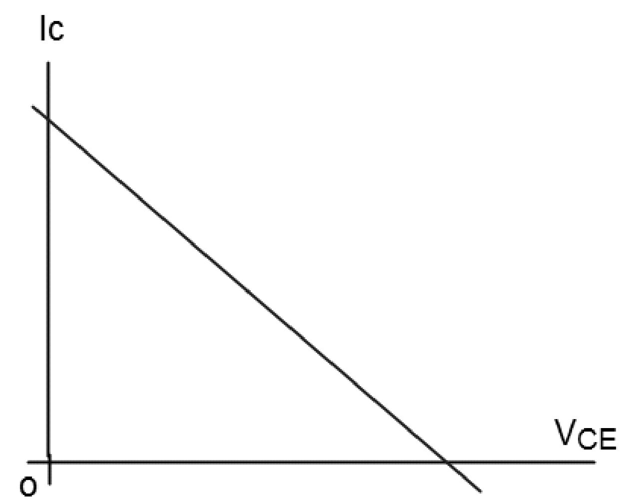
Polarización estabilizado en emisor

1. Fuente de alimentación (V_{CC})
2. Elección del transistor
   - $I_{C_{sat_t}}$
   - β_{DC}
3. $1/4\, I_{C_{sat_t}} \leq I_{C_{sat_C}} \leq 1/2\, I_{C_{sat_t}}$
   - $I_{C_{sat_C}} = \dfrac{Vcc}{R_C + R_E}$
4. $I_{CQ} = 1/2\, I_{C_{SAT_C}}$; $V_{CE_Q} = 1/2\, V_{CC}$
5. $1/10 V_{CC} \leq V_E \leq 1/4 V_{CC}$
6. $\beta = \dfrac{I_{CQ}}{I_B}$
7. $R_B = \dfrac{V_{CC} - V_{BE} - I_B \beta R_E}{I_{BQ}}$

Polarización por división de voltaje



Recta de carga de DC

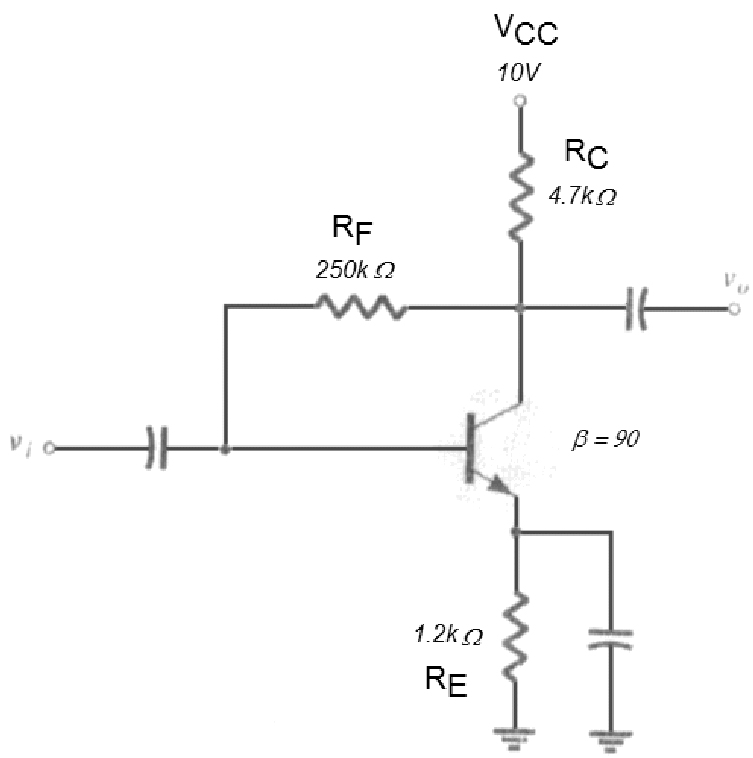


Diseño

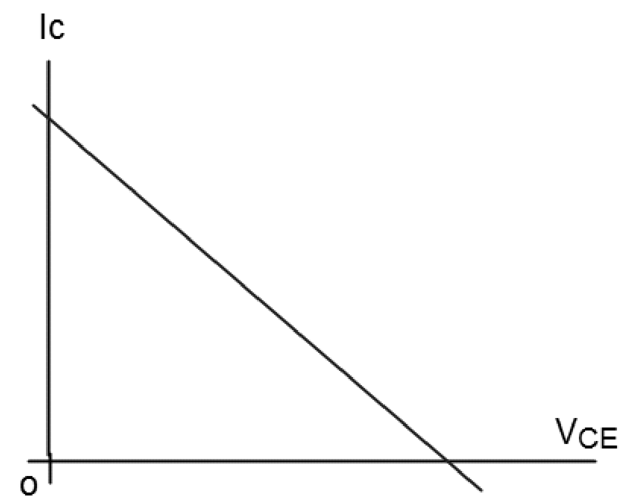
Polarización por división de voltaje

1. Fuente de alimentación (V_{CC})
2. Elección del transistor
   - $I_{c_{sat_t}}$
   - β_{DC}
3. $1/4\ I_{c_{sat_t}} \leq I_{c_{sat_c}} \leq 1/2\ I_{c_{sat_t}}$
   - $I_{c_{sat_c}} = \dfrac{Vcc}{R_c + R_E}$
4. $I_{CQ} = 1/2\ I_{C_{SAT_C}}$; $V_{CEQ} = 1/2\ V_{CC}$
5. $1/10\ V_{CC} \leq V_E \leq 1/4\ V_{CC}$
6. $R_E = \dfrac{V_E}{I_E}$ donde $I_E \cong I_{CQ}$
7. $\beta R_E \geq 10R_2$
8. $V_B = V_E + V_{BE} = \dfrac{R_2 V_{CC}}{R_1 + R_2}$

Polarización por realimentación del colector



Recta de carga de DC

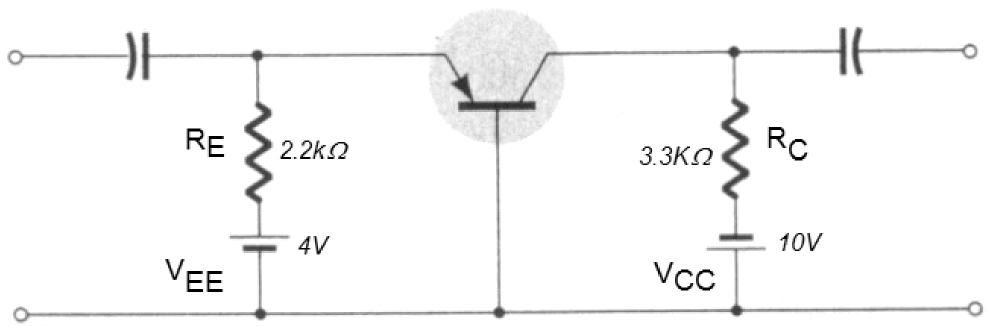


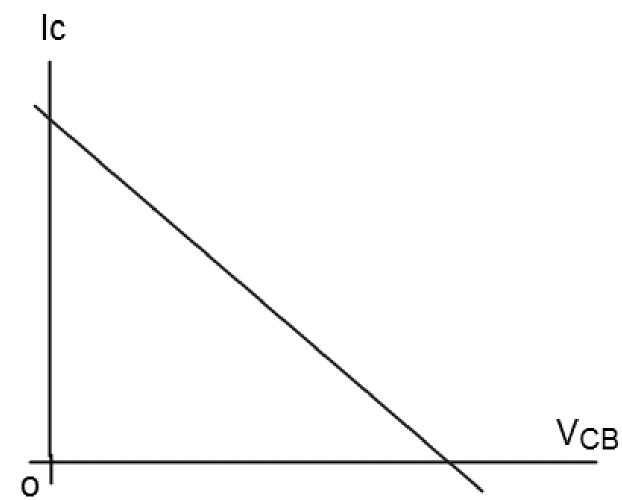
Diseño

Polarización por realimentación del colector

1. Fuente de alimentación (V_{CC})
2. Elección del transistor
   - $I_{c_{sat_t}}$
   - β_{DC}
3. $1/4\ I_{c_{sat_t}} \leq I_{c_{sat_c}} \leq 1/2\ I_{c_{sat_t}}$
   - $I_{c_{sat_c}} = \dfrac{Vcc}{R_c + R_E}$
4. $I_{CQ} = 1/2\ I_{C_{SAT_C}}$; $V_{CEQ} = 1/2\ V_{CC}$
5. $1/10\ V_{CC} \leq V_E \leq 1/4\ V_{CC}$
6. $R_E = \dfrac{V_E}{I_E}$ donde $I_E \cong I_{CQ}$
7. $\beta = \dfrac{I_{CQ}}{I_B}$
7. $I_B = \dfrac{V_{CC} - V_{BE}}{R_F + \beta(R_E + R_C)}$

Base común
(PNP)





Diseño

Polarización en base común

1. Fuente de alimentación (V_{CC} y V_{EE})

2. Elección del transistor

- $I_{C_{sat_t}}$
- β_{DC}

3. $1/4\ I_{C_{sat_t}} \leq I_{C_{sat_C}} \leq 1/2\ I_{C_{sat_t}}$

4. $I_{C_{sat_C}} = \dfrac{V_{CC}}{R_C}$

5. $I_{CQ} = 1/2\ I_{C_{sat_C}}$
   $V_{CB} = 1/2\ V_{CC}$

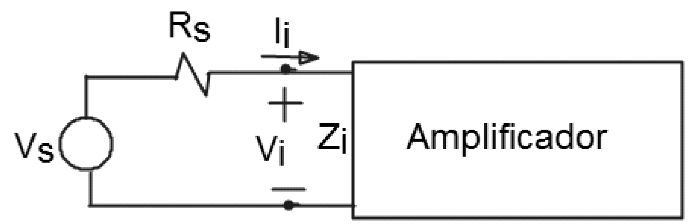
6. $I_E = \dfrac{V_{EE} + V_{BE}}{R_E}$

donde $I_E \cong I_{CQ}$ y $V_{BE} = -0.7V$

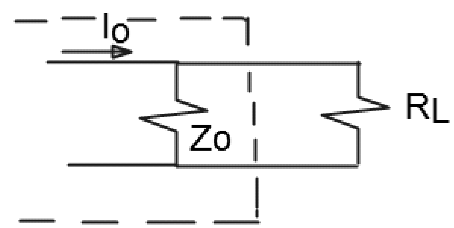
Análisis de señal pequeña ó análisis de AC

Parámetros importantes

Impedancia de entrada Z_i



Impedancia de salida Z_o

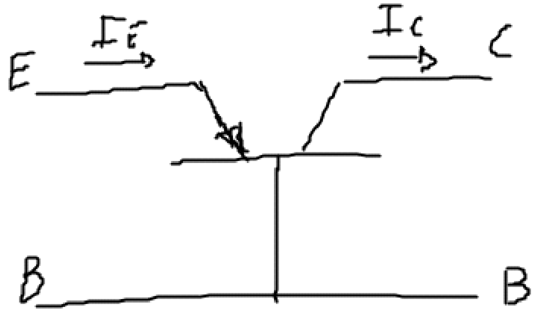


Ganancia de voltaje A_v

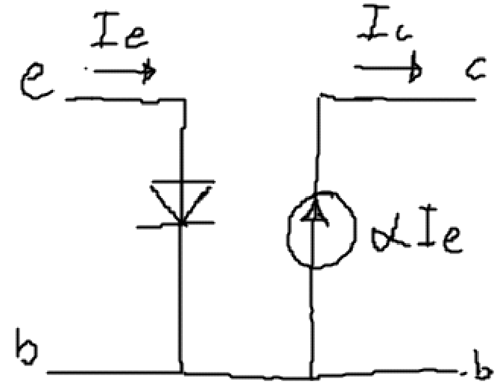
Ganancia de corriente A_i

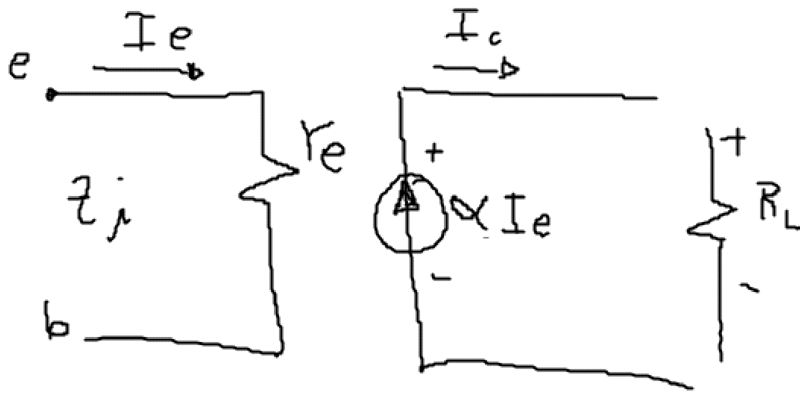
Modelo r_e del transistor TBJ

Base común



$\cong$





$$\boxed{Z_i = r_e}$$

$$\boxed{Z_o = \infty\,\Omega}$$

donde $r_e = \dfrac{26\,mV}{I_E}$

$A_v = \dfrac{V_o}{V_i}$

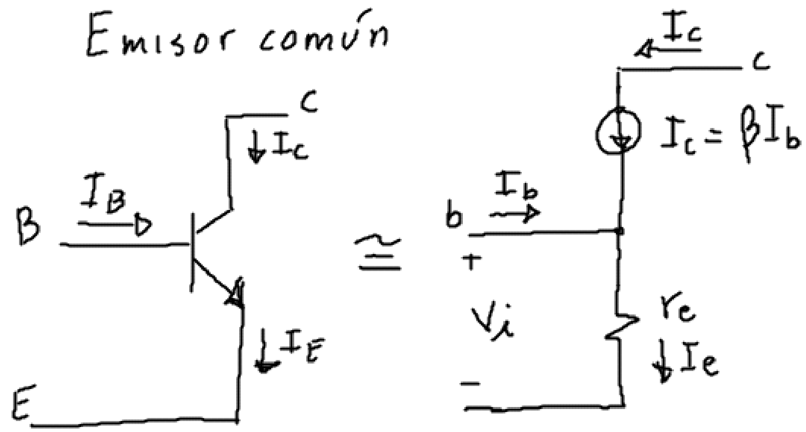
$$A_v = \frac{V_o}{V_i} = \frac{I_o Z_o}{I_i Z_i} = \frac{I_c Z_o}{I_e r_e} = \frac{\alpha I_e Z_o}{I_e r_e}$$

$$\boxed{A_v = \alpha \frac{Z_o}{r_e} \cong \frac{Z_o}{r_e}}$$

$$A_i = -\frac{I_o}{I_i} = -\frac{I_c}{I_e} = -\frac{\alpha I_e}{I_e} = -\alpha$$

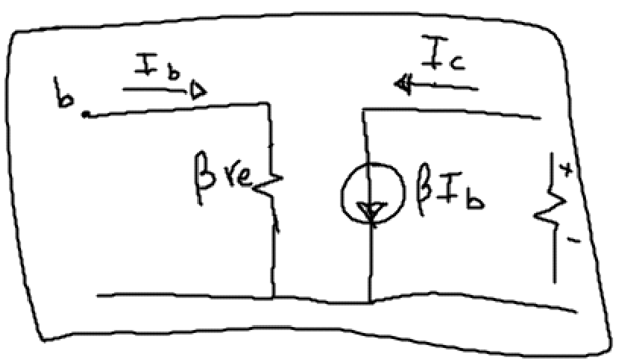
$$\boxed{A_i \cong -1}$$

Emisor común



$$I_e = I_b + \beta I_b$$

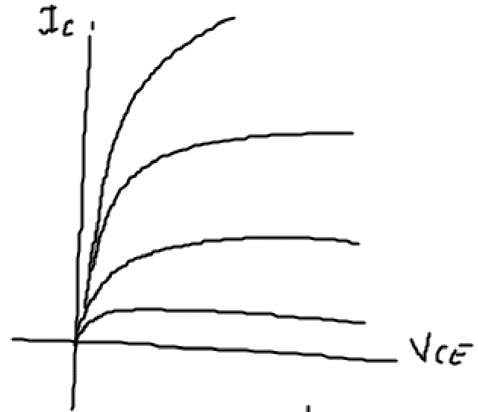
$$I_e = I_b(\beta + 1) \cong \beta I_b$$



$$\boxed{Z_i = \beta r_e}$$

$$\boxed{Z_o = r_o \cong \infty\,\Omega}$$

$$A_v = -\frac{V_o}{V_i} = -\frac{\beta I_b Z_o}{I_b \beta r_e}$$

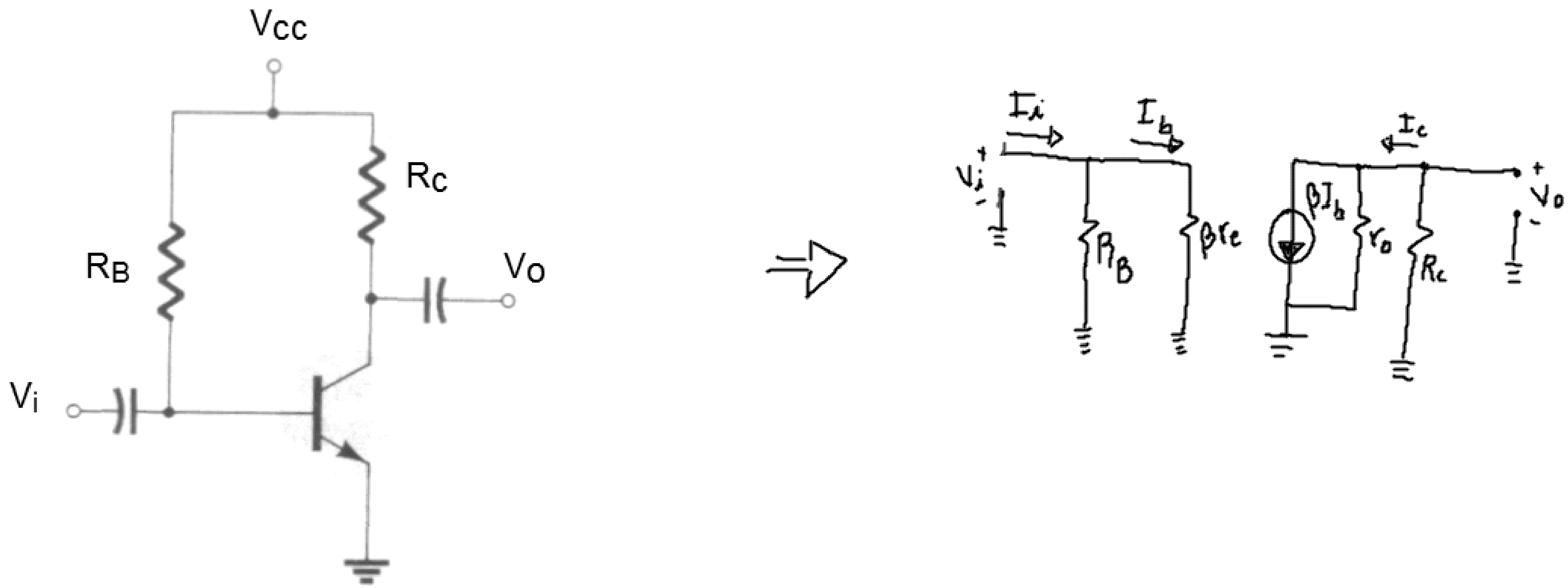


$$r_o = \frac{1}{\text{pendiente}}$$

$$\boxed{A_v = -\frac{Z_o}{r_e}}$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{I_c}{I_b} = \frac{\beta I_b}{I_b} = \beta}$$

Polarización Fija



$$\boxed{Z_i = R_B \| \beta r_e}$$

$$Z_o = r_o \| R_c \quad \text{si} \quad r_o >> R_c$$
$$(r_o > 10R_c)$$

$$\boxed{Z_o \cong R_c}$$

$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{\beta I_b (r_o \| R_c)}{I_b \beta r_e} = -\frac{r_o \| R_c}{r_e}}$$

si $r_o >> R_c$

$$\boxed{A_v \cong -\frac{R_c}{r_e}}$$

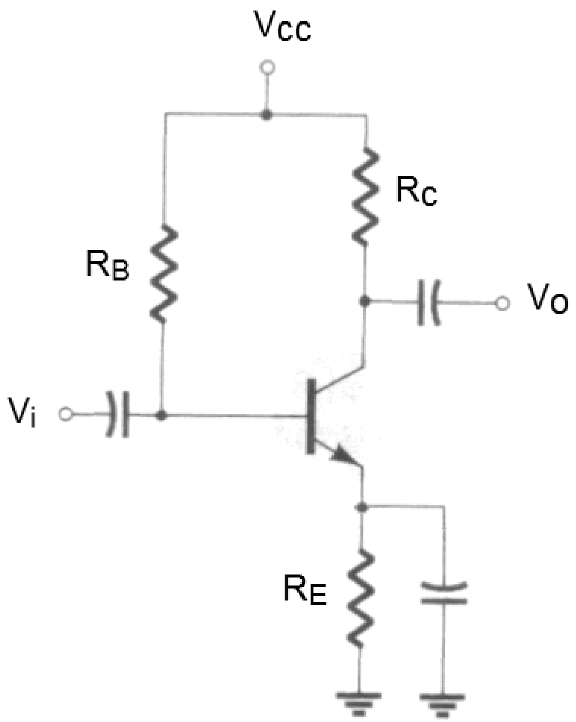
$$A_i = \frac{I_o}{I_i} = \frac{\beta I_b}{\frac{V_i}{Z_i}} = \frac{\beta I_b}{\frac{I_b \beta r_e}{R_B \| \beta r_e}} = \frac{\beta I_b (R_B \| \beta r_e)}{I_b \beta r_e}$$

$$\boxed{A_i = \frac{R_B \| \beta r_e}{r_e}}$$

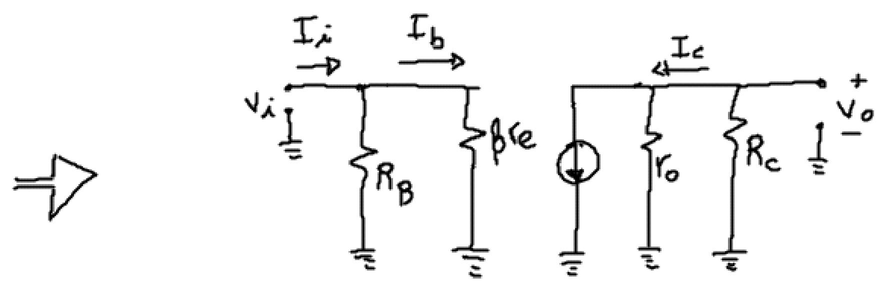
si $R_B >> \beta r_e$

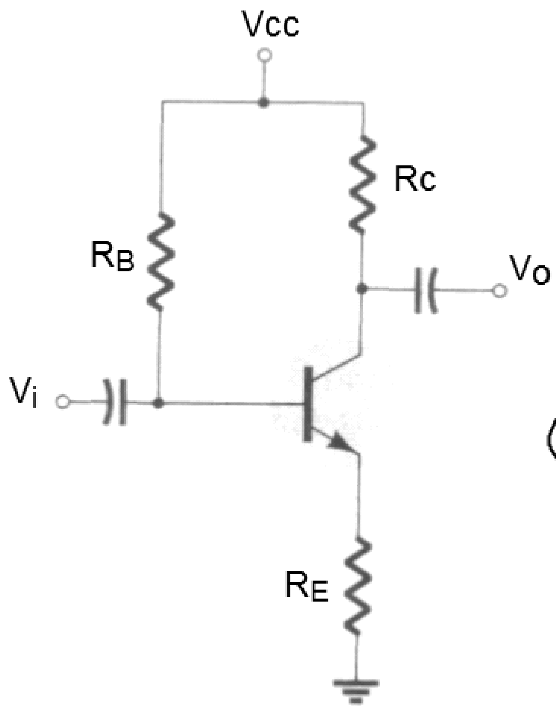
entonces $\boxed{A_i \cong \frac{\beta r_e}{r_e} = \beta}$

Polarización estabilizada en emisor

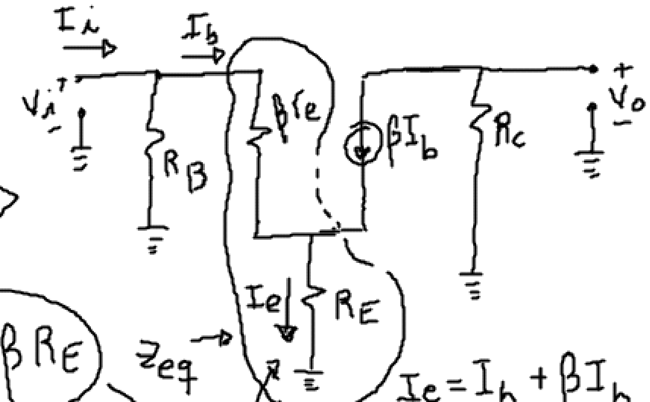


Caso A





Caso B



$V_E = I_b \beta R_E$

$Z_i = R_B \parallel Z_{eq}$

$I_e = I_b + \beta I_b$

$I_e = I_b(\beta + 1) \cong I_b \beta$

$I_e \cong \beta I_b$

donde

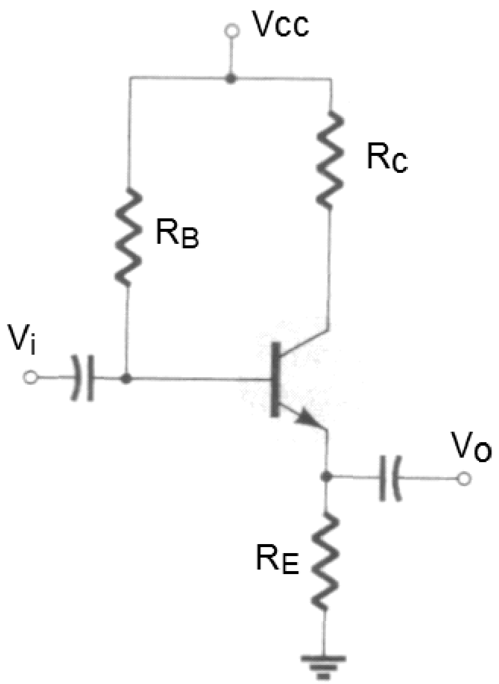
$$Z_{eq} = \beta r_e + \beta R_E = \beta(r_e + R_E)$$

$$\boxed{Z_o = R_C}$$

$$\boxed{A_v = -\frac{V_o}{V_i} = -\frac{\beta I_b R_C}{\beta I_b (r_e + R_E)} = -\frac{R_C}{r_e + R_E}}$$

$$A_i = \frac{I_o}{I_i} = \frac{\beta I_b}{\frac{V_i}{Z_i}} = \frac{\beta I_b}{\frac{\beta I_b (r_e + R_E)}{R_B \| \beta (r_e + R_E)}} =$$

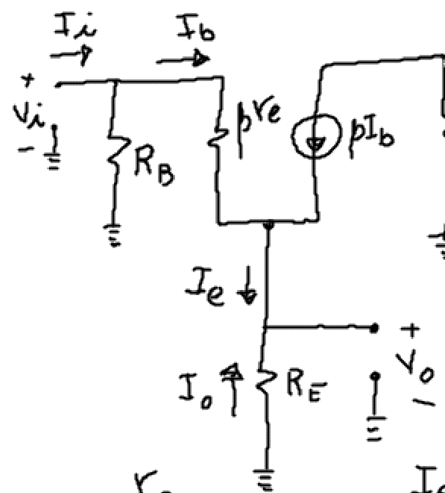
$$\boxed{A_i = \frac{R_B \| \beta (r_e + R_E)}{r_e + R_E}}$$



Emisor seguidor
Caso C

$I_b \beta r_e$

$\Rightarrow$



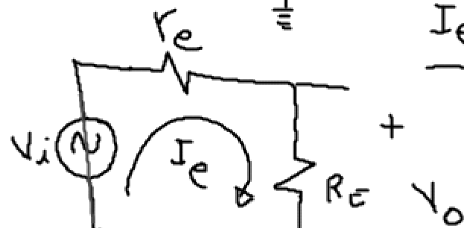
$I_e R_E$

$\underline{I_e = \beta I_b}$

$$\boxed{Z_i = R_B \| Z_{eq}}$$

donde

$$Z_{eq} = \beta (r_e + R_E)$$



$$\boxed{Z_o = r_e \| R_E}$$

$$A_v = \frac{V_o}{V_i} = \frac{I_e R_E}{I_b \beta (r_e + R_E)} = \frac{\beta I_b R_E}{\beta I_b (r_e + R_E)} = \frac{R_E}{r_e + R_E}$$

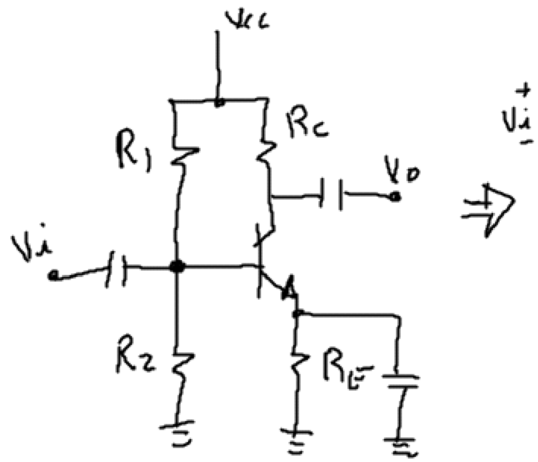
si $R_E >> r_e$

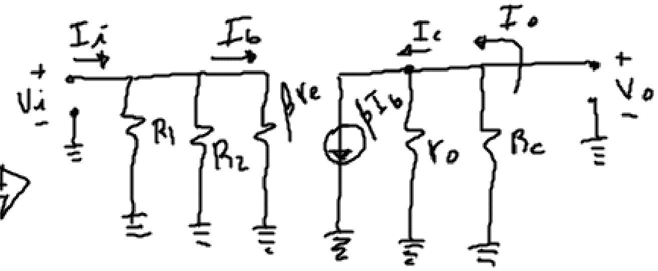
$$\boxed{A_v \cong \frac{R_E}{R_E} = 1}$$

$$A_i = \frac{I_o}{I_i} = -\frac{I_e}{\frac{V_i}{Z_i}} = -\frac{\beta I_b}{\frac{\beta I_b (r_e + R_E)}{R_B \| \beta (r_e + R_E)}} =$$

$$\boxed{A_i = -\frac{\beta R_B}{R_B + \beta (r_e + R_E)}}$$

Polarización por división de voltaje





$$Z_i = R_1 \| R_2 \| \beta r_e$$

$$Z_o = r_o \| R_c$$

$$A_v = -\frac{V_o}{V_i} = -\frac{I_o (r_o \| R_c)}{I_b \beta r_e}$$

$$A_v = -\frac{\beta I_b (r_o \| R_c)}{I_b \beta r_e} =$$

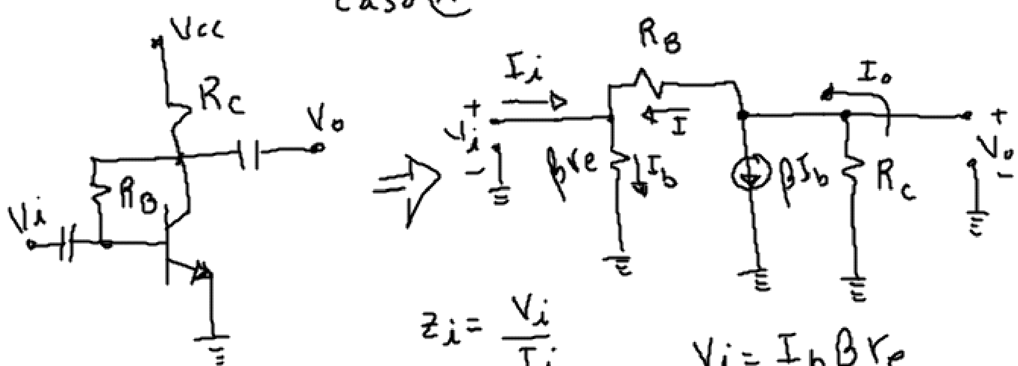
$$\boxed{A_v = -\frac{r_o \| R_c}{r_e}} \quad \text{si} \quad r_o >> R_c \quad \boxed{A_v \cong -\frac{R_c}{r_e}}$$

$$A_i = \frac{I_o}{I_i} = \frac{\beta I_b}{\frac{V_i}{Z_i}} = \frac{\beta I_b}{\frac{I_b \beta r_e}{R_1 \| R_2 \| \beta r_e}} = \frac{R_1 \| R_2 \| \beta r_e}{r_e}$$

Realimentación de voltaje

Realimentación de voltaje

caso A



$$z_i = \frac{V_i}{I_i}$$

$$V_i = I_b \beta r_e$$

$$I_b = I_i + I$$

$$I_i = I_b - I$$

$$V_o = -\beta I_b R_c$$

$$V_{R_B} = V_o - V_i = I R_B$$

$$I = \frac{V_o - V_i}{R_B} = \frac{-\beta I_b R_c - I_b \beta r_e}{R_B}$$

$$z_i = \frac{V_i}{I_i} = \frac{I_b \beta r_e}{I_b - I} = \frac{I_b \beta r_e}{I_b + \frac{\beta I_b R_c + I_b \beta r_e}{R_B}}$$

$$\boxed{z_i = \frac{I_b \beta r_e R_B}{I_b R_B + \beta I_b R_c + I_b \beta r_e} = \frac{\beta r_e R_B}{R_B + \beta (R_c + r_e)}}$$

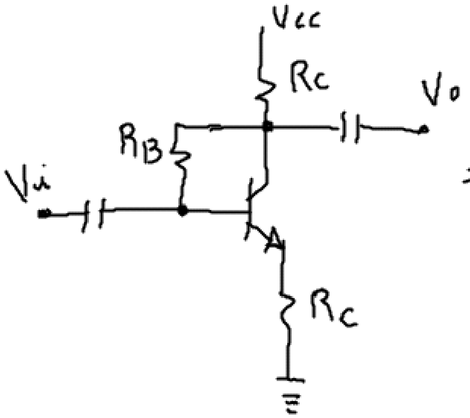
$$\boxed{z_o = R_B \| R_c}$$

$$\boxed{A_v = -\frac{V_o}{V_i} = -\frac{\beta I_b R_c}{I_b \beta r_e} = -\frac{R_c}{r_e}}$$

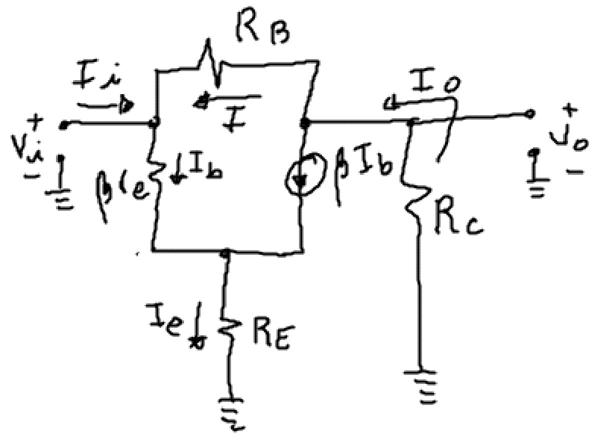
$$A_i = \frac{I_o}{I_i} = \frac{\beta I_b}{I_b - I} = \frac{\beta I_b R_B}{I_b R_B + \beta I_b R_c + I_b \beta r_e}$$

$$\boxed{A_i = \frac{\beta R_B}{R_B + \beta(R_c + r_e)}}$$

Caso B



$\Rightarrow$



$$Z_i = \frac{V_i}{I_i}$$

$$V_i = I_b \beta r_e + \beta I_b R_E$$

$$V_i = I_b \beta (r_e + R_E)$$

$$I_b = I_i + I$$

$$I_i = I_b - I$$

$$V_o = -\beta I_b R_C$$

$$I = \frac{V_o - V_i}{R_B} = \frac{-\beta I_b R_C - I_b \beta (r_e + R_E)}{R_B}$$

$$Z_i = \frac{V_i}{I_i} = \frac{I_b \beta (R_E + r_e)}{I_b - I} = \frac{I_b \beta (r_e + R_E) R_B}{I_b R_B + \beta I_b R_C + I_b \beta (r_e + R_E)}$$

$$\boxed{Z_i = \frac{\beta (r_e + R_E) R_B}{R_B + \beta (R_C + R_E + r_e)}}$$

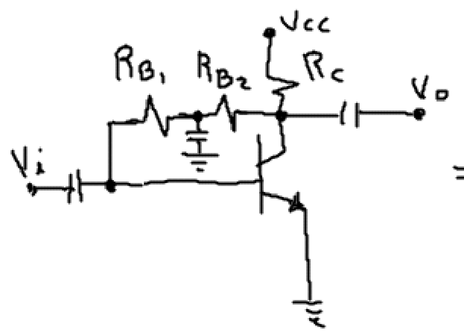
$$\boxed{Z_o = R_B \| R_C}$$

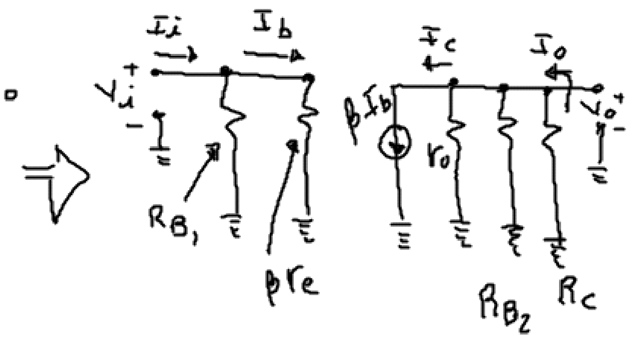
$$\boxed{A_v = -\frac{V_o}{V_i} = -\frac{\beta I_b R_C}{I_b \beta (r_e + R_E)} = -\frac{R_C}{r_e + R_E}}$$

$$A_i = \frac{I_o}{I_i} = \frac{\beta I_b}{I_b - I} = \frac{\beta I_b R_B}{I_b R_B + \beta I_b R_C + I_b \beta (r_e + R_E)}$$

$$\boxed{A_i = \frac{\beta R_B}{R_B + \beta (R_C + R_E + r_e)}}$$

Caso C





$$\boxed{Z_i = R_{B_1} \| \beta r_e}$$

$$\boxed{Z_o = r_o \| R_{B_2} \| R_C}$$

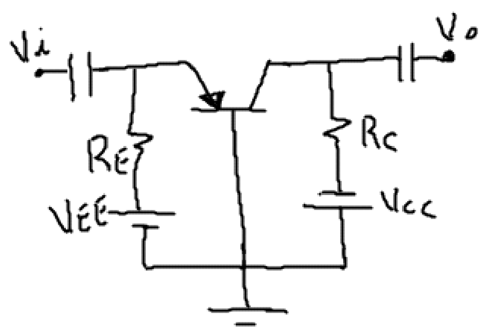
$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{\beta I_b (r_o \| R_{B_2} \| R_C)}{I_b \beta r_e} = -\frac{(r_o \| R_{B_2} \| R_C)}{r_e}}$$

$$A_i = \frac{I_o}{I_i} = \frac{\dfrac{(r_o \| R_{B_2})}{(r_o \| R_{B_2}) + R_C} \beta I_b}{\dfrac{V_i}{Z_i}} = \frac{\dfrac{(r_o \| R_{B_2})}{(r_o \| R_{B_2}) + R_C} \beta I_b}{\dfrac{I_b \beta r_e}{R_{B_1} \| \beta r_e}}$$

$$A_i = \frac{(r_o \| R_{B_2})(R_{B_1} \| \beta r_e) \beta I_b}{\left[(r_o \| R_{B_2}) + R_C\right] I_b \beta r_e} = \frac{(r_o \| R_{B_2})(R_{B_1} \| \beta r_e)}{r_e\left[(r_o \| R_{B_2}) + R_C\right]}$$

$$\boxed{A_i = \frac{R_{B_2} R_{B_1} \beta r_o}{(R_{B_1} + \beta r_e)\left[R_{B_2} r_o + R_c (R_{B_2} + r_o)\right]}}$$

Base común (PNP)



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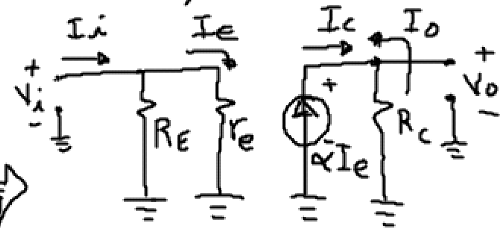

$$\boxed{Z_i = R_E \| r_e}$$

$$\boxed{Z_o = R_c}$$

$$A_v = \frac{V_o}{V_i} = \frac{\alpha I_e R_c}{I_e r_e}$$

$$\boxed{A_v = \alpha \frac{R_c}{r_e} \cong \frac{R_c}{r_e}}$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{-I_c}{\frac{V_i}{Z_i}} = -\frac{\alpha I_e}{\frac{I_e r_e}{R_E \| r_e}} = -\alpha \frac{R_E \| r_e}{r_e}}$$

si $R_E >> r_e$

entonces:

$$\boxed{A_i = \cong -\alpha \frac{r_e}{r_e} = -\alpha \cong 1}$$

Parámetros \ Polarización	EMISOR COMÚN	EMISOR SEGUIDOR	BASE COMÚN
Z_i	$\cong \beta r_e$ $\cong \beta(r_e + R_E)$ (centenas-miles)	$\cong \beta(r_e + R_E)$ (miles)	$\cong r_e$ (decenas)
Z_o	$\cong R_C$ (miles)	$\cong r_e$ (decenas)	$\cong R_C$ (miles)
A_v	$\cong -\frac{R_C}{r_e}$ centenas $\cong -\frac{R_C}{r_e + R_E}$ decenas	$\cong 1$	$\cong \frac{R_C}{r_e}$ centenas
A_i	$\cong \beta$ (decenas-centenas)	$\cong - \beta$ (decenas-centenas)	$\cong - 1$