Etapas amplificadoras básicas con BJT

Electrónica I

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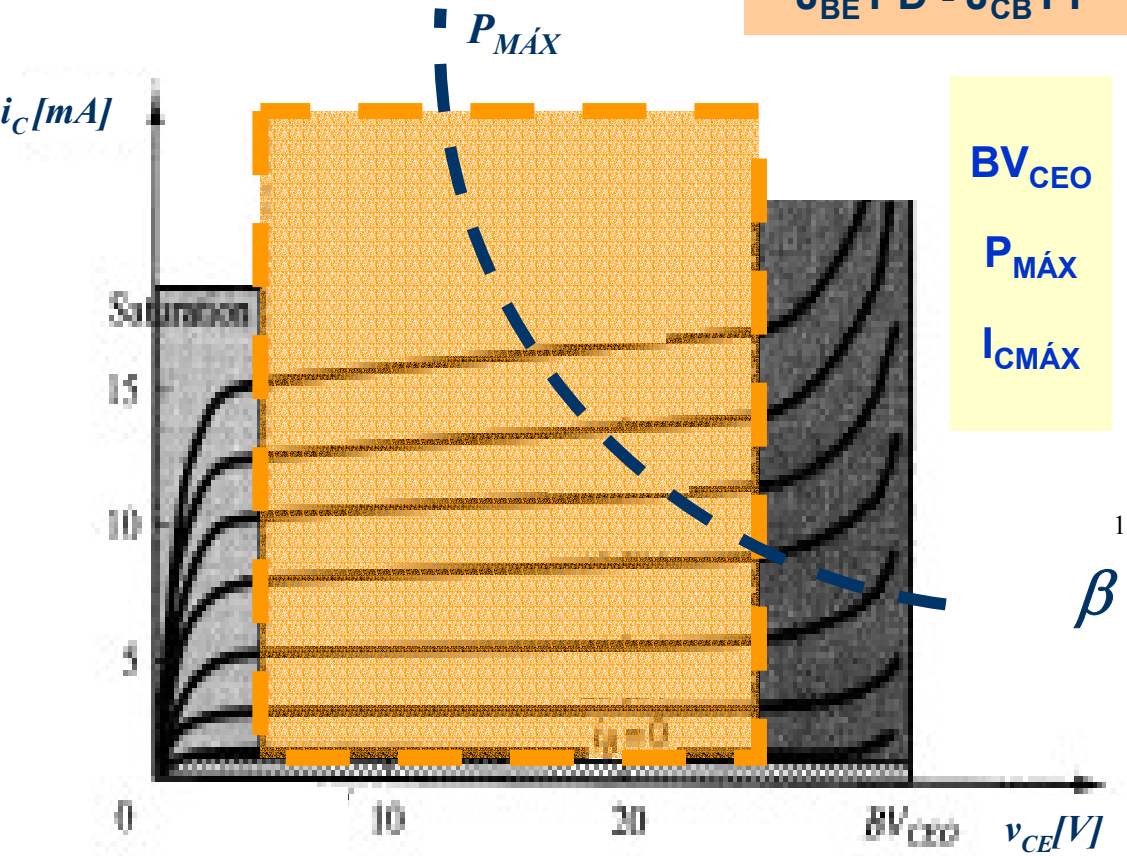
Punto de Trabajo

Zona Activa
J_{BE} PD - J_{CB} PI

Estable e independiente de la dispersión de los parámetros

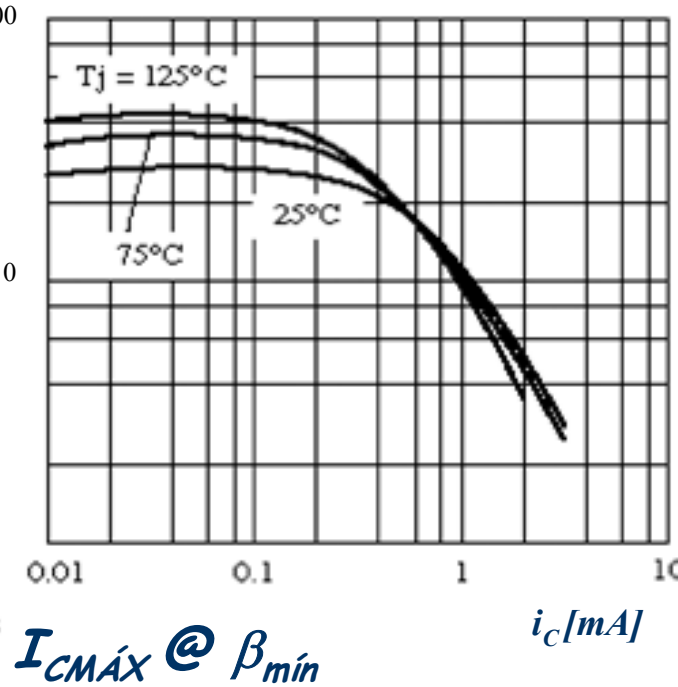
Mínima disipación de potencia



BV_{CEO}

$P_{MÁX}$

$I_{CMÁX}$



$I_{CMÁX}$ @ $\beta_{mín}$

Compatible con la excursión de señal de salida requerida

BJT polarizado

Punto de Trabajo

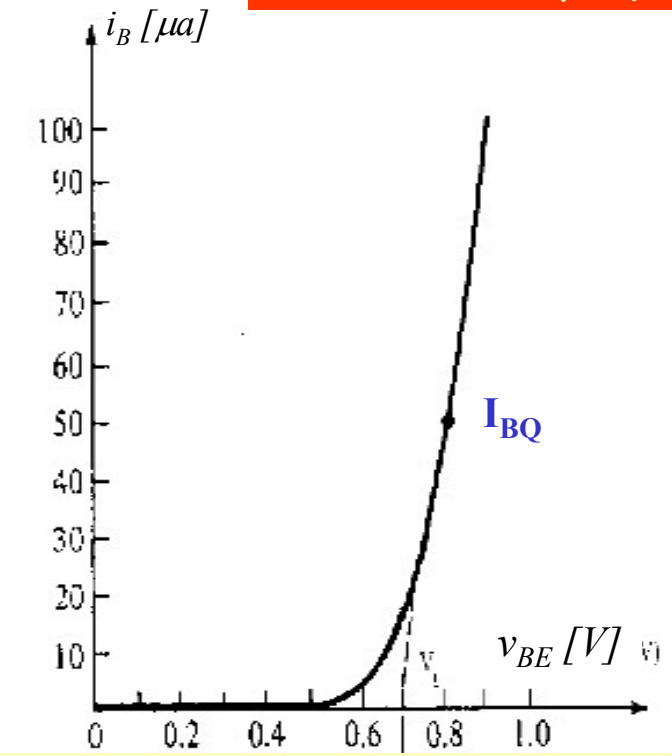
I_{CQ} V_{CEQ}

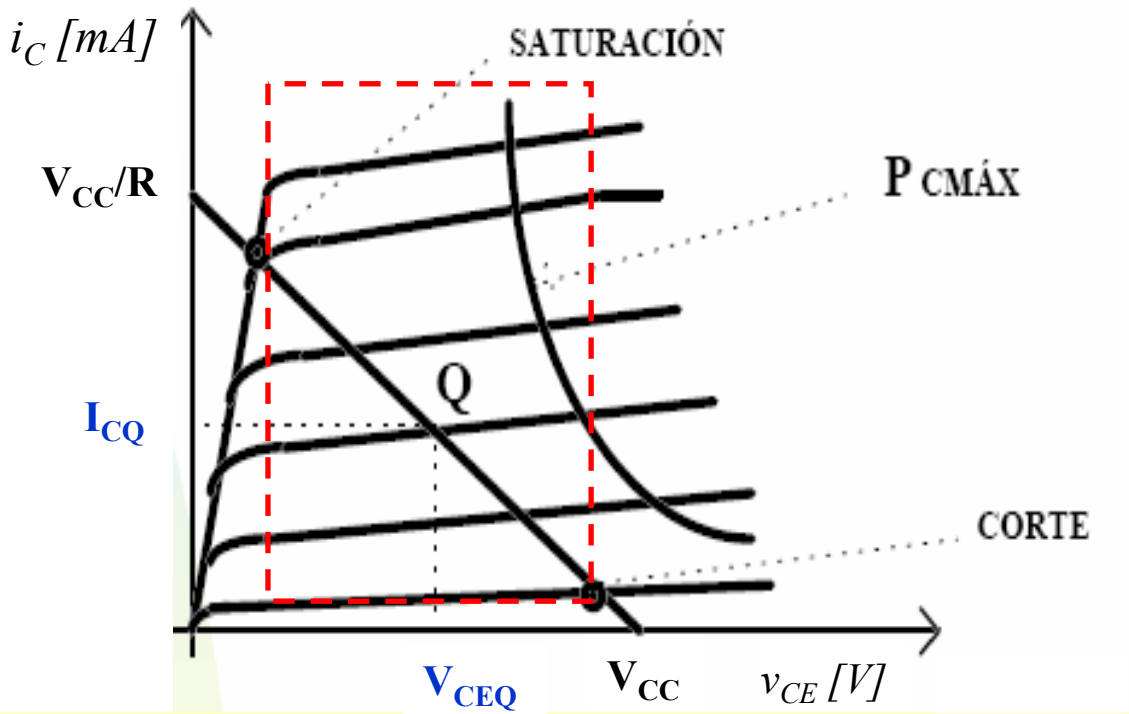
modelo lineal para el BJT

Superposición condicionada alrededor del punto de trabajo

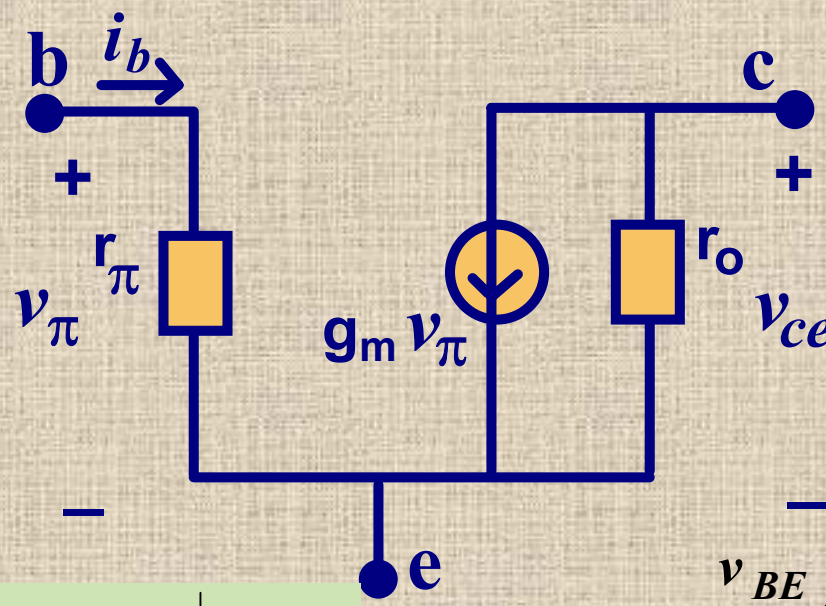
BJT funciona linealmente

modelo en pequeña señal





modelo BJT en pequeña señal



$$r_\pi = \left(\frac{\partial i_b}{\partial v_{be}} \right)^{-1} = \frac{v_\pi}{i_b}$$

$$g_m = \frac{\partial i_c}{\partial v_{be}} = \frac{\beta i_b}{v_{be}} = \beta / r_\pi$$

$$i_C \approx I_s e^{v_{BE}/V_T} = I_s e^{\frac{V_{BE\,Q} + v_{be}}{V_T}} = I_{C_Q} e^{\frac{v_{be}}{V_T}}$$

$$i_C \approx I_{C_Q} + \frac{I_{C_Q}}{V_T} v_{be} + \frac{1}{2!} \frac{I_{C_Q}}{V_T} v_{be}^2 + \Lambda\,\Lambda$$

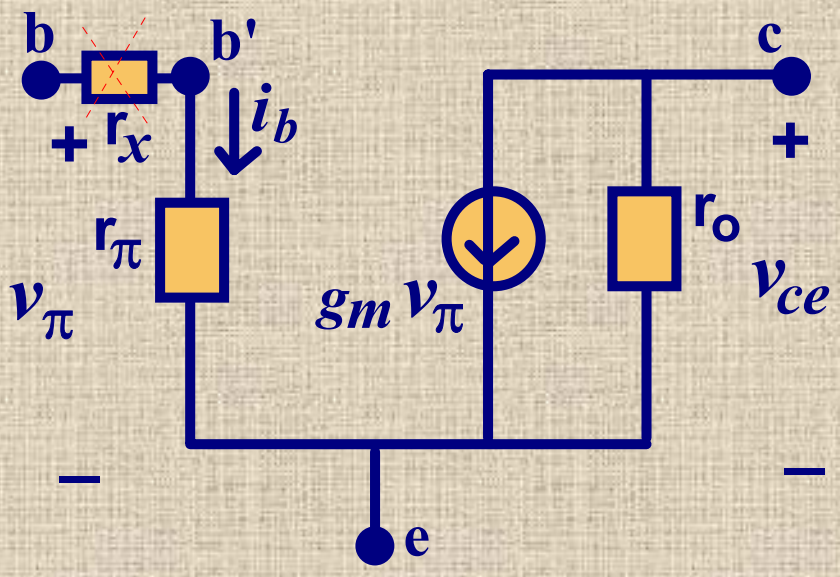
$$i_c \approx \frac{I_{C_Q}}{V_T} v_{be} = g_m v_{be} \Leftrightarrow g_m = \frac{I_{C_Q}}{V_T}$$

$$r_o = \left. \frac{v_{ce}}{i_c} \right|_{V_{CE_Q}}$$

$$r_o = \frac{I_{C_Q}}{-V_A}$$

Tensión Early

BJT en pequeña señal



Si $I_{CQ=}$=1mA $\beta \approx 200$

$z_i \approx 5K\Omega$ $g_m = 0,04A/V$

$$z_{i_{BJT}} = r_\pi = \frac{\beta V_T}{I_{C_Q}}$$

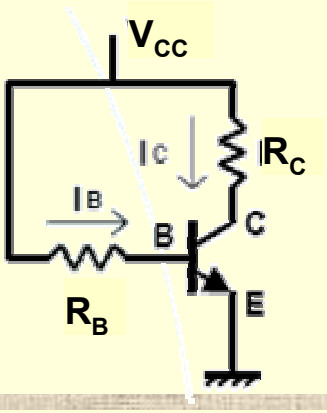
$$g_m r_\pi = \beta$$

$$z_o = r_o = \left(\frac{I_{C_Q}}{-V_A} \right)^{-1}$$

Si $I_{CQ=}$=1mA $V_A \approx$-200V

$z_o \approx 200K\Omega$

$$g_m = \frac{I_{C_Q}}{V_T}$$



recta polarización

$$I_{B_Q} = \left(V_{CC} - V_{BE_Q}\right) / R_B$$

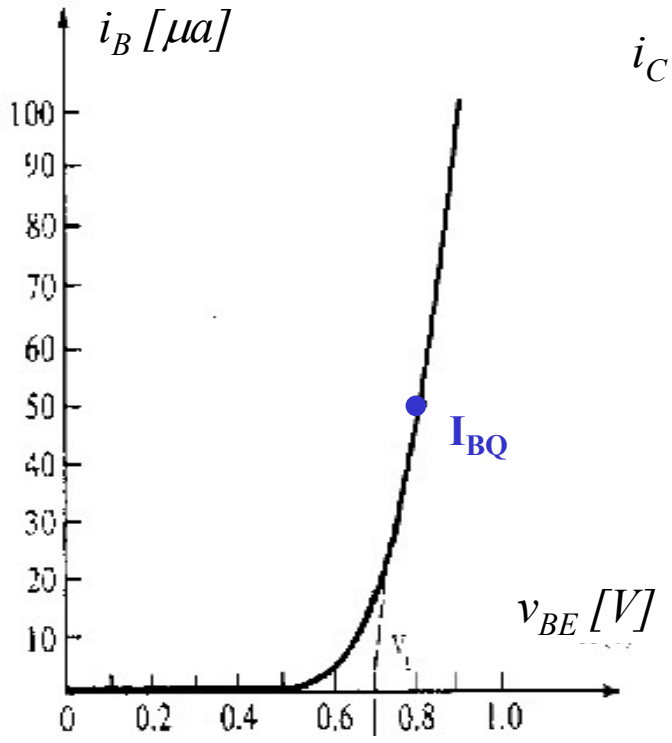
recta de carga

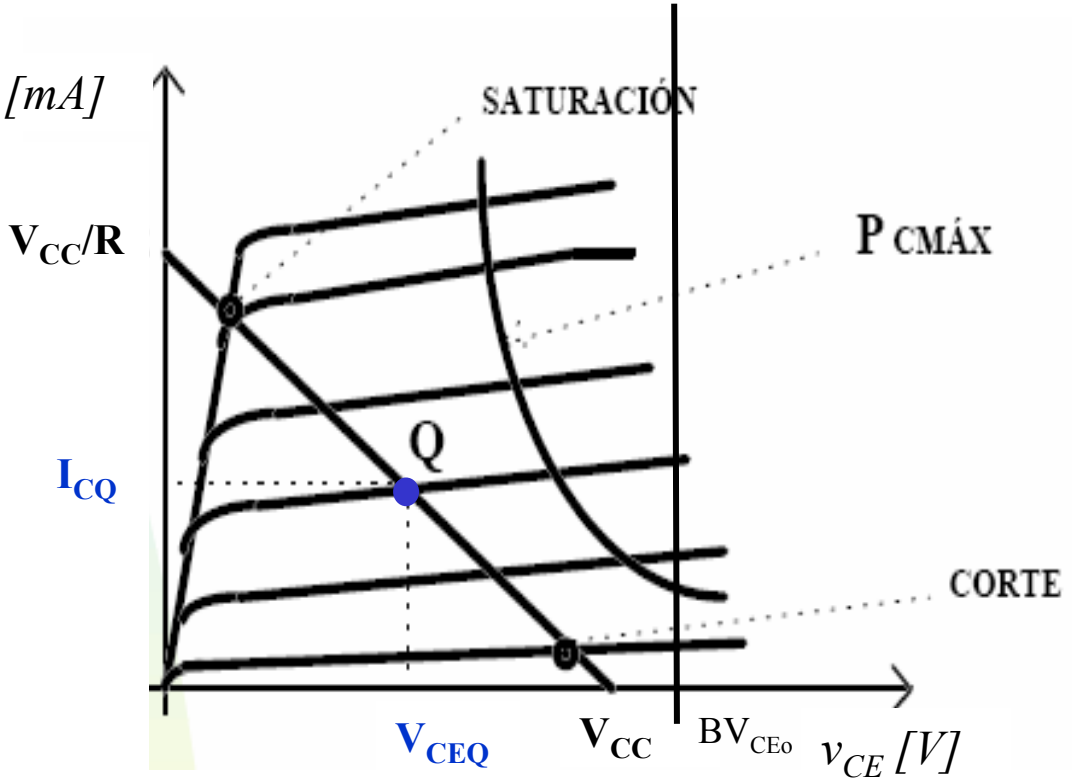
$$I_{C_Q} = \left(V_{CC} - V_{CE_Q}\right) / R_C$$

I_{B_Q}

I_{C_Q}

V_{CE_Q}





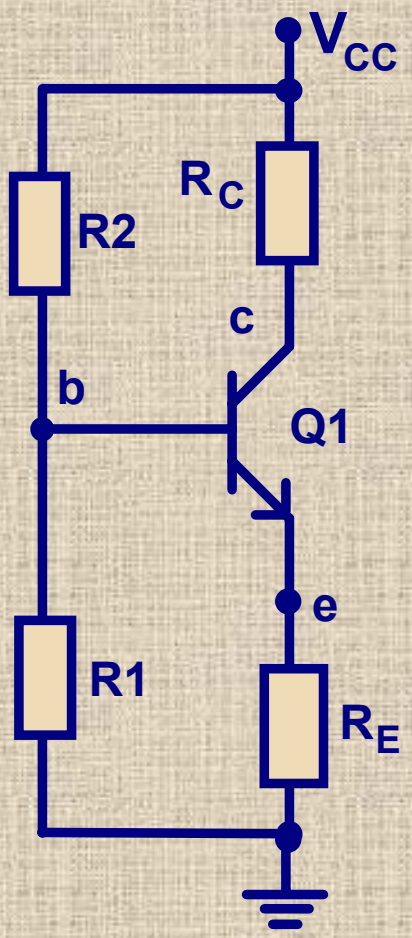
Característica de entrada

Característica de salida

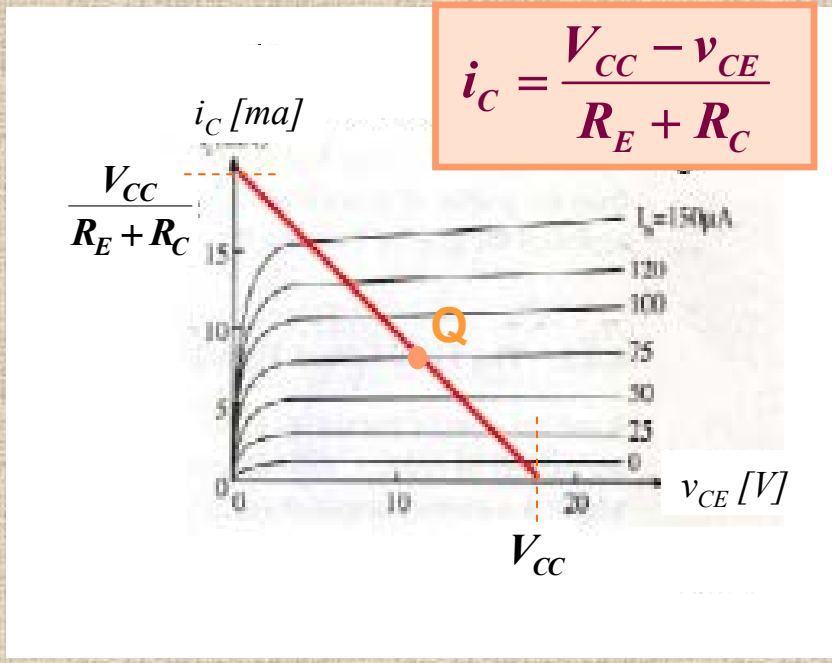
El circuito fija la corriente de emisor

$$I_B = \frac{I_{C_Q}}{\beta}$$

Zona activa



$$i_C = \frac{V_{CC} - v_{CE}}{R_E + R_C}$$



$$I_{E_Q} = \frac{V_{BB} - V_{BE_Q}}{R_E} \approx I_{C_Q}$$

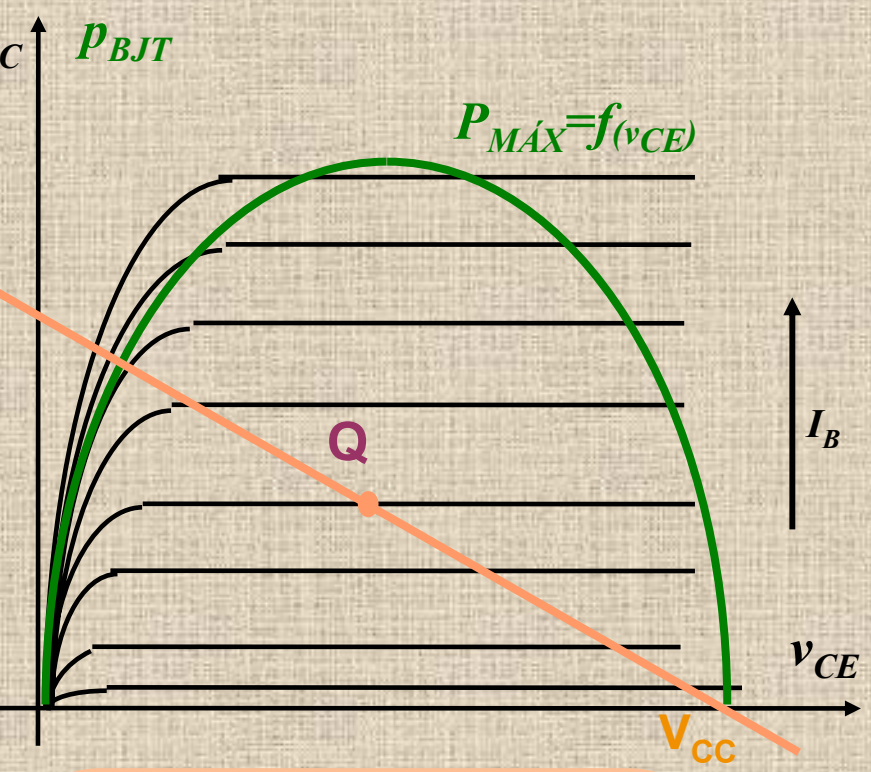
$$V_{BB} = V_{CC} \frac{R_1}{R_1 + R_2}$$

$$I_B << \frac{V_{CC}}{R_1 + R_2}$$

Criterios de Diseño

Selección del punto de trabajo

y elementos del circuito



$$p_{BJT} \approx i_C v_{CE} \approx \frac{V_{CC} - v_{CE}}{R_E + R_C} v_{CE}$$

Si $v_{CE}=V_{cc}/2 \Rightarrow P_{MÁX}$

Si $v_{CE}< V_{cc}/2$
cuando I_C aumenta
P_{BJT} disminuye

Si $v_{CE}> V_{cc}/2$
cuando I_C aumenta
P_{BJT} aumenta

Clase A

$V_{CEQ} \approx V_{CC}/2$

Evita embalamiento térmico, estabiliza punto de trabajo

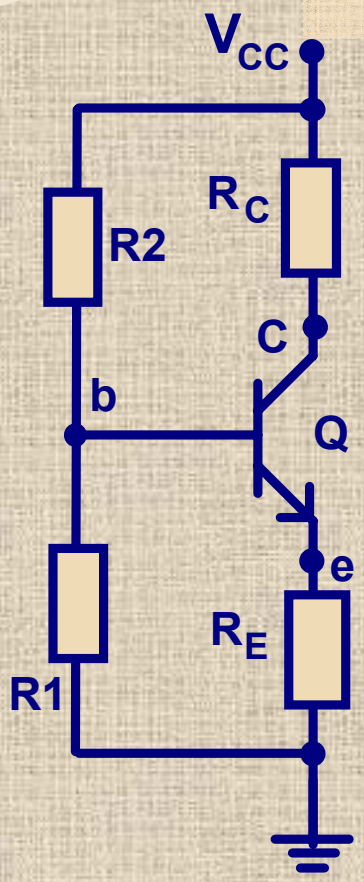
Disipación de Potencia

JT en
ona activa

recta de carga

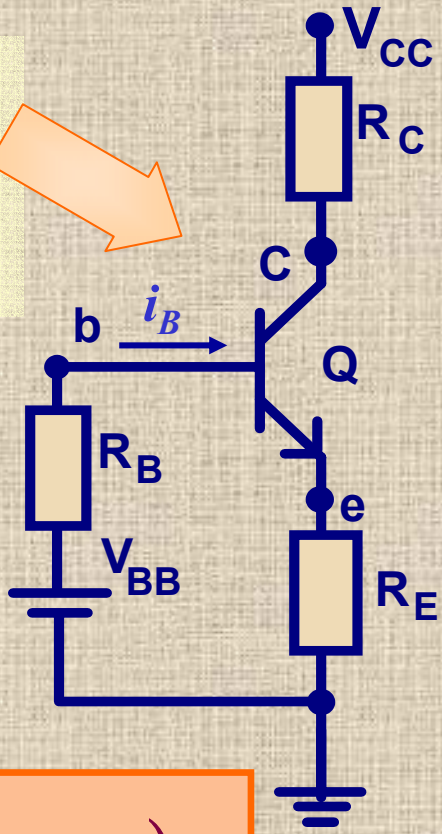
$$i_C = \frac{V_{CC} - v_{CE}}{R_E + R_C}$$

$$i_C = \beta i_B + (\beta + 1) I_{CO} \qquad i_B + i_C = i_E$$



thevenin $R_B = R_1 // R_2$

$$V_{BB} = \frac{V_{CC}}{R_1 + R_2} R_2$$



$$i_B R_B + i_E R_E = V_{BB} - V_{BE}$$

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

si $\beta >> 1$

$R_B << \beta R_E$

$$i_C \approx \frac{(V_{BB} - V_{BE})}{R_E}$$

Independiente características BJT

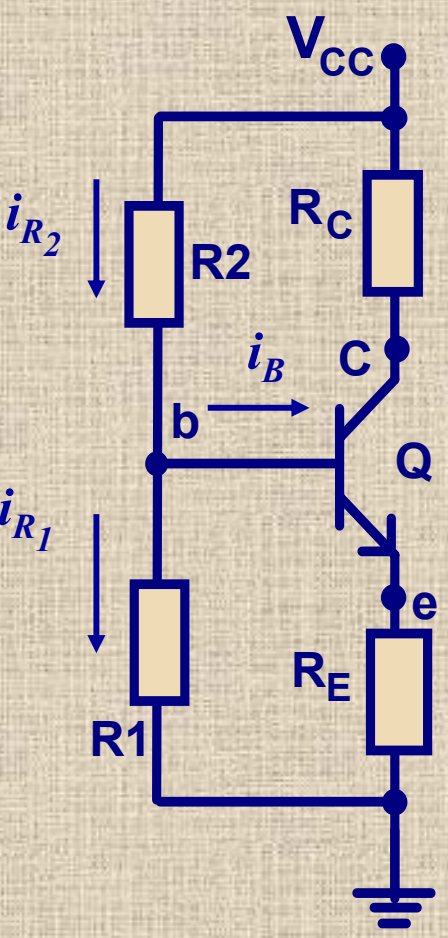
Criterios a tener en cuenta para la polarización

Elección BJT

Adopción V_{CC}

Adopción punto de trabajo I_{CQ}

$V_{CEQ} \approx V_{CC}/2$



$$i_{R_2} = i_B + i_{R_1} \approx i_{R_1}$$

Elegida I_{CQ} considerando $\beta_{mín}$

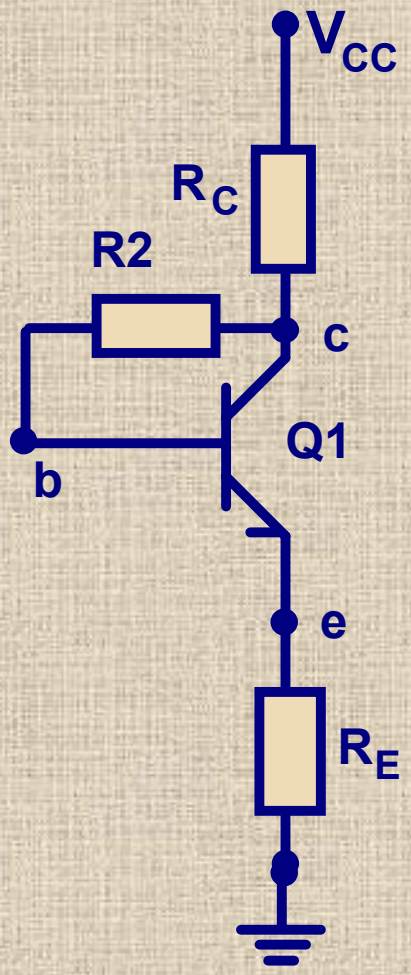
$$I_{B_Q MÁX} = I_{C_Q} / \beta_{mín}$$

$$si\ I_{B_Q\,MÁX} << \frac{V_{CC}}{R_1 + R_2} \approx i_{R_{1,2}} \Rightarrow V_{BB} = \frac{V_{CC} R_2}{R_1 + R_2}$$

$$R_B = R_1 // R_2$$

$$R_B << \beta R_E$$

Otro posible circuito



$$i_C = \frac{V_{CC} - v_{CE}}{R_E + R_C}$$

$$i_C = \beta i_B + (\beta + 1) I_{CO}$$

$$i_C = \frac{\beta}{\beta + 1} i_E$$

$$i_C = \frac{\beta (V_{CC} - V_{BE}) + I_{CO} (\beta + 1) R_2}{R_2 + \beta (R_C + R_E)}$$

Para independencia del β

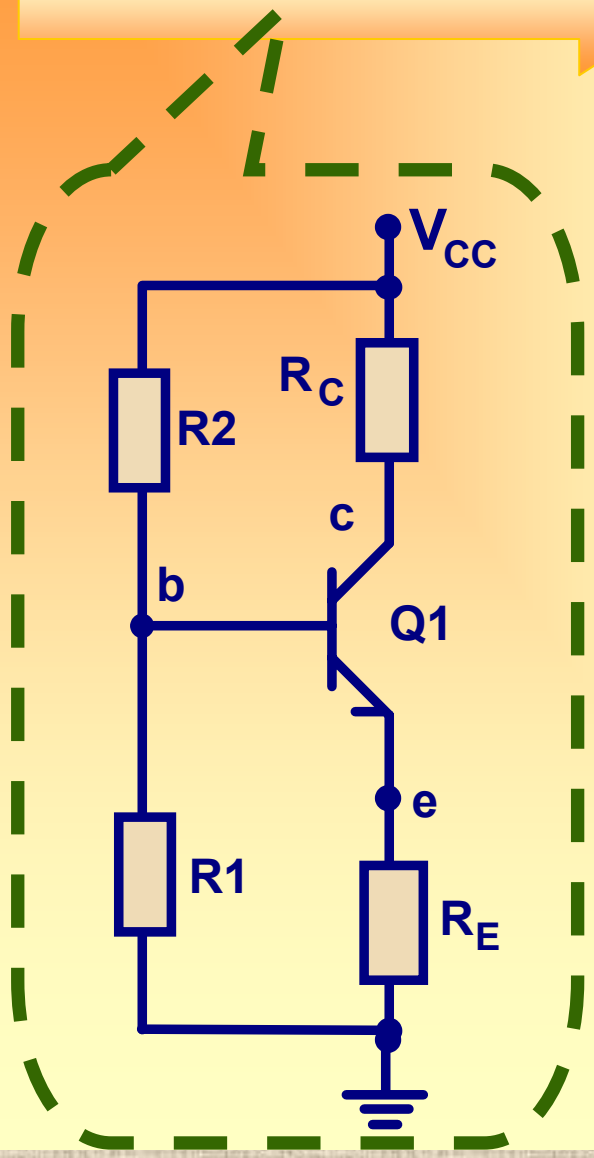
$$R_2 << \beta (R_C + R_E)$$

Difícil cumplimiento

$$R_2 \approx \beta (R_C + R_E)$$

BJT Polarizado

Etapas amplificadoras básicas



terminal de excitación
terminal de salida

Terminal común

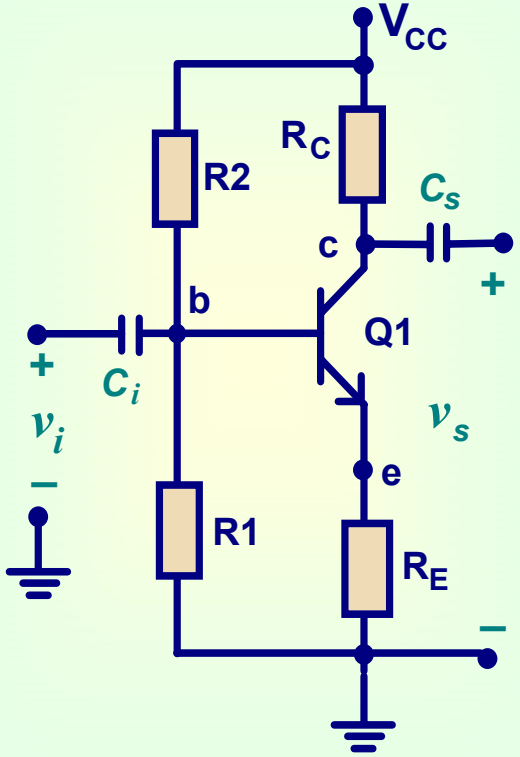
emisor común

base común

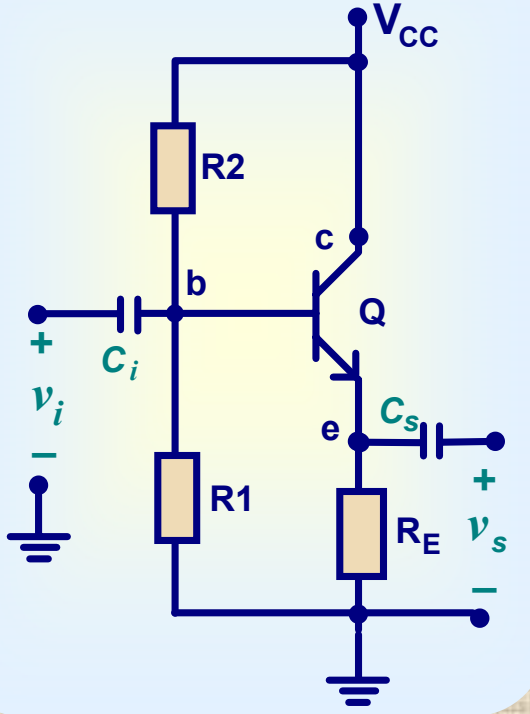
colector común

Etapas básicas amplificadoras

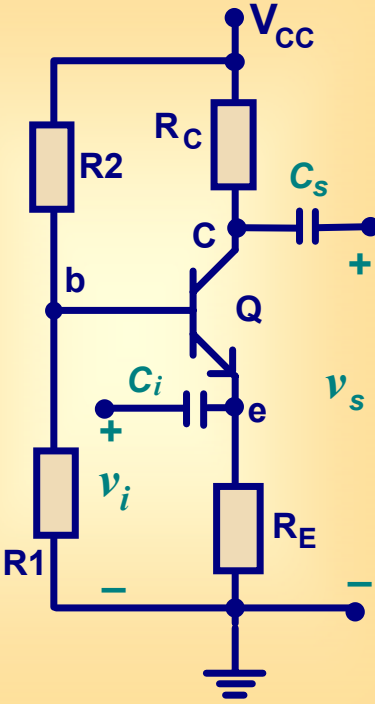
emisor común



colector común



base común

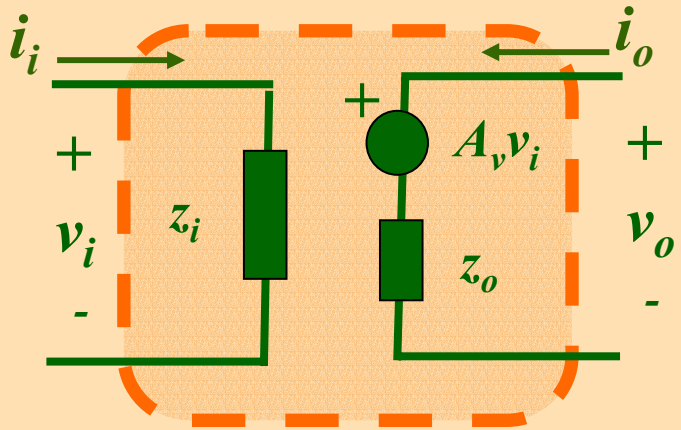


$$A_v = \frac{v_o}{v_i}$$

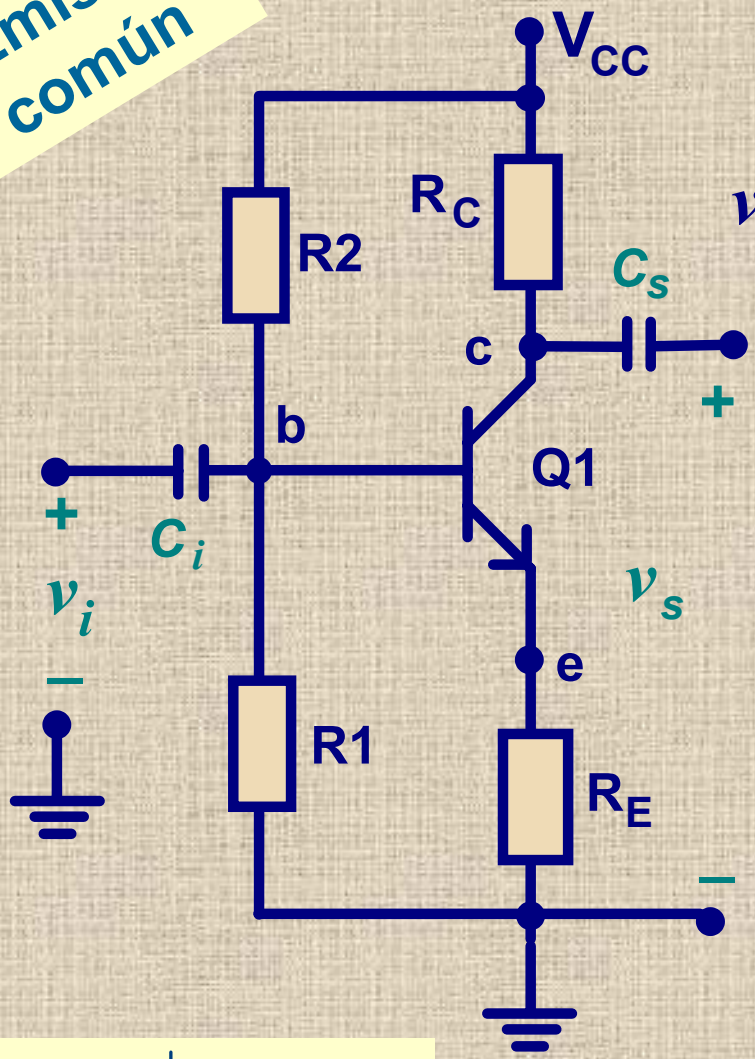
$$A_i = \frac{i_o}{i_i}$$

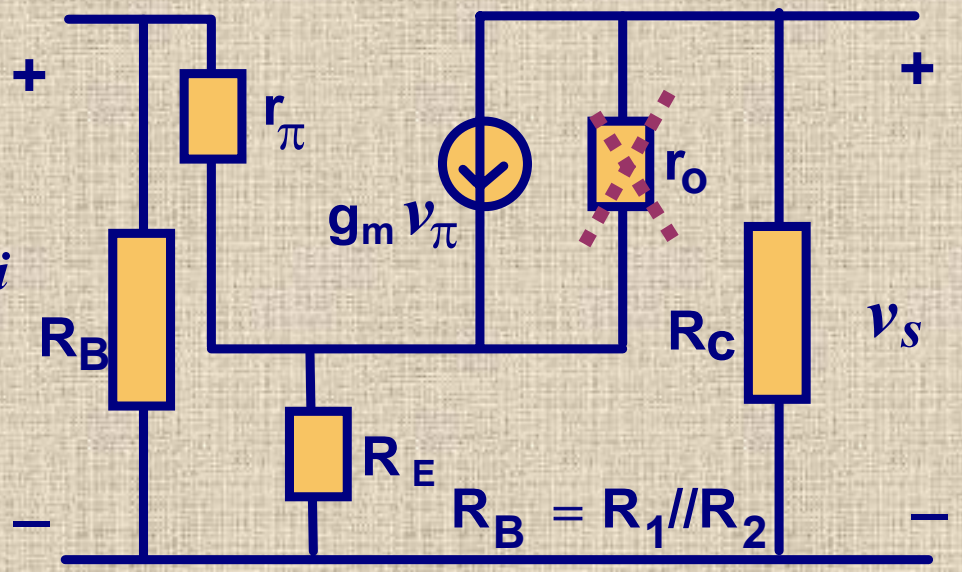
$$z_i = \frac{v_i}{i_i}$$

$$z_o = \left.\frac{v_o}{i_o}\right|_{v_i=0}$$



Emisor común





$$i_c = \frac{v_{ce}}{r_o} + g_m v_\pi \qquad v_o = - i_c R_C$$

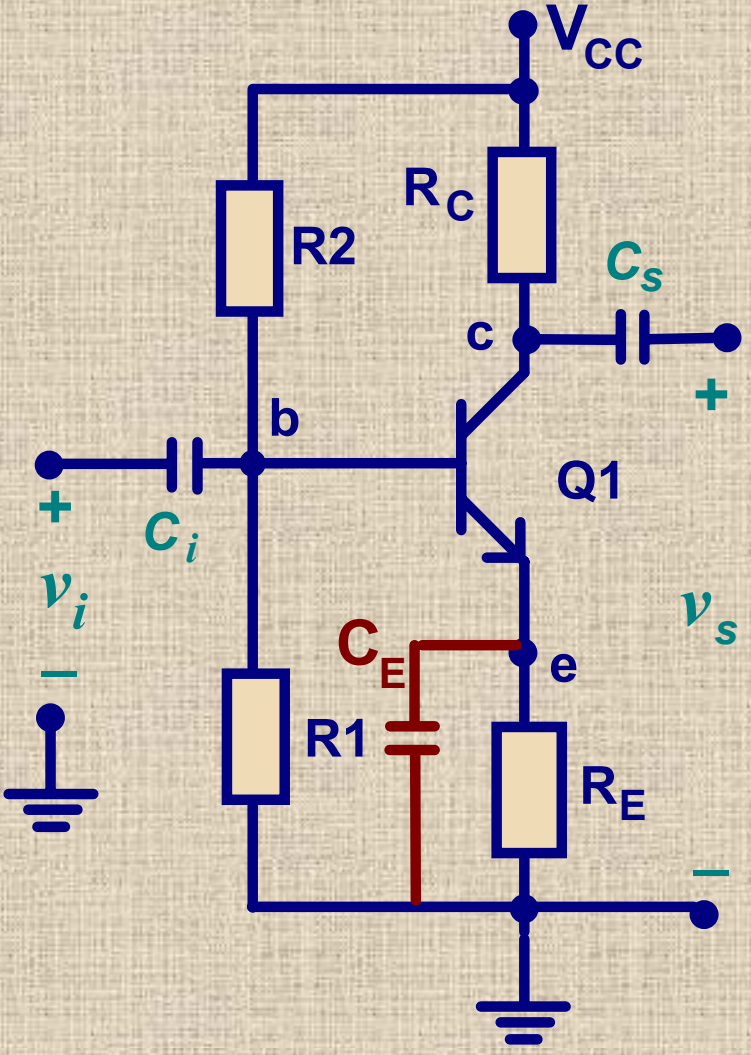
$$v_\pi = v_i - i_c R_E$$

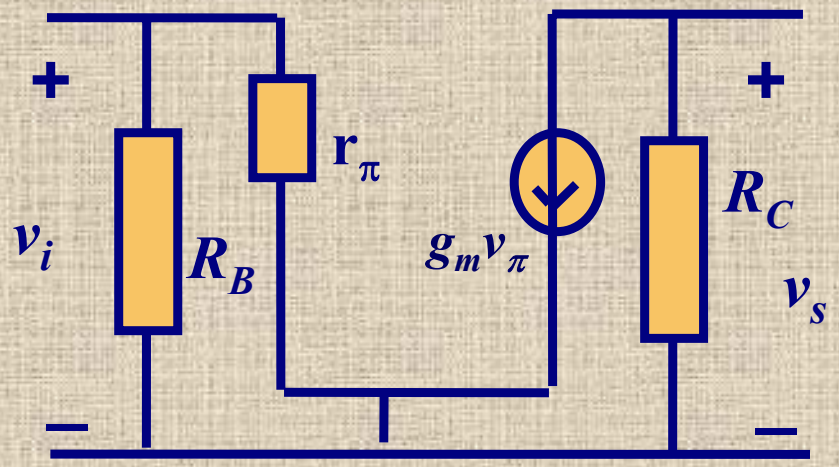
$$A_v \approx -\frac{g_m R_C}{1 + g_m R_E} \approx -\frac{R_C}{R_E}$$

$$z_o = \left.\frac{v_s}{i_s}\right|_{v_i = 0} \approx R_C$$

$$z_i \approx R_B // r_\pi \left(1 + g_m R_E\right) \approx R_B$$

Emisor común con capacitor de emisor



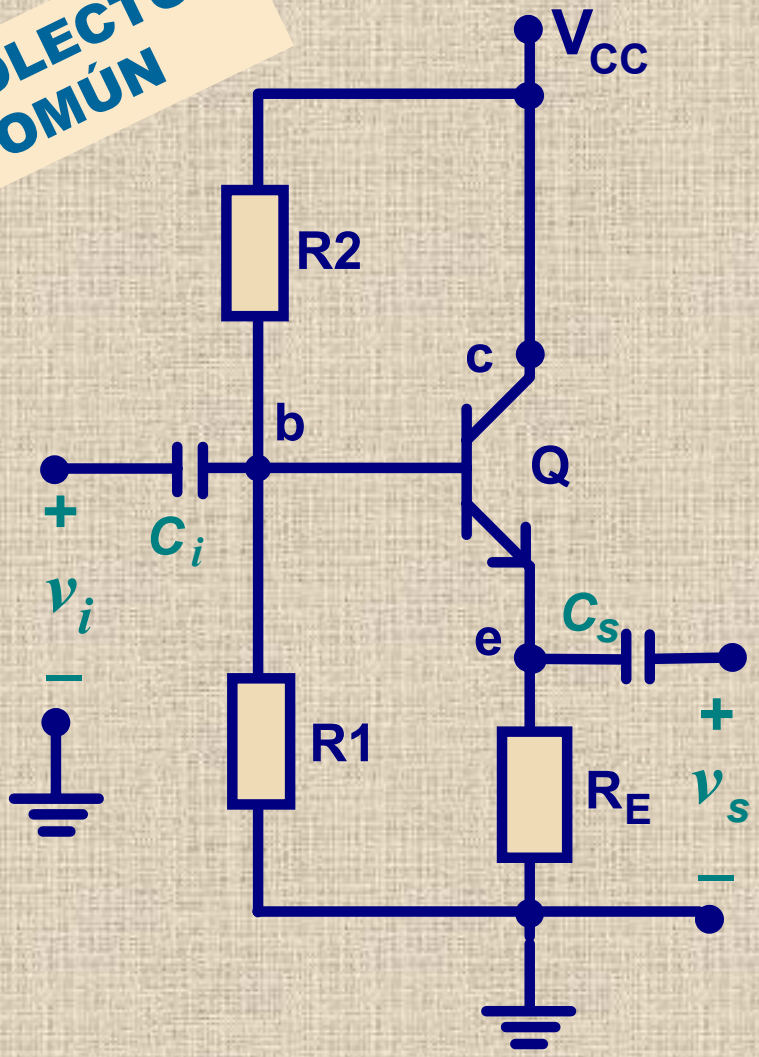


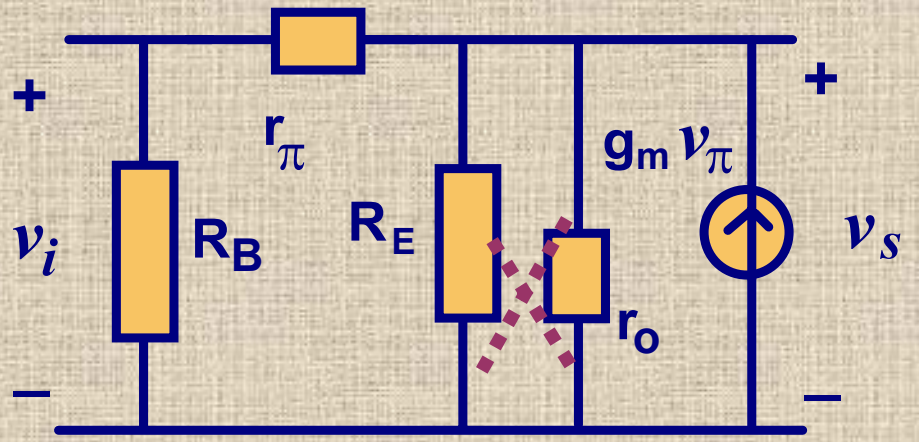
$$A_v \approx -g_m R_c$$

$$z_i \approx R_B \,//\, r_\pi \approx r_\pi$$

$$z_o \approx R_C$$

COLECTOR COMÚN





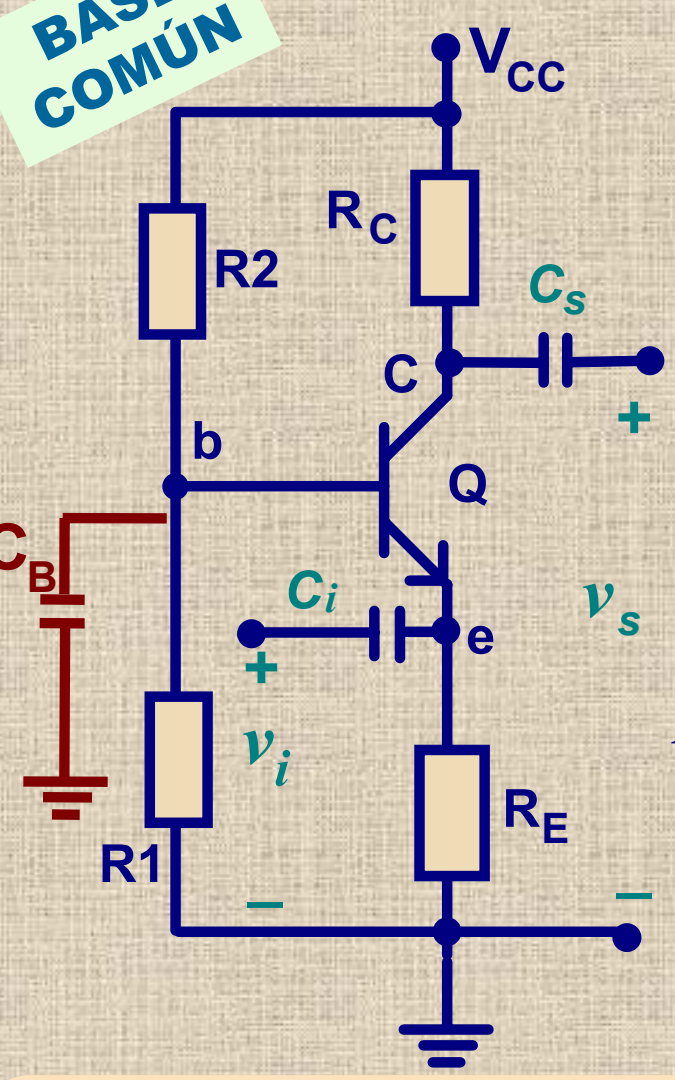
$$z_i = \frac{v_i}{i_i} \approx R_B // r_\pi \left(1 + g_m R_E\right)$$

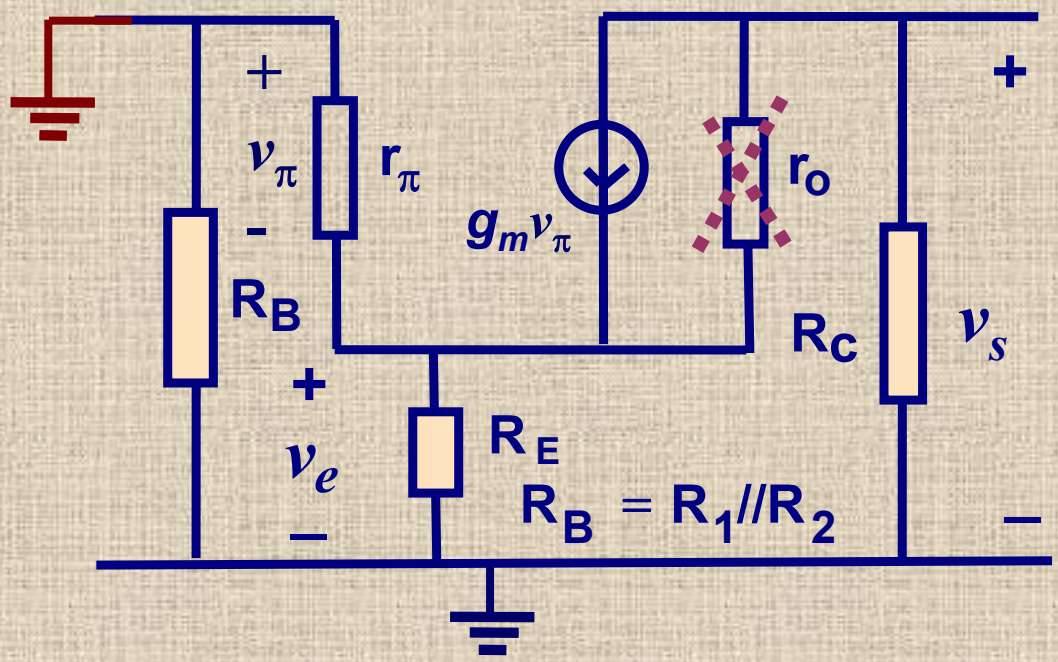
$$z_i \approx R_B // \beta R_E \approx R_B$$

$$z_o = \left.\frac{v_o}{i_s}\right|_{v_i = 0} \approx r_\pi // R_E // \frac{1}{g_m} \approx g_m^{-1}$$

$$A_v = \frac{v_s}{i_i} \approx \frac{R_E\left(1 + g_m r_\pi\right)}{r_\pi + R_E\left(1 + g_m r_\pi\right)} \approx \frac{g_m R_E}{1 + g_m R_E} \approx 1$$

BASE COMÚN





$$A_v \approx g_m R_c \frac{r_\pi}{r_\pi + R_B} \approx g_m R_c \qquad A_i \approx 1$$

$$z_i \; ; \; R_E // \frac{r_\pi + R_B}{1 + g_m r_\pi} \approx \frac{r_\pi + R_B}{1 + \beta} \approx g_m^{-1}$$

Si R_s = resistencia generador

z_o depende de R_s

$$z_o = r_o \left(1 + g_m r_\pi \frac{R_E^*}{r_\pi + R_B} \right)$$

$$R_E^* = R_s // R_E // (r_\pi + R_B)$$

$$z_o = r_o (1 + g_m R_E)$$

ec

$$A_v \approx -\frac{g_m R_C}{1+g_m R_E} \approx -\frac{R_C}{R_E}$$

$$z_i \approx R_B // r_\pi \left(1+g_m R_E\right)$$

$$z_i \approx R_B$$

$$z_o \approx R_C$$

amplificador de tensión y corriente

cc

$$z_i \approx R_B // \beta R_E \approx R_B$$

$$A_v = \frac{v_s}{v_e} \approx 1$$

$$z_o \approx r_\pi // R_E // \frac{1}{g_m} \approx g_m^{-1}$$

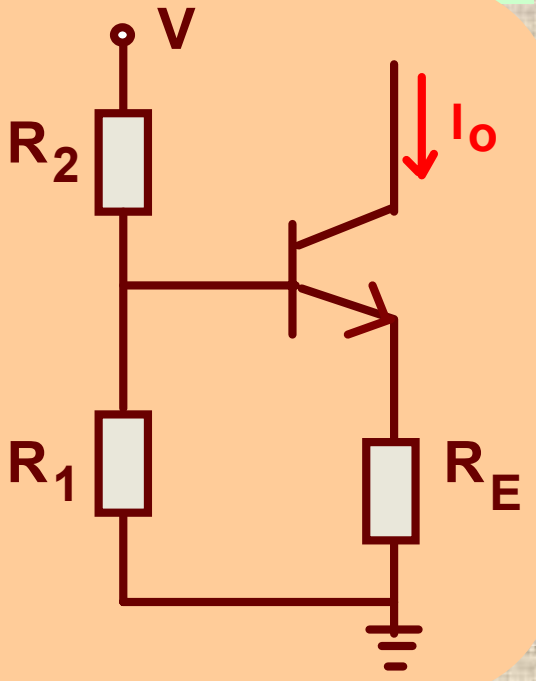
adaptador de impedancia amplifica corriente

bc

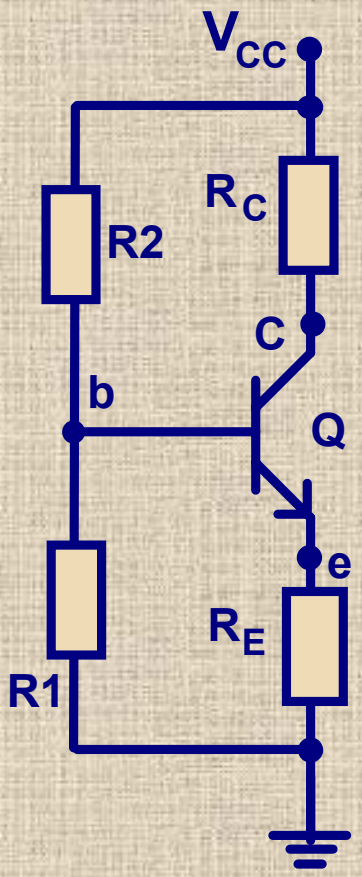
$$I_o = \frac{V_{BB} - V_{BE}}{R_E}$$

$$z_o \approx r_o \left(1+g_m R_E\right)$$

fuente de corriente o carga activa



Otros criterios a tener en cuenta



ec

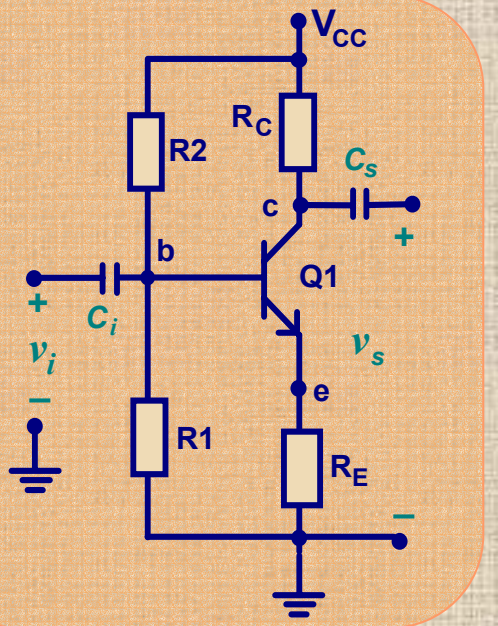
$$A_v \approx -\frac{R_C}{R_E}$$

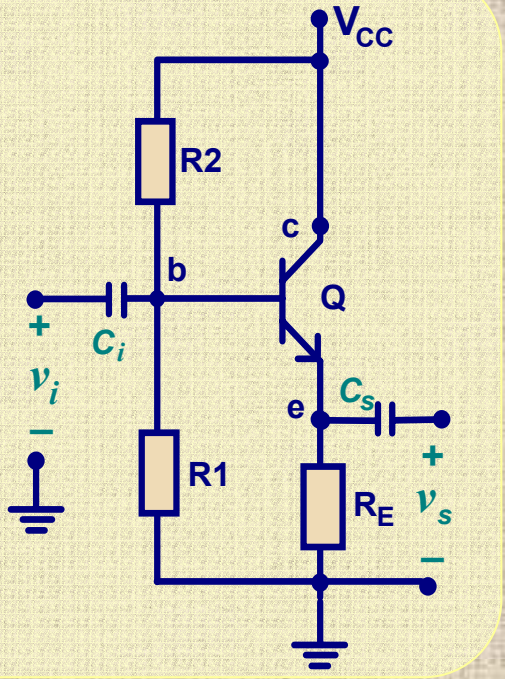
$$R_E < R_C$$

$$z_i = R_1 // R_2 \approx R_B$$

cc

$$R_C = 0$$





BJT Polarizado
FET Polarizado

Etapas amplificadoras básicas

BJT

emisor común
base común
colector común

FET

fuente común
puerta común
drenaje común

Terminal común

terminal de excitación
terminal de salida

ec emisor común

$$A_v \approx -\frac{g_m R_C}{1+g_m R_E} \approx -\frac{R_C}{R_E}$$

$$z_i \approx R_B // r_\pi (1+g_m R_E) \approx R_B$$

$$z_o = \left.\frac{v_s}{i_s}\right|_{v_i=0} \approx R_C$$

sc fuente común

$$A_v = \frac{v_o}{v_i} \approx \frac{-g_m R_D}{1+g_m R_S}$$

$$z_i = R_G // z_{iFET} \approx R_G$$

$$z_o \equiv \left.\frac{v_o}{i_o}\right|_{e_i=0} \approx R_D$$

Amplificador de tensión

cc

colector común

$$A_v \approx \frac{g_m R_E}{1 + g_m R_E} \approx 1$$

$$z_i \approx R_B // \beta R_E \approx R_B$$

$$z_o \approx g_m^{-1}$$

drenaje común

dc

$$A_v \approx \frac{g_m R_S}{1 + g_m R_S} < 1$$

$$z_i = R_G = R_1 // R_2$$

$$z_o \approx g_m^{-1}$$

Adaptador de impedancia

amplifica corriente

bc

$$A_v \approx g_m R_C \frac{r_\pi}{r_\pi + R_B}$$

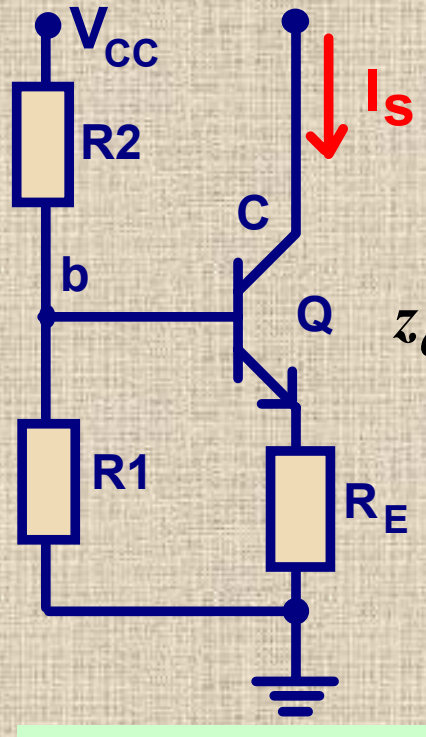
$$z_i \approx \frac{r_\pi + R_B}{1+\beta}$$

gc

$$z_i = g_m^{-1} // R_S \approx g_m^{-1}$$

$$A_v \approx g_m R_D$$

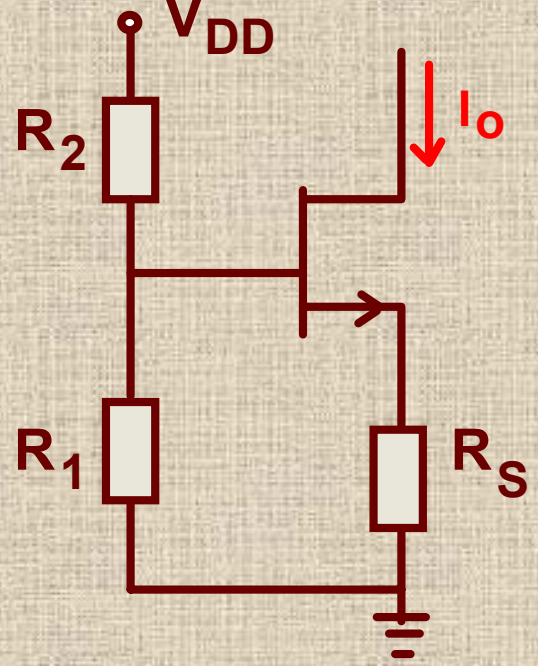
fuente de corriente o carga activa



$$I_S \approx \frac{V_{BB} - V_{BE}}{R_E}$$

$$z_o \approx r_o\left(1 + \frac{g_m r_\pi R_E}{r_\pi + R_B + R_E}\right)$$

R1 puede ser reemplazada por un zener



$$z_o \approx r_o\left(1 + g_m R_S\right)$$

base común

puerta común