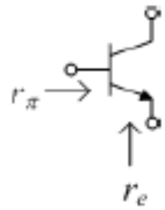
Miglioramenti del modello a T:

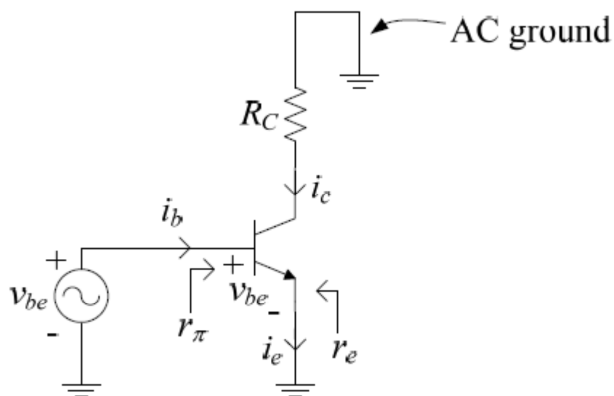
Resistenze equivalenti 'guardando' nella base e nell' emettitore



$r_e = \frac{V_T}{I_C}$ resistenza dinamica della giunzione BE in zona attiva

$g_m = \frac{1}{r_e} = \frac{I_C}{V_T}$ transconduttanza (per piccoli segnali) del transistor

$$g_m = \frac{1}{r_e} \sim \frac{dI_C}{dV_{BE}} \sim \frac{i_c}{v_{be}} \rightarrow i_c \simeq g_m v_{be} \rightarrow i_b \simeq \frac{g_m}{\beta} v_{be}$$



$$r_\pi = \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \frac{\beta V_T}{I_C}$$

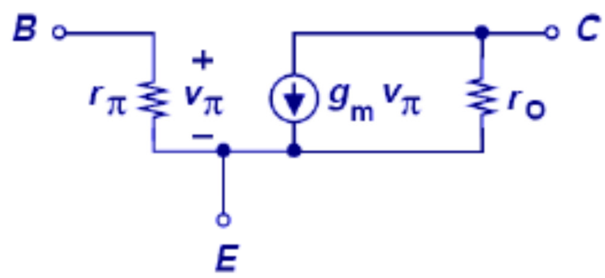
$$i_E = \frac{i_C}{\alpha} = \frac{I_C}{\alpha} + \frac{i_c}{\alpha}$$

$$i_e = \frac{i_c}{\alpha} = \frac{I_C}{\alpha}\frac{v_{be}}{V_T} = \frac{I_E v_{be}}{V_T}$$

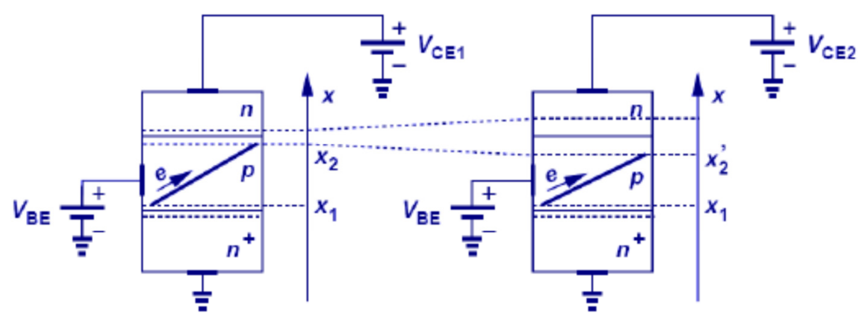
$$r_e = \frac{v_{be}}{i_e} = \frac{V_T}{I_E} = \frac{\alpha}{g_m}\left(\approx \frac{1}{g_m}\right)$$

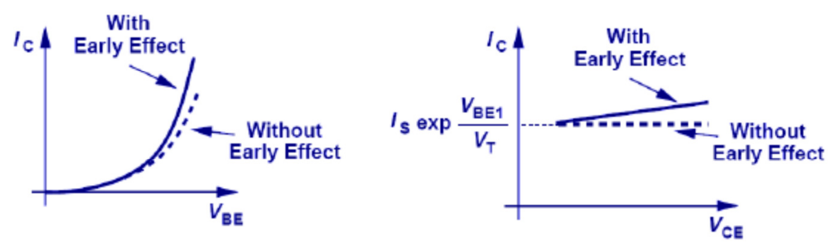
$$\rightarrow r_\pi = \frac{\beta}{g_m} = \frac{\beta}{\alpha} r_e = \frac{\beta}{\beta}(\beta+1) r_e = (\beta+1) r_e$$

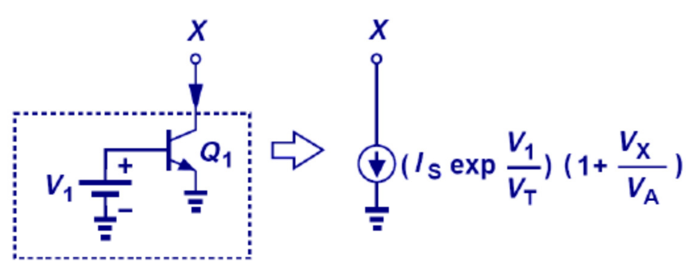
Modello a π ibrido: Versione a bassa frequenza



r_0 legata all'effetto Early: I_C non indipendente da V_{CE}

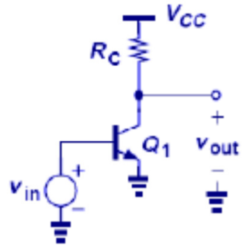


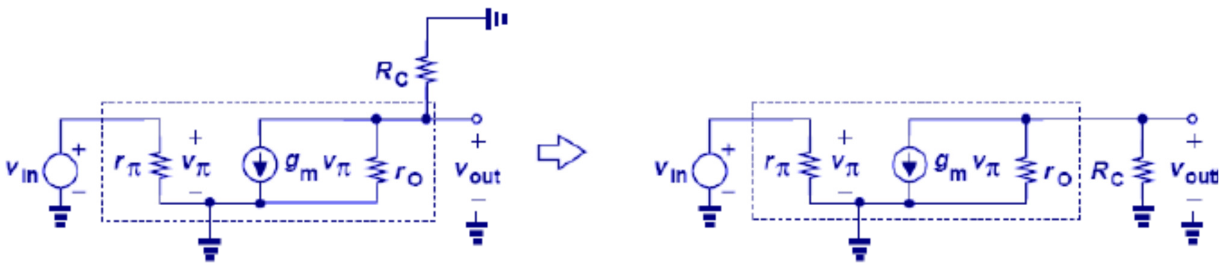




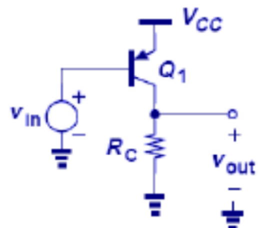
C generatore non ideale di corrente $\rightarrow r_0 < \infty$ in parallelo al generatore di corrente

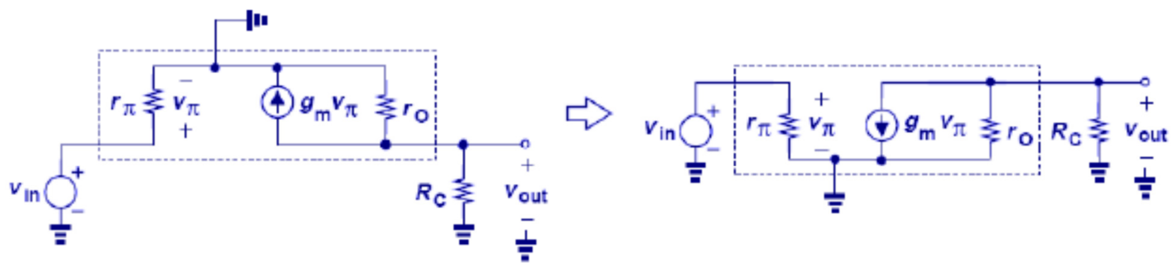
Esempio: Applicazione a stadio semplice CE





Identico per PNP:





Impedenze intrinseche del BJT (in zona attiva!):

Base: Si 'guarda' dentro B

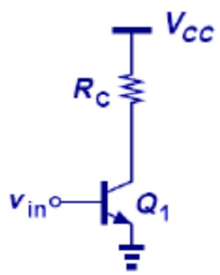
$R_b = r_\pi$; stato uscita irrilevante perche' r_π a ground

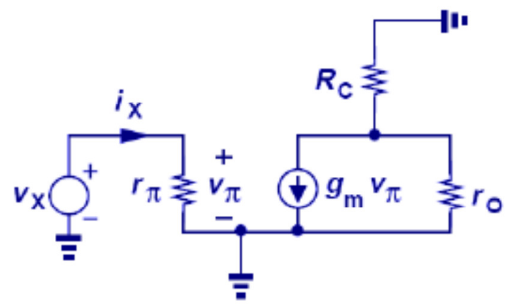
Collettore: Si 'guarda' dentro C

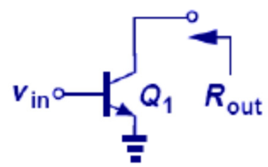
$R_c = r_0 \simeq \infty,\ r_0 \to \infty;$ B (ed E) a ground $\to v_\pi = 0 \to g_m v_\pi = 0$

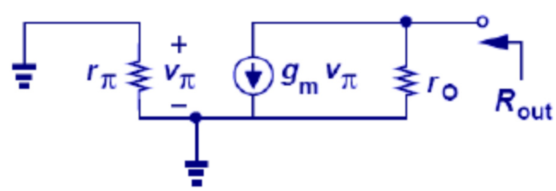
Emettitore: Si 'guarda' dentro E

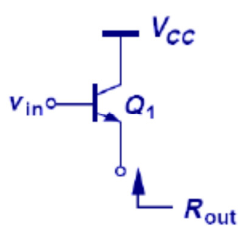
$$R_e = \frac{v_x}{i_x} = \frac{1}{g_m + \frac{1}{r_\pi}} \simeq \frac{1}{g_m},\ r_0 \to \infty;\ \text{B e C a ground} \to i_x = \frac{v_\pi}{r_\pi} + g_m v_\pi$$

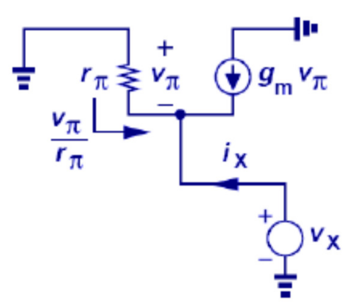








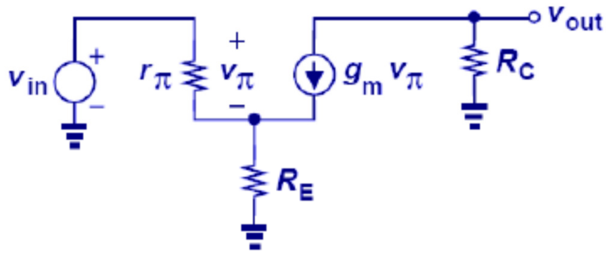




Applicazione: Stadio CE con resistenza su emettitore

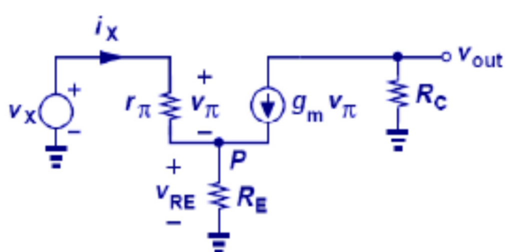
NB: Non considerate resistenze del partitore di bias

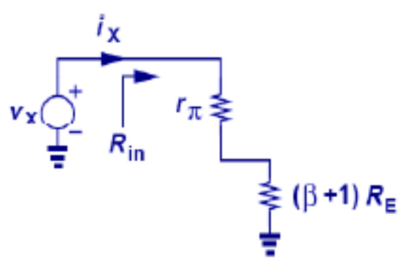
Non considerato effetto Early



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

Impedenza di ingresso:

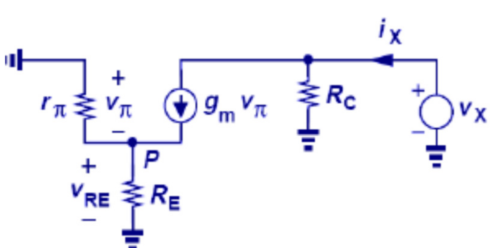




$$v_x = \left[r_\pi + R_E(1+\beta)\right] i_x$$

$$\rightarrow R_{in} = \frac{v_x}{i_x} = r_\pi + R_E(1+\beta)$$

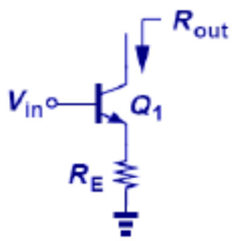
Impedenza di uscita:

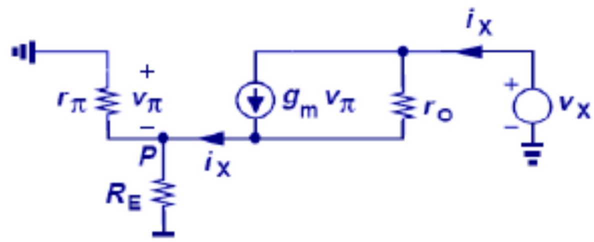


$$v_{in} = v_\pi + \left(\frac{v_\pi}{r_\pi} + g_m v_\pi\right) R_E = 0 \rightarrow v_\pi = 0$$

$$\rightarrow R_{out} = \frac{v_x}{i_x} = R_C$$

Tenendo conto dell'effetto Early:

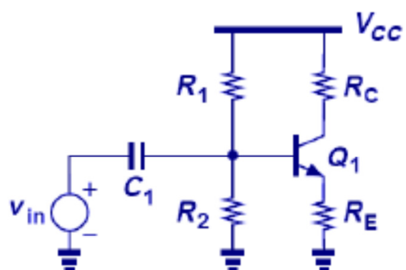


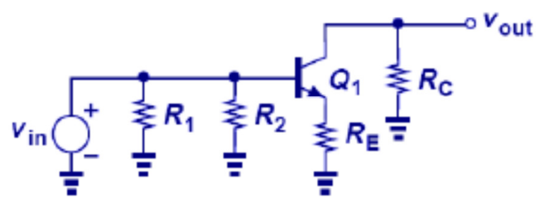


$$R_{out} = \left[1 + g_m (R_E \| r_\pi)\right] r_O + R_E \| r_\pi$$
$$R_{out} = r_O + (g_m r_O + 1)(R_E \| r_\pi)$$
$$R_{out} \approx r_O \left[1 + g_m (R_E \| r_\pi)\right]$$

R_{out} aumentata $\rightarrow$ Migliorato generatore di corrente

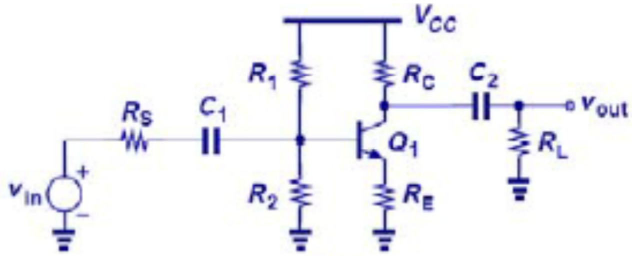
Tenendo conto del partitore di bias:



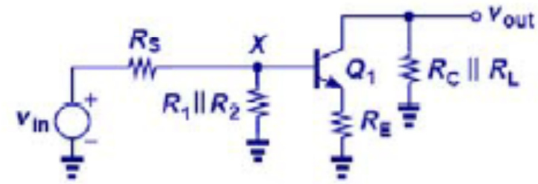


$$A_v = \frac{-R_C}{\frac{1}{g_m} + R_E}$$
$$R_{in} = \left[r_\pi + (\beta + 1) R_E\right] \| R_1 \| R_2$$
$$R_{out} = R_C$$

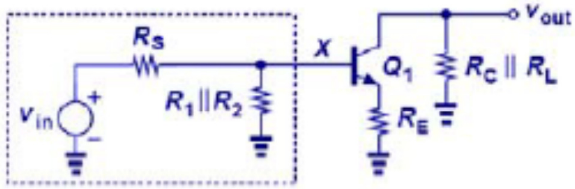
Al gran completo:



(a)



(b)

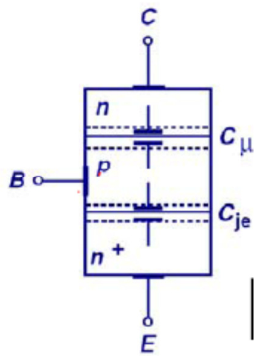


(b)

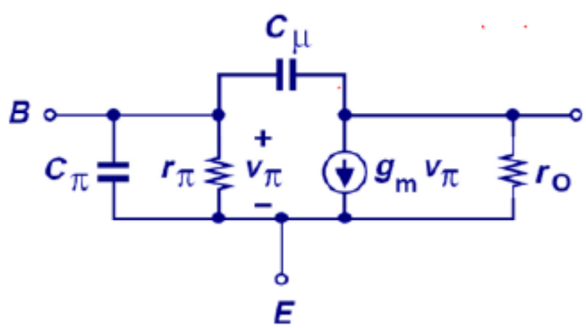
$$A_v = \frac{-R_C \parallel R_L}{\dfrac{1}{g_m} + R_E + \dfrac{R_s \parallel R_1 \parallel R_2}{\beta + 1}}$$

Comportamento del BJT ad alta frequenza:
Legato a caratteristiche reattive delle giunzioni

Zona attiva:
Giunzione di emettitore pol. diretta → Cap. di transizione + Cap. di diffusione
Giunzione di collettore pol. inversa → Capacita' di transizione

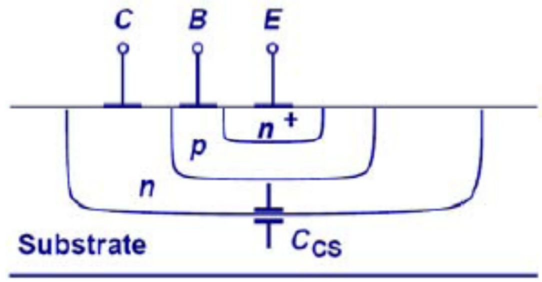


Modello a π ibrido esteso ad elementi reattivi:

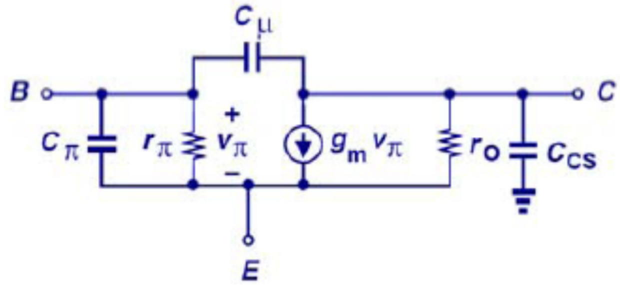


Capacita' effettive delle giunzioni:
$C_\pi = C_{be} + C_{diff}$ transizione + diffusione
$C_\mu = C_{bc}$ transizione

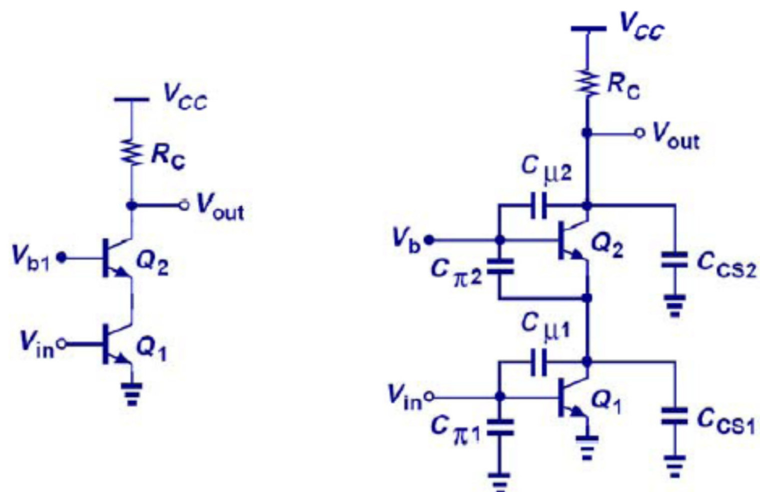
Inoltre, nei circuiti integrati:
C_{cs} capacita' collettore-substrato



Modello completo per BJT in CI:



Es: Capacita' in un circuito specifico ('Cascode', v. dopo)

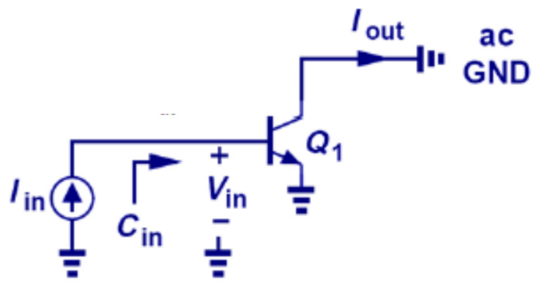


Effetto principale della capacita' C_π:

Riduzione del guadagno di corrente ad alta frequenza

Def: ω_T frequenza di guadagno unitario

Misura 'concettuale':



$$I_{out} = g_m V_{in}$$

$$V_{in} = Z_{in} I_{in}$$

$$\rightarrow I_{out} = g_m Z_{in} I_{in}$$

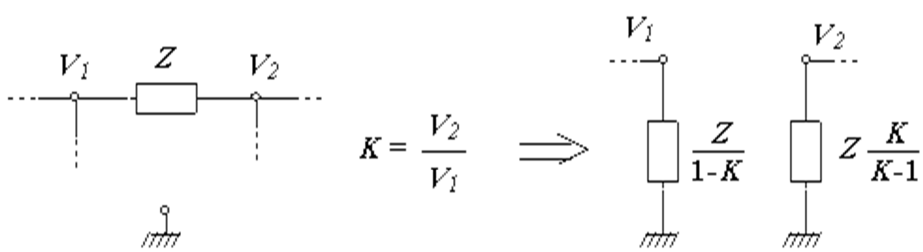
$$\rightarrow \frac{I_{out}}{I_{in}} = g_m Z_{in} = g_m \frac{1}{j\omega C_\pi}$$

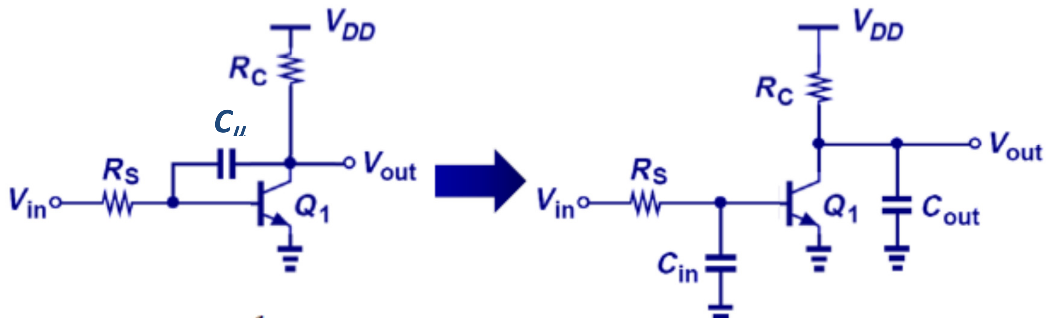
$$\left| \frac{I_{out}}{I_{in}} \right| = 1 \rightarrow \frac{g_m}{\omega_T C_\pi} = 1 \rightarrow \omega_T = \frac{g_m}{C_\pi}$$

Effetto di C_μ: ???

Difficile da visualizzare: Capacita' 'floating', senza terminali a ground

$\rightarrow$ Teorema di Miller (non dimostrato):





$$Z_1 = \frac{\frac{1}{j\omega C_\mu}}{1-A_v} = \frac{1}{j\omega C_\mu\left(1-A_v\right)}$$

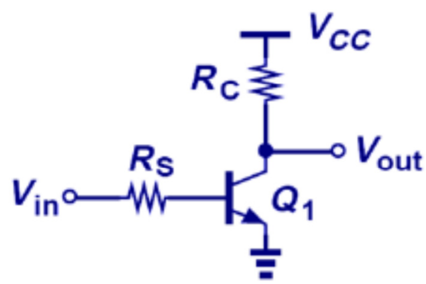
$$Z_2 = \frac{\frac{1}{j\omega C_\mu}}{1-\frac{1}{A_v}} = \frac{1}{j\omega C_\mu\left(1-\frac{1}{A_v}\right)}$$

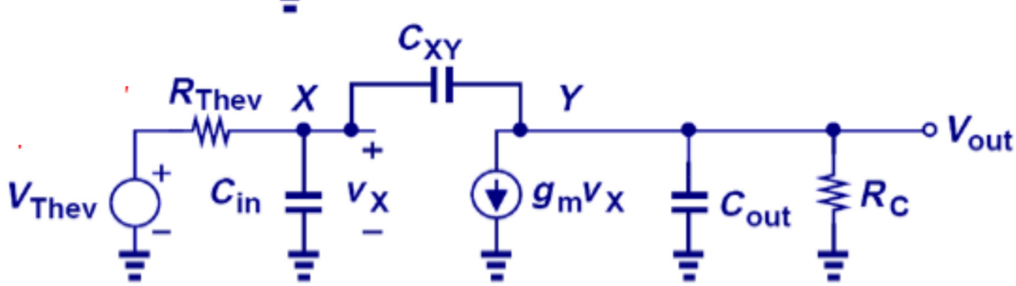
$A_v < 0 \rightarrow C_\mu \nearrow$:

Effetto Miller = Aumento della capacita' floating

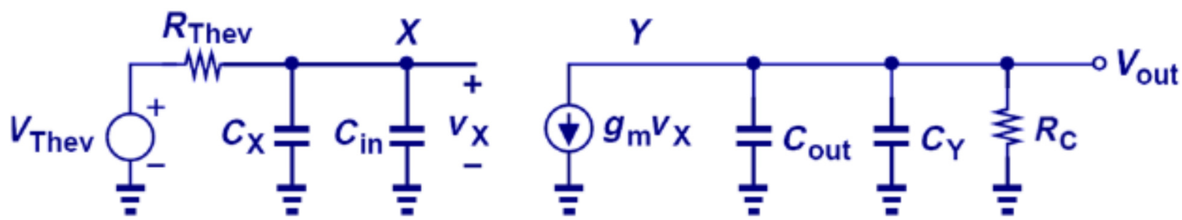
$\left|A_v\right| \gg 1 \rightarrow$ Effetto dominante quello di C_{in}

Applicazione a stadio *CE*:





Teorema di Miller:



$$V_{Thev} = V_{in}\frac{r_\pi}{r_\pi + R_S}$$

$$R_{Thev} = R_S \| r_\pi$$

$$C_X = C_\mu\,(1 + g_m R_C)$$

$$C_Y = C_\mu\,(1 + \frac{1}{g_m R_C})$$

Frequenze di taglio, ingresso e uscita, per guadagno:

$$\omega_{p,in} = \frac{1}{R_{Thev}\left(C_{in} + \left(1 + g_m R_C\right) C_\mu\right)}$$

$$\omega_{p,out} = \frac{1}{R_C\left(C_{out} + \left(1 + \frac{1}{g_m R_C}\right) C_\mu\right)}$$

Impedenze di ingresso e uscita:

$$Z_{in} \approx \frac{1}{j\omega\left[C_\pi + \left(1 + g_m\left(R_C \| r_o\right)\right) C_\mu\right]} \| r_\pi$$

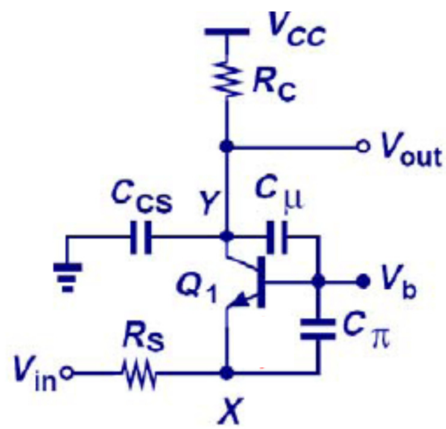
$$Z_{out} = \frac{1}{j\omega\left[C_\mu + C_{CS}\right]} \| R_C \| r_o$$

Applicazione a stadio a *CB*:

Vantaggi notevoli nella risposta in frequenza

Nessuna capacita' floating

$\rightarrow$ No effetto Miller $\left(\leftarrow V_b \text{ sta a valore fisso!}\right)$



$$\omega_{p,Y} = \frac{1}{R_C C_Y}$$

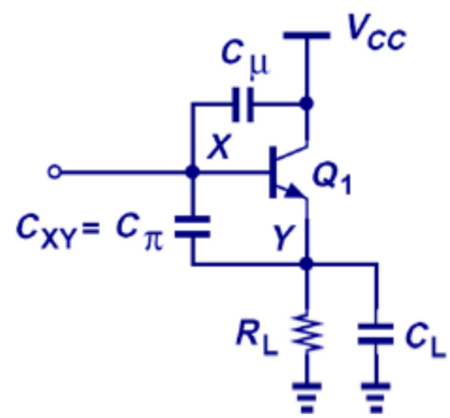
$$C_Y = C_\mu + C_{CS}$$

$$\omega_{p,X} = \frac{1}{\left(R_S \,\|\, \frac{1}{g_m}\right) C_X} > \omega_T$$

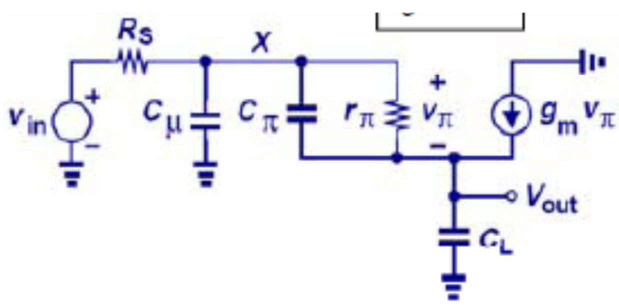
$$C_X = C_\pi$$

$\rightarrow$ Frequenze di taglio $\sim$ Essenzialmente indipendenti dal guadagno

Applicazione a stadio a CC (Emitter follower):



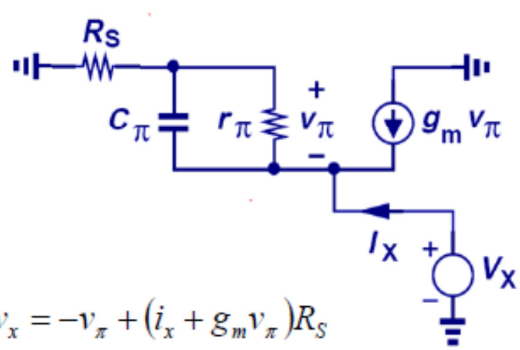
Modello a π ibrido (trascurando r_0):



$$C_X = (1 - A_v)C_\pi = \frac{C_\pi}{1 + g_m R_L}$$

$$C_Y = \left(1 - \frac{1}{A_v}\right)C_\pi = \frac{-C_\pi}{g_m R_L}$$

$$\boxed{C_{in} = C_\mu + \frac{C_\pi}{1 + g_m R_L}}$$



$$v_x = -v_\pi + (i_x + g_m v_\pi)R_S$$

$$v_\pi = -(i_X + g_m v_\pi)\left(r_\pi \| \frac{1}{j\omega C_\pi}\right) \qquad v_x = -v_\pi + (i_x + g_m v_\pi)R_S$$

$$Z_{out} \equiv \frac{v_X}{i_X} = \frac{R_S r_\pi C_\pi (j\omega) + r_\pi + R_S}{r_\pi C_\pi (j\omega) + \beta + 1} = \frac{r_\pi + R_S}{\beta + 1} \cdot \frac{1 + \dfrac{j\omega}{(r_\pi + R_S)/R_S r_\pi C_\pi}}{1 + \dfrac{j\omega}{(\beta + 1)/r_\pi C_\pi}} = \begin{cases} \dfrac{r_\pi + R_S}{1 + \beta} & \text{for low } \omega \\ R_S & \text{for high } \omega \end{cases}$$