

TRANSISTORI

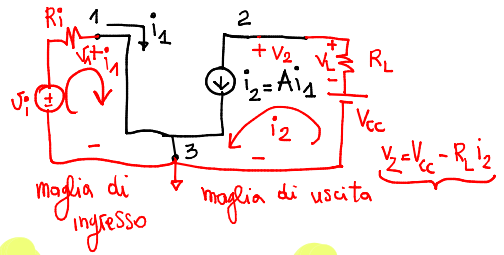
dispositivi a 3 terminali

→ funzionano da **generatori di corrente controllati**

- dalla tensione sul 3° terminale [transistori a effetto di campo]
- dalla corrente nel 3° terminale [transistori bipolari]

transfer-resistor

Generatore di corrente controllato da corrente



$$V_2 = -R_L i_2 = -R_L A i_1 = -\underbrace{R_L A}_{R_i} V_i$$

Amplificazione di tensione

Potenza erogata da V_i

$$P_i = V_i i_i = \frac{V_i^2}{R_i}$$

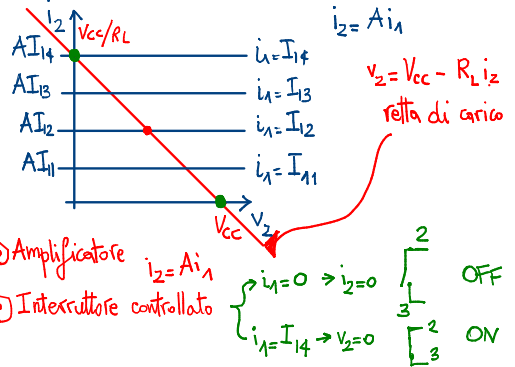
Potenza assorbita dal carico (R_L)

$$P_u = \frac{V_L^2}{R_L} = \left[\frac{R_L A}{R_i} V_i \right]^2 \cdot \frac{1}{R_L} = \frac{A^2 R_L}{R_i^2} V_i^2$$

Amplificazione di potenza = P_u/P_i

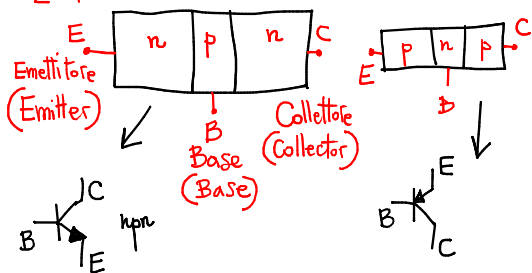
$$P_u/P_i = \left(\frac{A^2 R_L}{R_i} \right) \left[\text{se } \frac{P_u}{P_i} > 1 \text{ ho un amplificatore} \right]$$

Caratteristiche di uscita



Transistori bipolari a giunzione

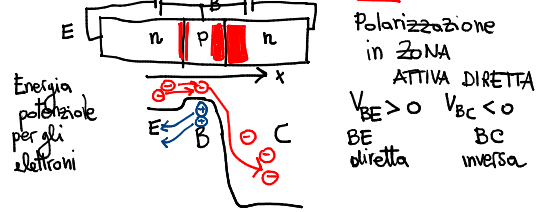
[Bipolar Junction Transistor - BJT]

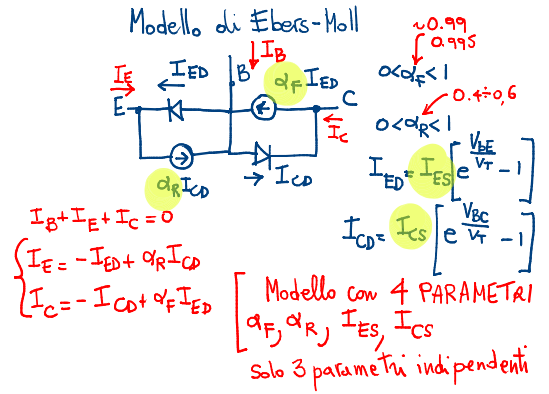
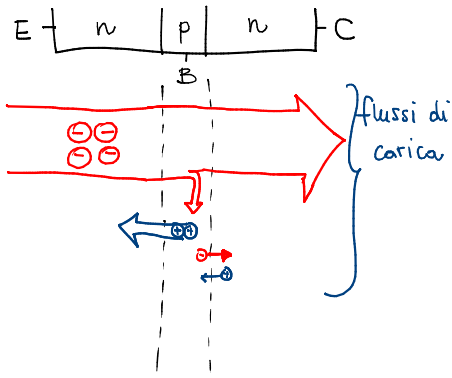


Funzionamento BJT

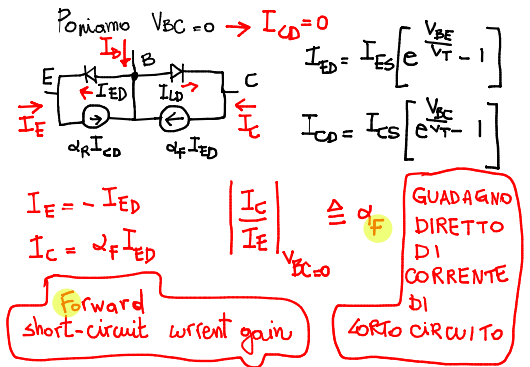


NO, perché la base è **costa!**





Condizione di reciprocità
 se $V_{BE} = V_{BC}$ allora $I_B = I_{CD} + I_{ED}$
 quindi $\alpha_F I_{ED} = \alpha_R I_{CD}$
 $\alpha_F I_{ES} \left[e^{\frac{V_{BE}}{V_T}} - 1 \right] = \alpha_R I_{CS} \left[e^{\frac{V_{BC}}{V_T}} - 1 \right]$
 $\alpha_F I_{ES} = \alpha_R I_{CS}$



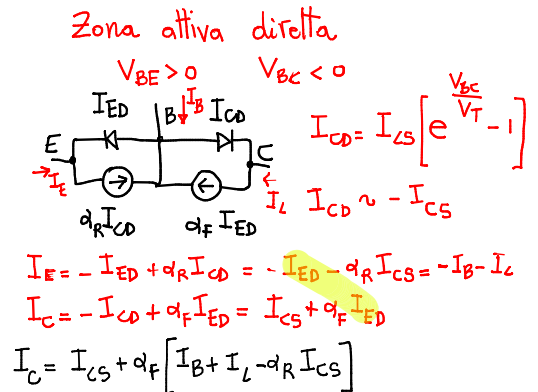
se $V_{BE} = 0$ $V_{BC} > 0 \rightarrow I_{ED} = 0$

$I_C = -I_{CD}$
 $I_E = \alpha_R I_{CD}$

$\alpha_R \cong \left| \frac{I_E}{I_C} \right|_{V_{BE}=0}$

GUADAGNO INVERSO DI CORRENTE DI CIRCUITO CORTO

Reverse short-circuit current gain

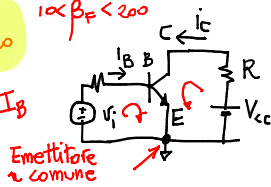


$$I_C = \frac{\alpha_F}{1-\alpha_F} I_B + \frac{(1-\alpha_F\alpha_R)}{1-\alpha_F} I_{CS} \approx I_{CO}$$

Guadagno di corrente diretto β_F in configurazione a emettitore comune

$$I_C = \beta_F I_B + (\beta_F + 1) I_{EO}$$

Praticamente: $I_C \approx \beta_F I_B$



Emettitore comune

Zona attiva inversa

$$V_{BE} < 0 \quad V_{BC} > 0$$

$$I_{ED} \approx -I_{ES} \rightarrow I_E = \beta_R I_B + (1 + \beta_R) I_{EO}$$

$$\text{dove } \beta_R = \frac{\alpha_R}{1-\alpha_R}$$

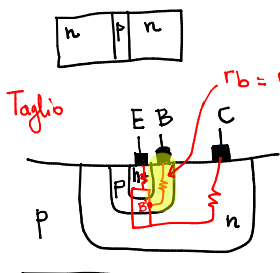
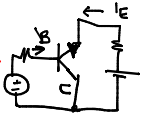
$$I_{EO} = (1 - \alpha_F \alpha_R) I_{ES}$$

In pratica $I_E \approx \beta_R I_B$

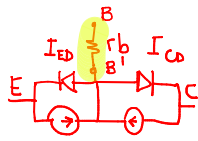
$$\alpha_R = 0.4 \div 0.6$$

$$\alpha_R = 0.6 \rightarrow \beta_R = 1.5$$

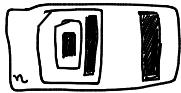
β_R guadagno di corrente inverso a collettore comune



resistenza serie della base



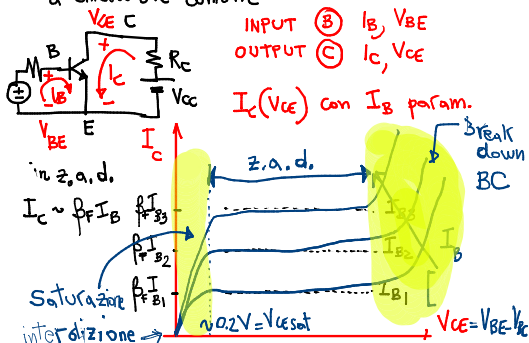
Dall'alto



Regioni di funzionamento di un BJT (npn)

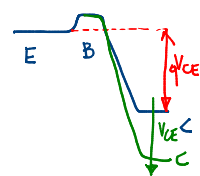
	V_{BE}	V_{BC}	
ZONA ATTIVA DIRETTA	> 0 DIR	< 0 INV	
ZONA ATTIVA INVERSA	< 0 INV	> 0 DIR	
SATURAZIONE	> 0 DIR	> 0 DIR	
INTERDIZIONE CUT OFF	< 0 INV	< 0 INV	

Caratteristiche di uscita del BJT a emettitore comune



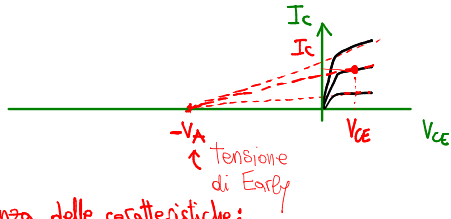
EFFETTO EARLY

En. potenziale per gli elettroni in z.a.d.



se aumento V_{CE}
 1) aumenta la barriera tra base e collettore
 2) si allarga la zona di svuotamento tra base e collettore

Si restringe la regione di base (neutra) viene facilitata la diffusione nella base
 aumenta β_F, I_C



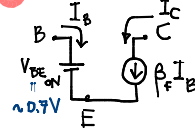
pendenza delle caratteristiche:

$$\frac{I_C}{V_{CE} + V_A} \sim \frac{I_C}{V_A}$$

$V_A > V_{CE}$

Modello del BJT per grandi segnali

1. Zona attiva diretta



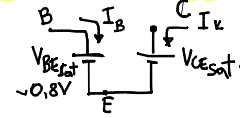
$$I_C = \beta_F I_B$$

Condizioni

$$\begin{cases} V_{CE} > V_{CEsat} \sim 0.2V \\ I_C > 0 \end{cases}$$



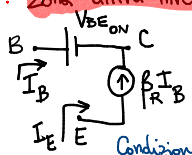
2. Saturazione (diretta)



Condizioni

$$\begin{cases} I_C > 0 \\ I_C < \beta_F I_B \end{cases}$$

3. Zona attiva inversa



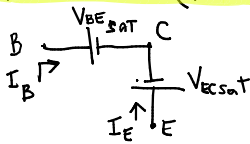
$$I_E = \beta_R I_B$$

Condizioni

$$\begin{cases} I_E > 0 \\ V_{CE} < -V_{CEsat} \sim -0.2V \end{cases}$$



4. Saturazione (inversa)

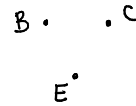


$$V_{BEsat} \sim 0.8V$$

Condizioni:

$$\begin{cases} I_B, I_E > 0 \\ I_E < \beta_R I_B \end{cases}$$

5. Interdizione (cut off)

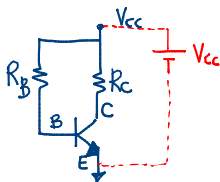


$$I_B = I_C = I_E = 0$$

Condizioni

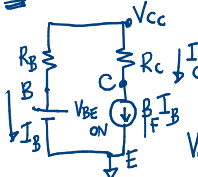
$$\begin{cases} V_{BE} < V_{BEon} \\ V_{BC} < V_{BEon} \end{cases}$$

Es.



$$\begin{aligned} \beta_F &= 100 \\ R_B &= 300 \text{ k}\Omega \\ R_C &= 2 \text{ k}\Omega \\ V_{CC} &= 10 \text{ V} \end{aligned}$$

Hp. 2.A.D



$$I_B = \frac{V_{CC} - V_{BEon}}{R_B} = 31 \mu\text{A}$$

$$I_C = \beta_F I_B = 3.1 \text{ mA}$$

Condizioni: $I_C > 0$ ok

$$V_{CE} = V_{CC} - R_C I_C = 3.8 \text{ V} > V_{CEsat} \text{ ok}$$

Es.2 Come prima, tranne $R_B = 150 \text{ k}\Omega$

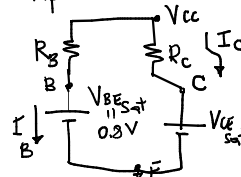
Hp. 2.A.D $I_B = 62 \mu\text{A}$, $I_C = 6.2 \text{ mA}$

Condizioni: $I_C > 0$ ok

$$V_{CE} = V_{CC} - R_C I_C = 2.4 \text{ V} > V_{CEsat}$$

(No)

Hp. Saturazione



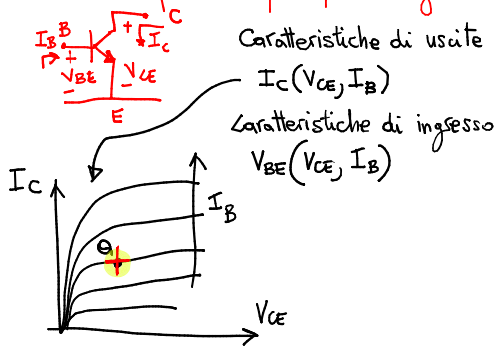
$$I_B = 62 \mu\text{A}$$

$$I_C = \frac{V_{CC} - V_{CEsat}}{R_C} = 4.9 \text{ mA}$$

Condizioni

$$\begin{cases} I_B, I_C > 0 \\ \frac{I_C}{I_B} < \beta_F \end{cases} \sim 80 < \beta_F \text{ ok}$$

Circuito equivalente per i piccoli segnali



$$i_c = i_c(V_{ce}, I_B)$$

$$I_C + i_c = i_c(V_{ce} + v_{ce}, I_B + i_b) \quad \text{Esp. al 1° ordine}$$

$$I_C + i_c = i_c(V_{ce}, I_B) + \left. \frac{\partial i_c}{\partial V_{ce}} \right|_{V_{ce}=0, I_B=0} v_{ce} + \left. \frac{\partial i_c}{\partial I_B} \right|_{V_{ce}=0, I_B=0} i_b$$

$$i_c = h_{fe} i_b + h_{oe} v_{ce}$$

$$v_{BE} = V_{BE}(V_{ce}, I_B)$$

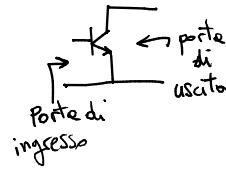
$$V_{BE} + v_{be} = V_{BE}(V_{ce} + v_{ce}, I_B + i_b)$$

$$V_{BE} + v_{be} = V_{BE}(V_{ce}, I_B) + \left. \frac{\partial V_{BE}}{\partial V_{ce}} \right|_{V_{ce}=0, I_B=0} v_{ce} + \left. \frac{\partial V_{BE}}{\partial I_B} \right|_{V_{ce}=0, I_B=0} i_b$$

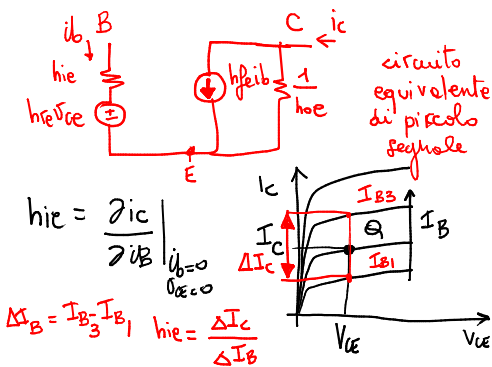
$$v_{be} = h_{re} v_{ce} + h_{ie} i_b$$

$$\begin{cases} i_c = h_{fe} i_b + h_{oe} v_{ce} \\ v_{be} = h_{ie} i_b + h_{re} v_{ce} \end{cases} \rightarrow \begin{bmatrix} i_c \\ v_{be} \end{bmatrix} = \begin{bmatrix} h_{fe} & h_{oe} \\ h_{ie} & h_{re} \end{bmatrix} \begin{bmatrix} i_b \\ v_{ce} \end{bmatrix}$$

Modello a parametri ibridi del transistor a emettitore comune



- dipende da qual'è il terminal a comune
- dipende dal punto di riposo
- vale solo in un intorno del punto di riposo



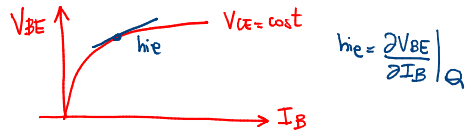
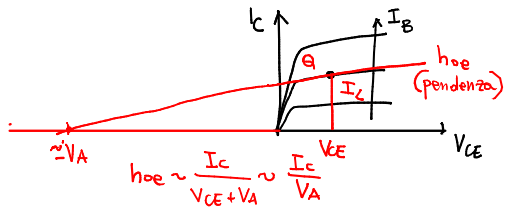
Dal modello di Ebers e Moll

in z.a.d. $i_c = \beta_F i_B + (\beta_F + 1) I_{C0}$

$$h_{fe} = \frac{\partial i_c}{\partial i_b} \Big|_{v_{ce}=0} \cong \beta_F$$

$$h_{oe} \cong \frac{\partial i_c}{\partial v_{ce}} \Big|_{v_{ce}=0, i_b=0} = I_B \frac{\partial \beta_F}{\partial v_{ce}} = I_C \frac{\partial \beta_F}{\partial v_{ce}} \cdot \frac{1}{\beta_F} \cdot \frac{1}{V_A}$$

$$\boxed{h_{oe} = \frac{I_C}{V_A}}$$



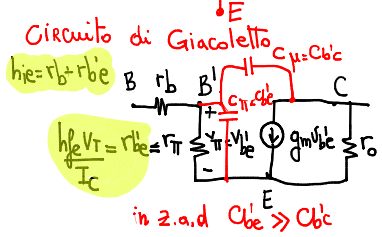
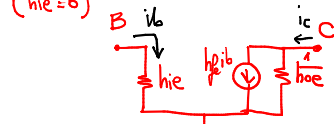
$I_C = \beta_F I_B + (\beta_F + 1) I_{CO}$

$I_B = I_{ES} \left[e^{\frac{V_{BE}}{V_T}} - 1 \right] (1 - \alpha_F)$

$\frac{\partial I_C}{\partial V_{BE}} \Big|_Q = \frac{I_{ES}}{V_T} e^{\frac{V_{BE}}{V_T}} (1 - \alpha_F) \sim \frac{I_C (1 - \alpha_F)}{V_T \alpha_F} = \frac{I_C}{\beta_F V_T}$

$h_{ie} \approx \frac{\beta_F V_T}{I_C} = \frac{h_{fe} V_T}{I_C}$

Circuito equivalente a parametri ibridi



$h_{fe} i_b = g_m v_{be}$

$g_m = \frac{h_{fe}}{r_{be}}$

$r_o = \frac{1}{hoe}$

