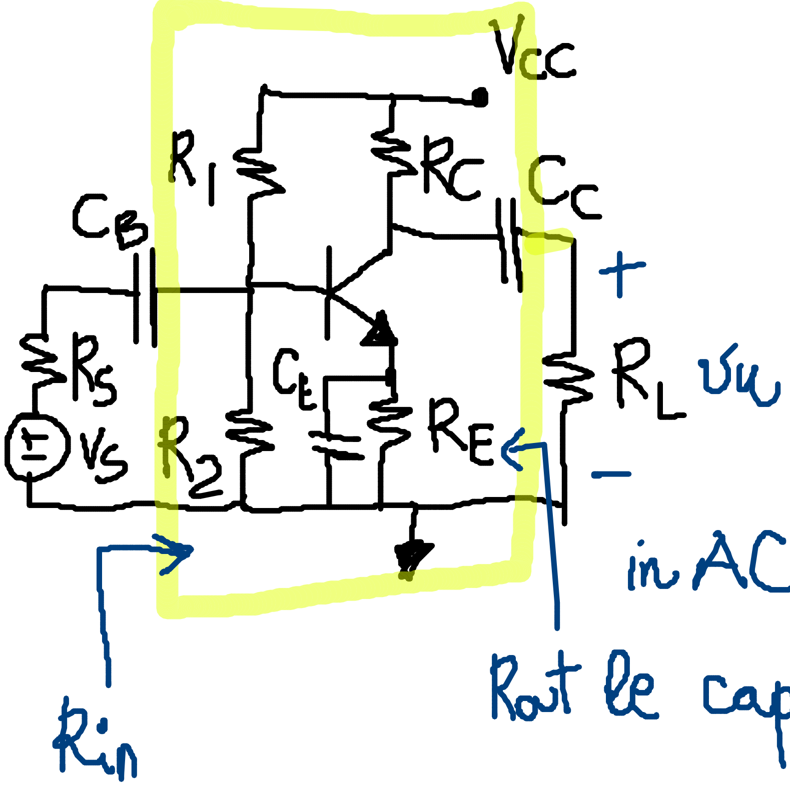
Amplificatori a BJT

→ Amplificatore a Emettitore Comune (CE Common Emitter)

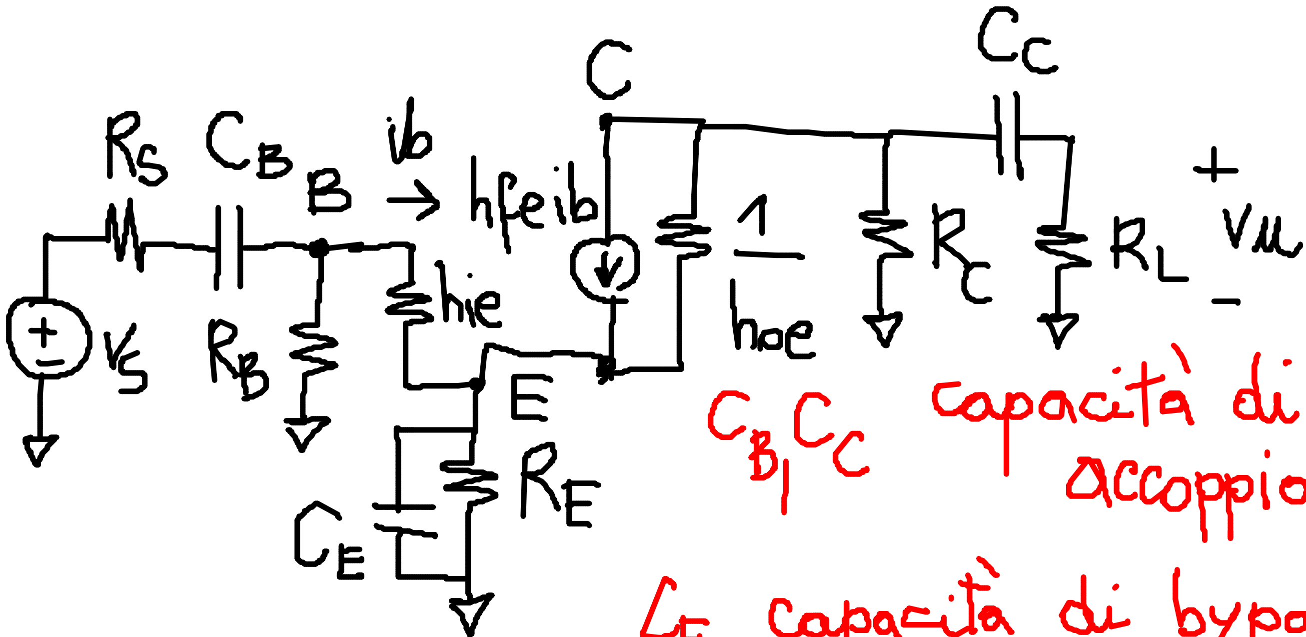


in DC le C sono un circuito aperto
↳ il BJT dipende solo dal circuito di autopolarizzazione

in AC (alla f del segnale) le capacità sono un c.c.

Circuito equivalente di piccolo segnale

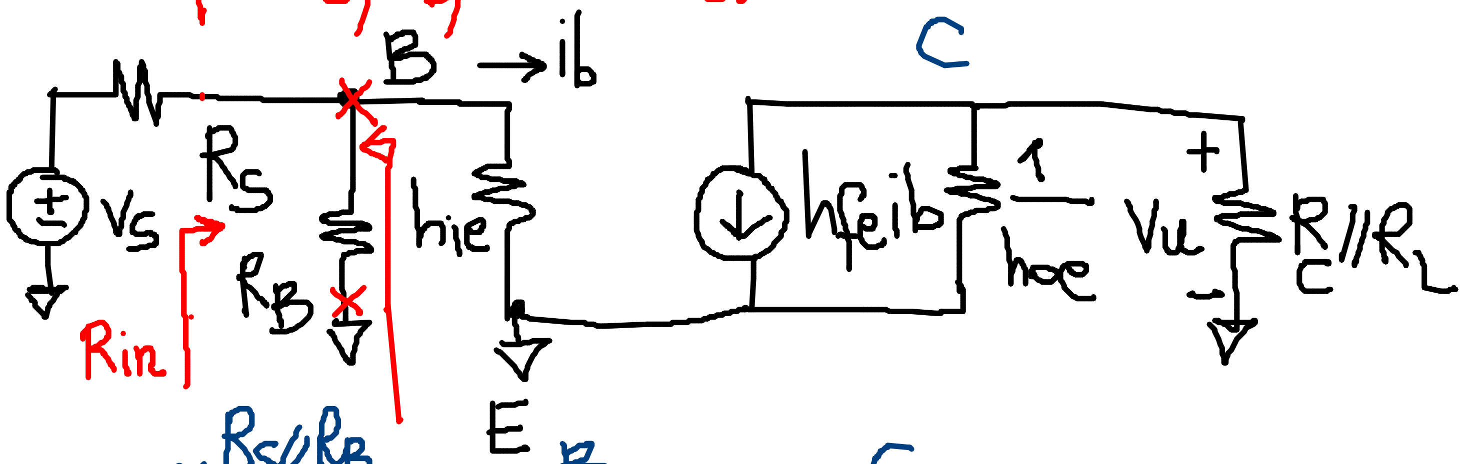
- R, L, C, gen. dip ⟶ Tutti
- Gen. continui V, I ⟶ V → c.c, I → c.a.
- Dispositivi non lineari ⟶ circuito eq. p. s.

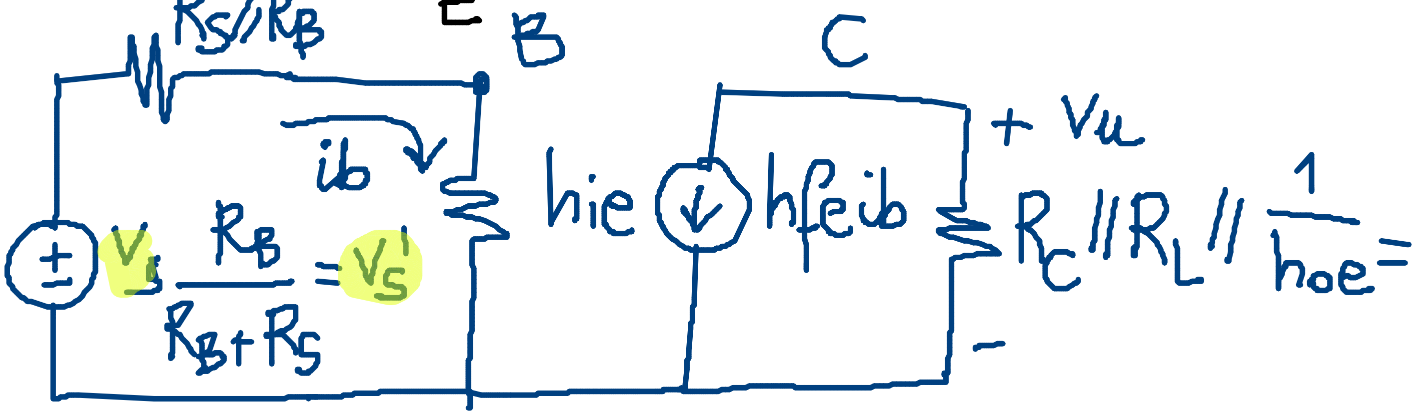


C_B, C_C capacità di accoppiamento

C_E capacità di bypass

Hp C_E, C_B, C_C c.c.





$$V_S \frac{R_B}{R_B + R_S} = V_S'$$

$$R_C // R_L // \frac{1}{h_{oe}} = R_L'$$

$$i_b = \frac{V_S'}{R_S \| R_B + h_{ie}}$$

$$v_u = - R_L' h_{fe} i_b$$

$$A_V = \frac{v_u}{v_S} = \frac{-R_L' h_{fe}}{h_{ie} + R_S \| R_B} \cdot \frac{R_B}{R_B + R_S}$$

amplificazione (div) di uno stadio CE a centrobanda

- Amplificazione intrinseca a vuoto

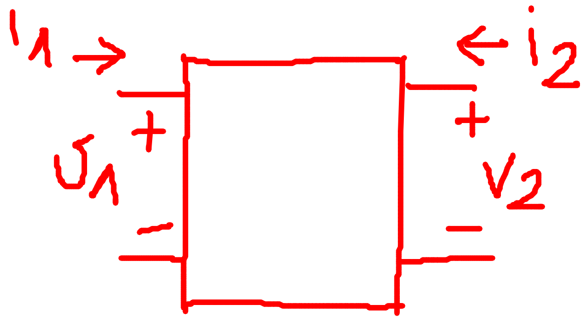
$$A_V\left[R_S = 0,\ R_L \to \infty\right] = A_{V_0}^{*} = -\frac{\left(R_C \| \frac{1}{h_{oe}}\right) h_{fe}}{h_{ie}}$$

- $R_{in} \to$ Resistenza vista dal gen. di ingresso

$$R_{in} = R_B \| h_{ie}$$

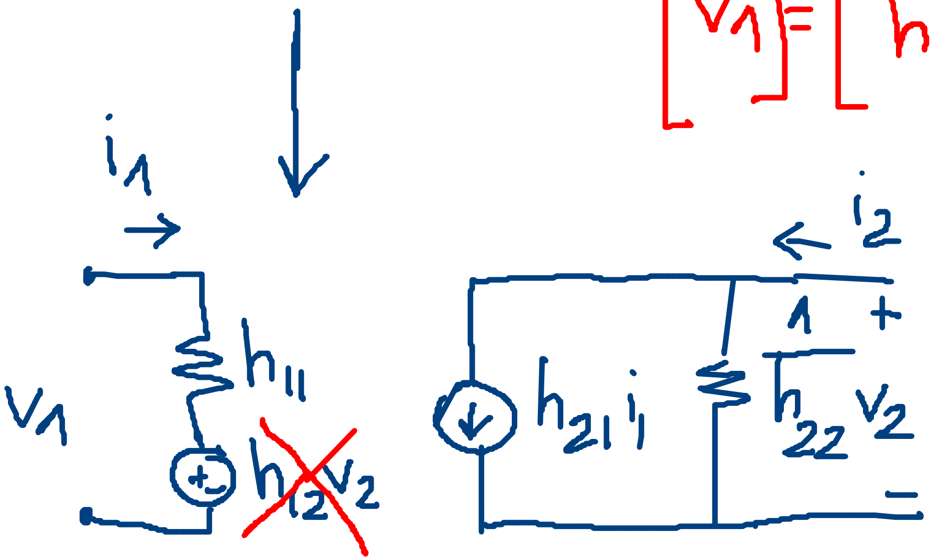
- $R_{out} \to R_V$ dal carico $\quad R_{out} = R_C \| \left(\frac{1}{h_{oe}}\right)$

Sistema lineare a 2 porte



Parametri

$$\begin{bmatrix} i_2 \\ V_1 \end{bmatrix} = \begin{bmatrix} h_{21} & h_{22} \\ h_{11} & h_{12} \end{bmatrix} \begin{bmatrix} i_1 \\ V_2 \end{bmatrix}$$

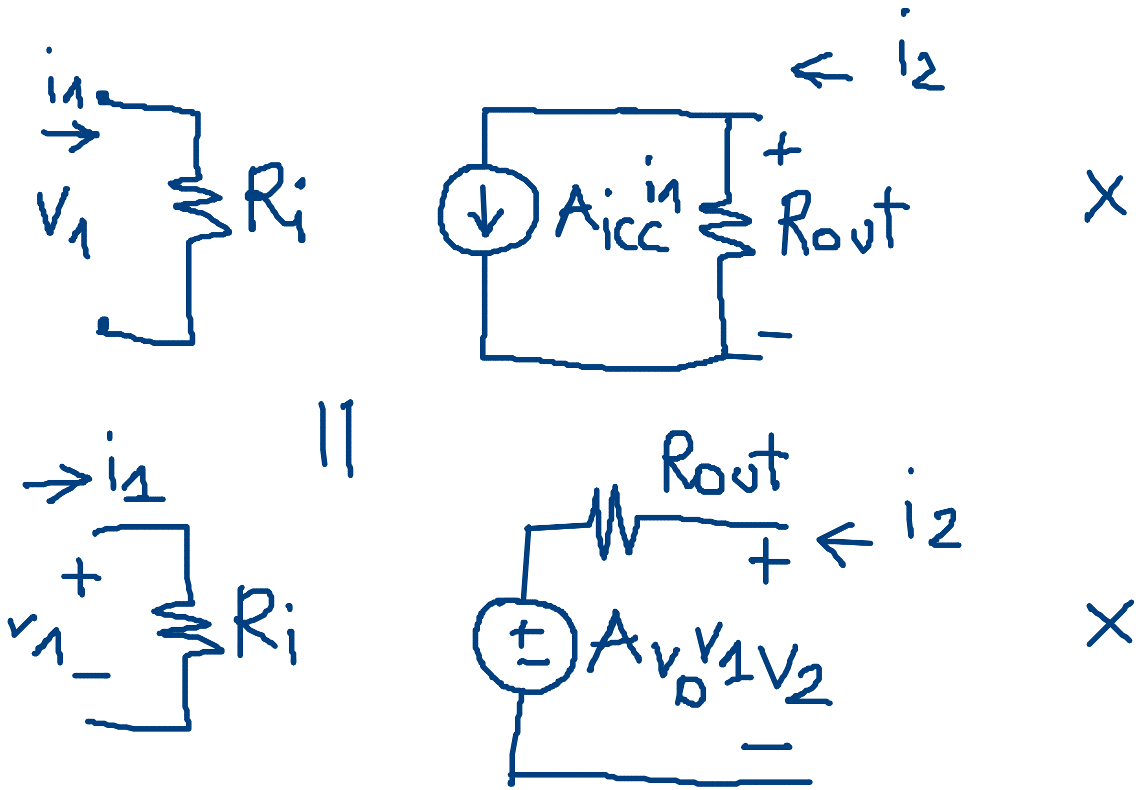


Amplif. di corr. di cc

$h_{11} = R_{in}$

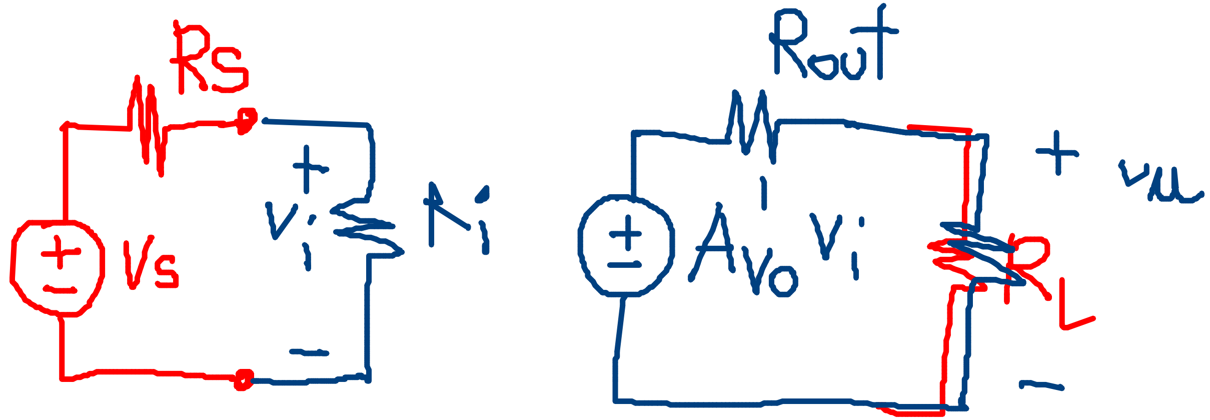
$\frac{1}{h_{22}} = R_{out}$

$h_{21} = A_{icc}$



$$A_{vo} v_1 = -A_{icc}\, i_1 R_{out}$$

$$\left[A_{vo} = -\frac{A_{icc} R_{out}}{R_i} \right]$$



$$V_i = V_S \frac{R_i}{R_i + R_S}$$

$$V_u = \frac{R_L}{R_L + R_{out}} A'_{vo} V_i$$

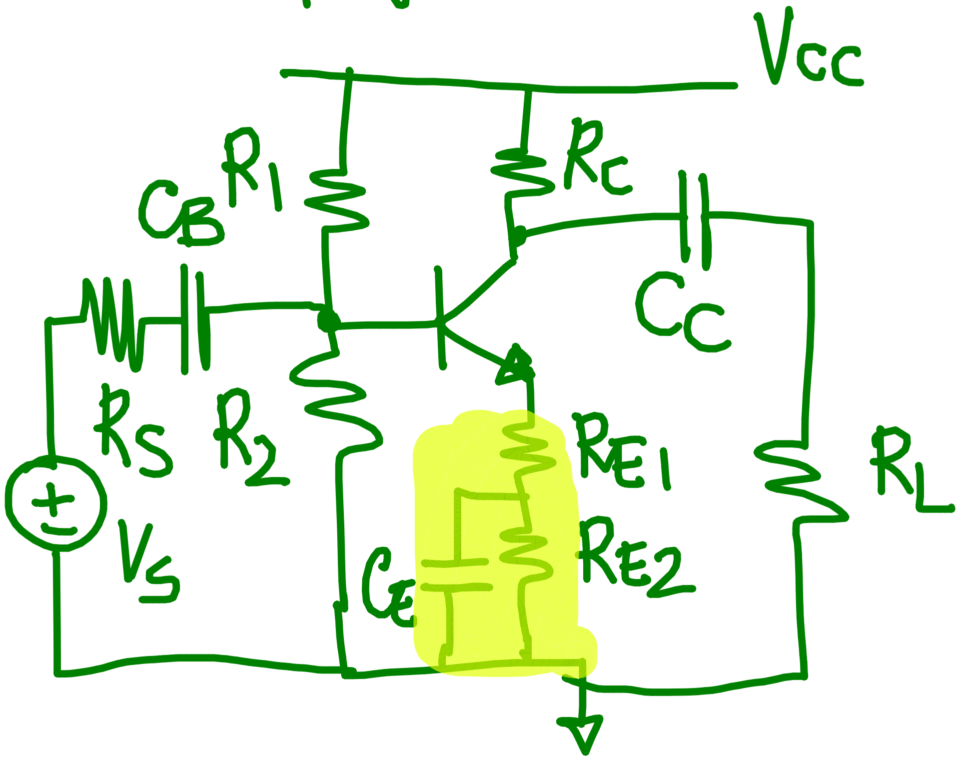
$$A_V = \frac{V_u}{V_S} = \frac{R_L}{R_L + R_{out}} A'_{vo} \frac{R_i}{R_i + R_S} \leq A'_{vo}$$

Es. CE

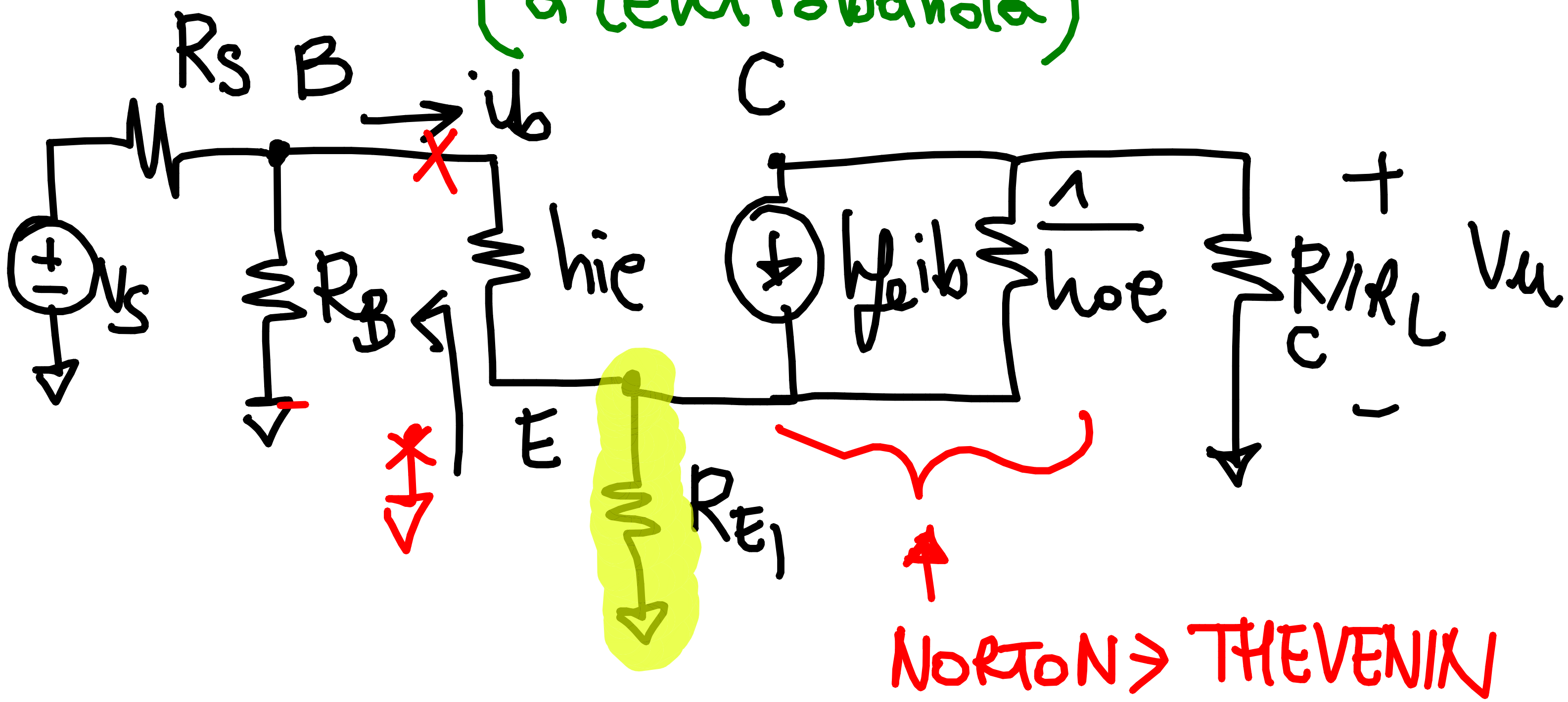
$$A_v = \frac{v_u}{v_s} = \frac{R_L}{R_L + R_C \parallel \frac{1}{h_{oe}}} \left[- \frac{h_{fe} \, R_C \parallel \frac{1}{h_{oe}}}{h_{ie}} \right] \frac{h_{ie} \parallel R_B}{h_{ie} \parallel R_B + R_S}$$

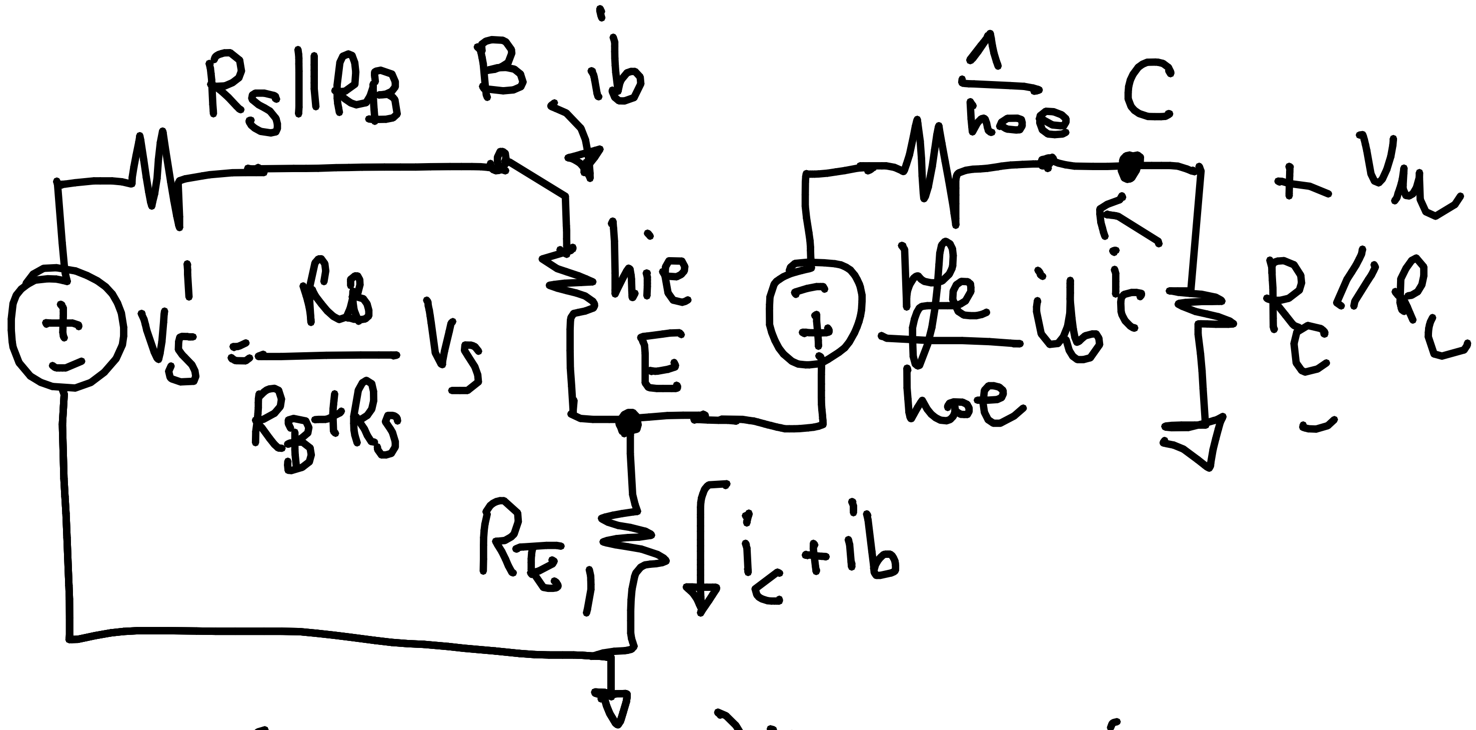
R_L'

Amplificatore CE con RE



Circuito per i piccoli segnali
(a centrobanda)





$$V_S' = (R_S \| R_B + R_{E_1} + h_{ie})\, i_b + R_{E_1}\, i_c$$

$$\frac{h_{fe}\, i_b}{h_{oe}} = + R_{E_1}\, i_b + \left[R_C \| R_L + \frac{1}{h_{oe}} \right] i_c \rightarrow$$

$$\frac{i_c}{i_b} = \frac{h_{fe} - R_{E_1} h_{oe}}{1 + h_{oe}(R_C // R_L)} = h_{fe}'$$

$h_{fe}' < h_{fe}$ se $h_{oe} = 0 \rightarrow h_{fe}' = h_{fe}$

$$i_c = v_s' \frac{h_{fe}'}{R_S \| R_B + h_{ie} + R_{E_1}(h_{fe}' + 1)}$$

$$A_v = \frac{v_u}{v_s} = \frac{-h_{fe}' R_C}{R_S \| R_B + h_{ie} + R_{E_1}(h_{fe}' + 1)} \cdot \frac{R_B}{R_B + R_S}$$

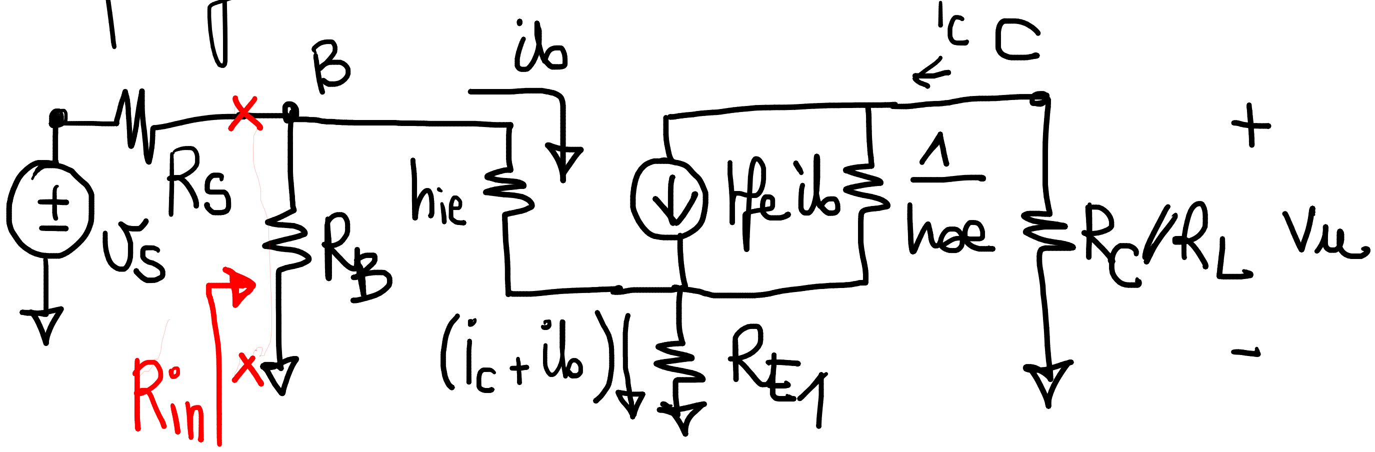
Es: se $R_{E1} = 0$

$A_V \rightarrow A_V$ del caso CE

$\rightarrow$ la presenza di R_{E1} abbassa A_V

$R_{E1} \uparrow$

Amplificatore CE con RE.



$$\frac{i_c}{i_b} = h_{fe}' = \frac{h_{fe} - h_{oe} R_{E1}}{1 + (R_C \| R_L) h_{oe}} \qquad (h_{fe}' \leq h_{fe})$$

Calcolo di Rin

- tolgo R_B $\rightarrow v_b = h_{ie} i_b + R_{E1} i_b (h_{fe}' + 1)$

$$\frac{v_b}{i_b} = h_{ie} + R_{E1}(1 + h_{fe}') \rightarrow$$

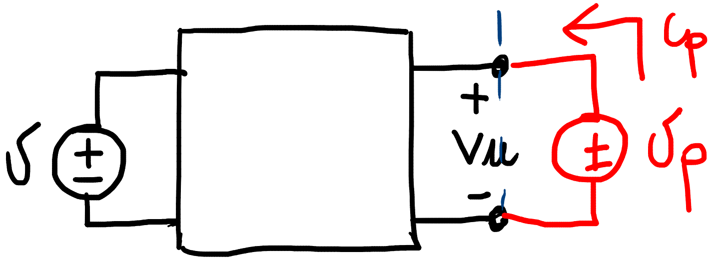
Reinserisco R_B

$$R_{in} = R_B // \left[h_{ie} + R_{E_1}(1 + h_{fe}') \right]$$

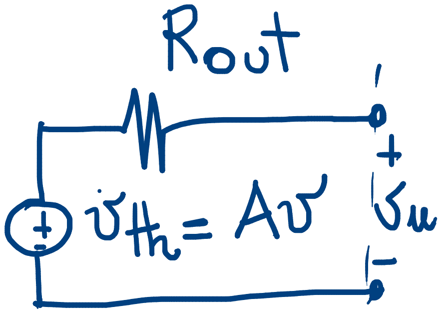
(se $R_{E_1} = 0$ ricado nel caso CE)

$\Rightarrow R_{E_1} \uparrow \quad R_{in} \uparrow$

Resistenza di uscita



$$R_{out} \triangleq \left.\frac{v_p}{i_p}\right|_{\text{tutti i gen. indipendenti spenti}}$$



(Rout è la Resistenza eq. di thevenin)

·) Calcolare $v_{u0} = v_{th}$

↑ tensione di uscita a vuoto

·) Calcolare i_{ucc} (corrente di uscita di corto circuito)

$$\boxed{R_{out} = \frac{v_{u0}}{i_{ucc}}}$$

$$v_{u0} = v_S A_V \Big|_{R_L \to \infty} = v_S \frac{\left(-h_{fe}'^{*} R_C\right)}{R_B \| R_S + h_{ie} + \left(h_{fe}'^{*} + 1\right) R_{E_1}} \cdot \frac{R_B}{R_B + R_S}$$

$$h_{fe}'^{*} = \frac{h_{fe} - h_{oe} R_{E_1}}{1 + R_C h_{oe}}$$

$$i_{ucc} = \lim_{R_L \to 0} \frac{v_u}{(R_C \| R_L)} = \lim_{R_L \to 0} \left(\frac{v_S A_V}{R_C \| R_L} \right) =$$

$$= \lim_{R_L \to 0} \left[\frac{-h_{fe}' \cancel{(R_C \| R_L)}}{R_B \| R_S + h_{ie} + \left(h_{fe}' + 1\right) R_{E_1}} \cdot \frac{R_B}{R_B + R_S} \cdot \frac{v_S}{\cancel{R_C \| R_L}} \right] =$$

$$= \frac{-h_{fe}'^{**}}{R_B \| R_S + h_{ie} + \left(1 + h_{fe}'^{**}\right) R_{E_1}} \cdot \frac{R_B}{R_B + R_S} v_S \qquad \left[h_{fe}'^{**} = \frac{h_{fe} - h_{oe} R_{E_1}}{1} \right]$$

$$R_{out} = \frac{v_{uo}}{u_{cc}} = \frac{h_{fe}'^{*} R_C}{R_B \| R_S + h_{ie} + (h_{fe}'^{*} + 1) R_{E_1}} \cdot \frac{R_B \| R_S + h_{ie} + (1 + h_{fe}'^{**}) R_E}{h_{fe}'^{**}}$$

$\rightarrow$ se $h_{oe} = 0 \rightarrow h_{fe}'^{*} = h_{fe}'^{**} = h_{fe} \rightarrow \underline{\underline{R_{out} = R_C}}$

altrimenti

$$R_{out} = \frac{(h_{fe} - h_{oe} R_{E_1}) R_C}{[R_B \| R_S + h_{ie}](1 + h_{oe} R_C) + (h_{fe} + 1 - h_{oe} R_{E_1}) R_{E_1}} \times$$

$$\times \frac{[R_B \| R_S + h_{ie}] + (h_{fe} + 1 - h_{oe} R_{E_1}) R_{E_1}}{(h_{fe} - h_{oe} R_{E_1})}$$

$$R_{out} = R_C \frac{R_B \| R_S + h_{ie} + (h_{fe} + 1 - h_{oe} R_{E_1}) R_{E_1}}{[R_B \| R_S + h_{ie}](1 + h_{oe} R_C) + (h_{fe} + 1 - h_{oe} R_{E_1}) R_{E_1}}$$

in generale $R_{out} \leq R_C$

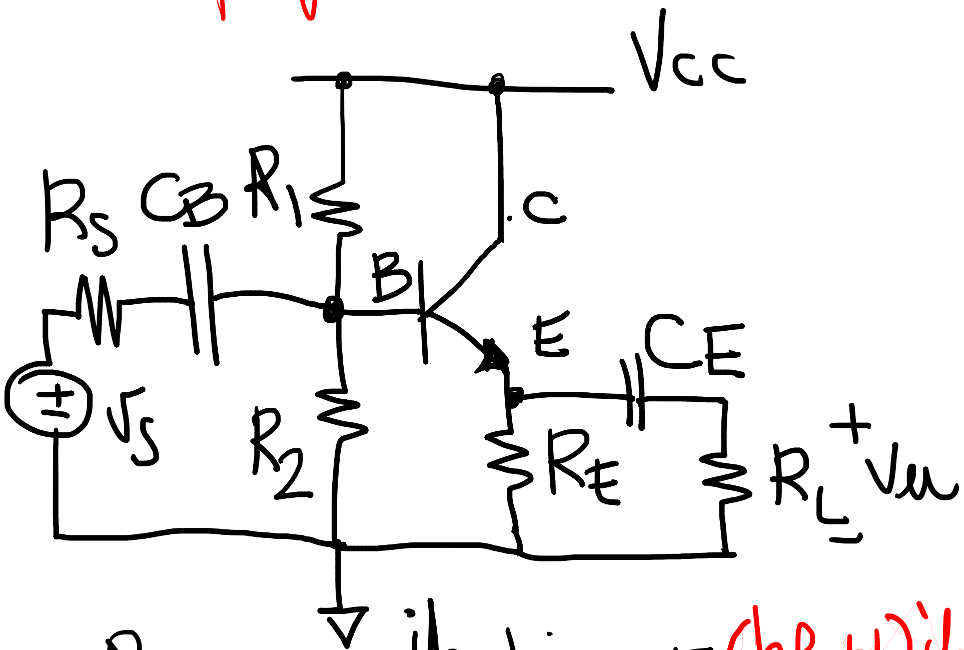
se $h_{oe} R_C \ll 1$ allora $R_{out} \sim R_C$

$$h_{fe}' = \frac{h_{fe} - h_{oe} R_{E_1}}{1 + (R_C \| R_L) h_{oe}} \rightarrow$$

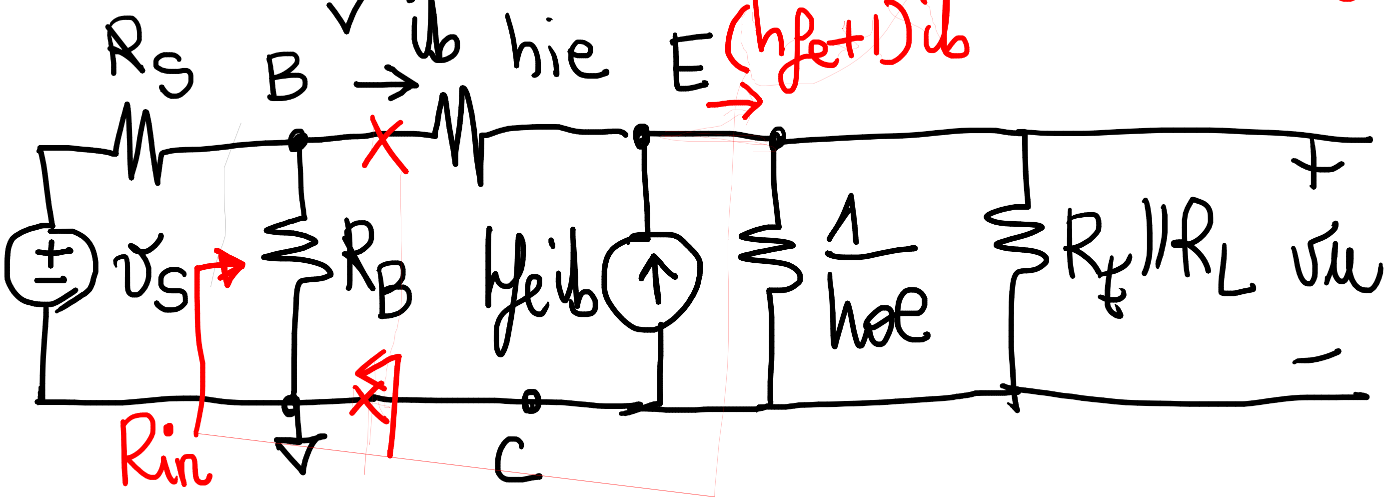
Se $\left(\frac{1}{h_{oe}}\right) \ll R_{E_1}, R_C \longrightarrow h_{fe}' \sim h_{fe}$

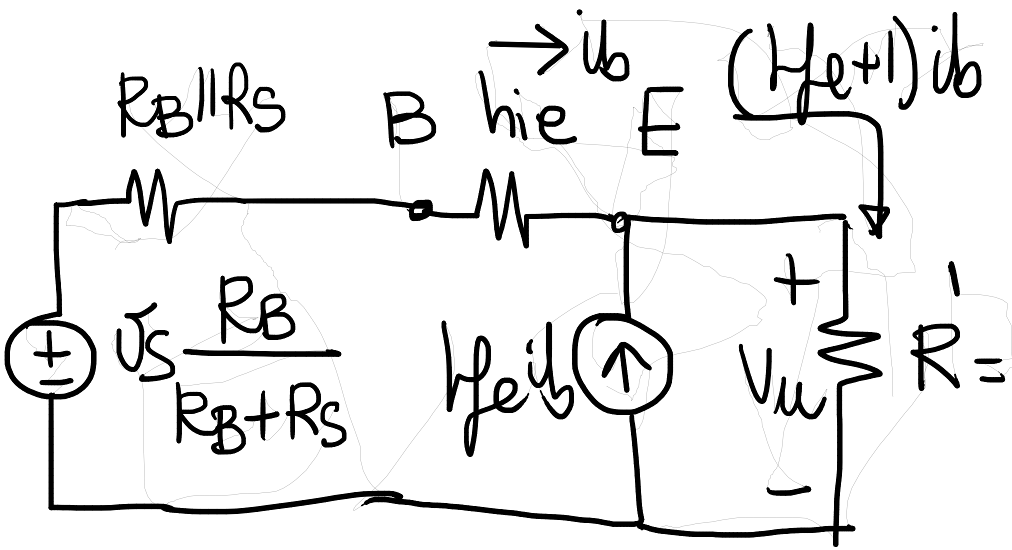
Si può considerare $h_{oe} = 0$

Amplificatore a Collettore Comune (CC)



circuito per le variazione





$$R' = R_E \,//\, R_L \,//\, \left(\frac{1}{h_{oe}}\right)$$

$$v_S \frac{R_B}{R_B+R_S} = (R_B \| R_S + hie)\, i_b + \underbrace{R'(h_{fe}+1)\, i_b}_{v_u}$$

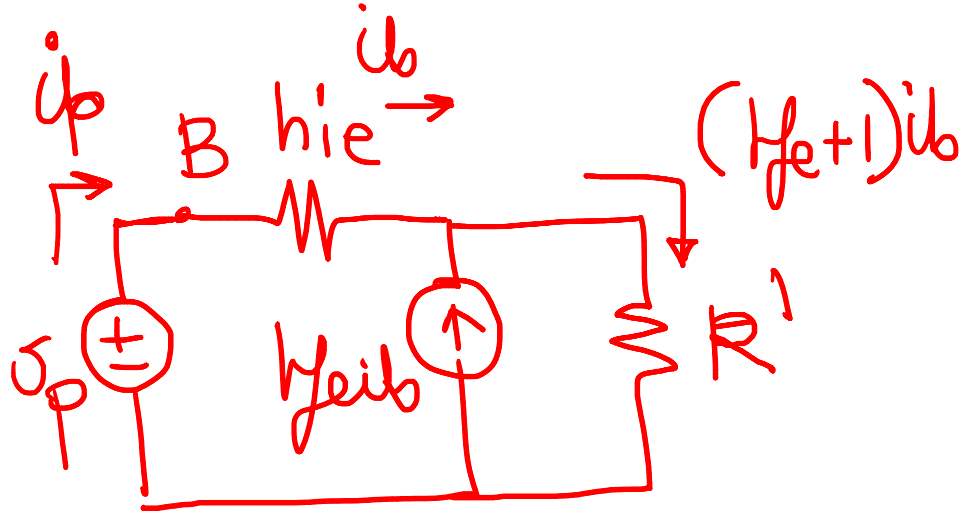
$$A_v = \frac{v_u}{v_S} = \frac{R'(h_{fe}+1)}{R'(h_{fe}+1) + (R_B \| R_S + hie)} \cdot \frac{R_B}{R_B+R_S}$$

1) $A_v > 0$

R_{in}

1) Tolgo R_B

2) calcolo $\frac{v_p}{i_p}$



$$\frac{v_p}{i_p} = h_{ie} + R'(h_{fe}+1)$$

3) Reinserisco R_B

$$R_{in} = R_B \parallel \left[h_{ie} + \underbrace{R'}_{R_E \parallel R_L \parallel \left(\frac{1}{h_{oe}}\right)}(h_{fe}+1) \right]$$

$$R_{out} = \frac{V_{uo}}{I_{ucc}} \qquad V_{uo} = \frac{R_B}{R_B + R_S} \cdot \frac{\left(R_E \parallel \frac{1}{h_{oe}}\right)\left[1 + h_{fe}\right] v_s}{R_B \parallel R_S + h_{ie} + \left[R_E \parallel \left(\frac{1}{h_{oe}}\right)\right]\left[h_{fe} + 1\right]}$$

$$I_{ucc} = \lim_{R_L \to 0} \frac{v_u}{R_L} = \lim_{R_L \to 0} \left[\frac{A_v \, v_s}{R_L} \right]$$

$$= \lim_{R_L \to 0} \left[\frac{\left[R_E \parallel R_L \parallel \frac{1}{h_{oe}}\right](1 + h_{fe})}{R_B \parallel R_S + h_{ie} + \left[R_E \parallel R_L \parallel \frac{1}{h_{oe}}\right](1 + h_{fe})} \cdot \frac{R_B}{R_B + R_S} \cdot \frac{v_s}{R_L} \right]$$

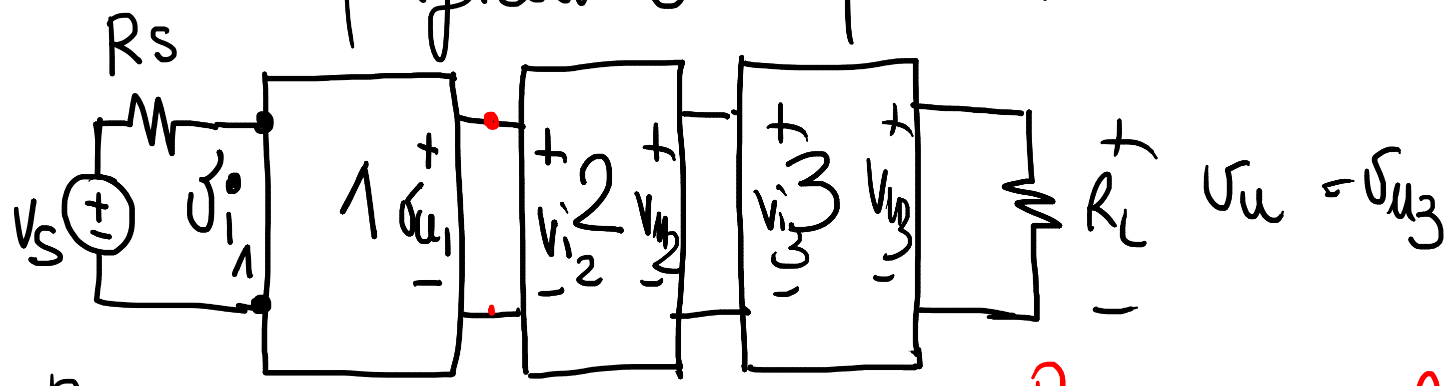
$$I_{ucc} = \frac{(1 + h_{fe})}{R_B \parallel R_S + h_{ie}} \cdot \frac{R_B}{R_B + R_S} \, v_s$$

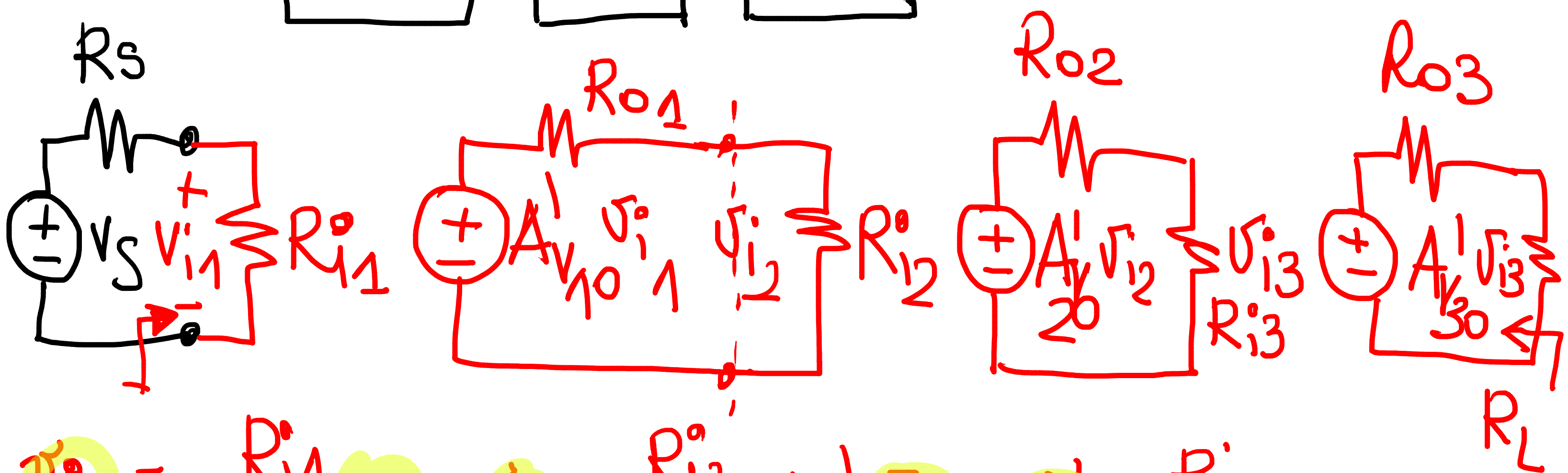
$$R_{out} = \frac{v_{ue}}{i_{uec}} = \frac{\left(R_E \parallel \frac{1}{h_{oe}}\right)\left(R_B \parallel R_S + h_{ie}\right)}{R_B \parallel R_S + h_{ie} + \left(R_E \parallel \frac{1}{h_{oe}}\right)(1 + h_{fe})}$$

$$R_{out} \simeq \left[\frac{R_B \parallel R_S + h_{ie}}{1 + h_{fe}}\right]$$

	Avo	R_{in}	R_{out}
CE	<0 alta ($\propto h_{fe}$)	media	alta
CE con RE	<0 media	alta	alta
CC	>0 bassa ($0<A_v<1$)	alta	bassa

Amplificatore a più stadi



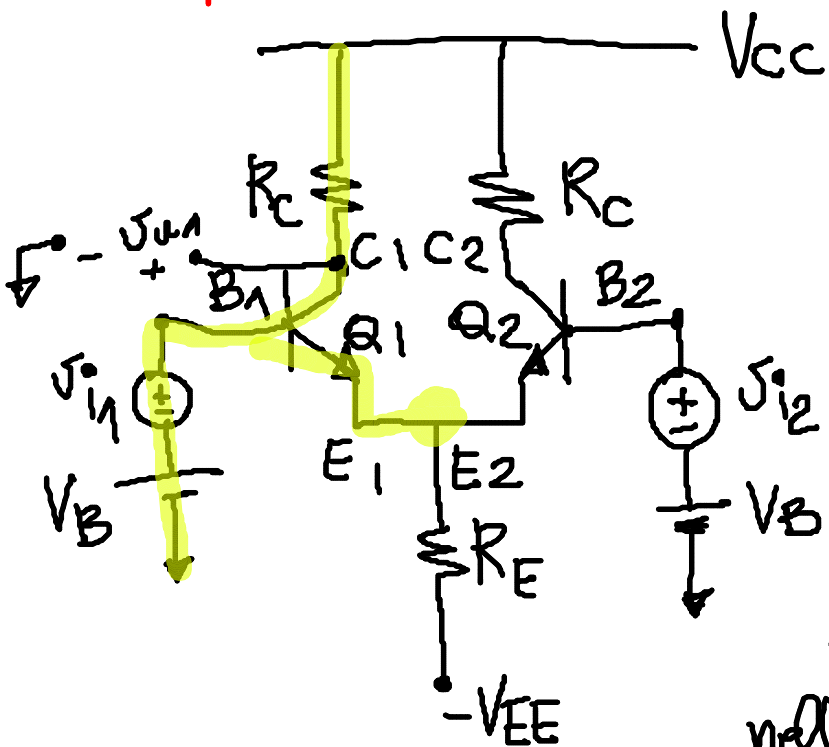


$$v_{i1} = \frac{R_{i1}}{R_{i1}+R_S} v_S \, ; \quad v_{i2} = \frac{R_{i2}}{R_{i2}+R_{o1}} A'_{v10} v_{i1} \, ; \quad v_{i3} = \frac{R_{i3}}{R_{i3}+R_{o2}} A'_{v20} v_{i2}$$

$$v_u = \frac{R_L}{R_L + R_{o3}} A'_{v30}\, v_{i3}$$

$$A_v = \frac{v_u}{v_S} = A'_{v10}\, A'_{v20}\, A'_{v30} \underbrace{\frac{R_L}{R_L + R_{o3}} \frac{R_{i3}}{R_{i3} + R_{o2}} \cdot \frac{R_{i2}}{R_{i2} + R_{o1}} \cdot \frac{R_{i1}}{R_{i1} + R_S}}_{< 1}$$

Amplificatore differenziale a BJT



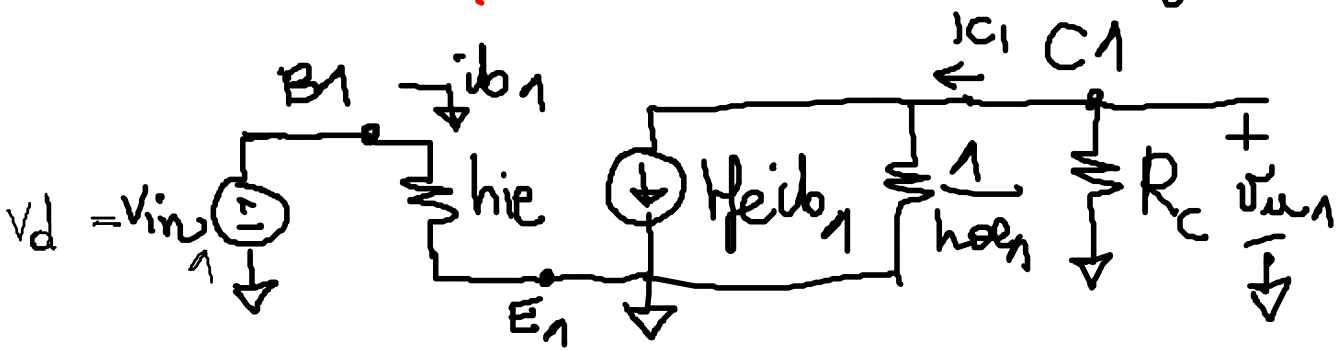
Circuito perfettamente **SIMMETRICO**

i 2 transistor sono polarizzati (bias) nello stesso punto di riposo

Funzionamento in MODO DIFFERENZIALE

- → $v_{i1} = -v_{i2} = v_d$
- → tutti i nodi simmetrici rispetto ai due generatori hanno variazione nulla
- → Posso studiare solo metà circuito (l'altra metà ha variazione uguali e opposte in segno)

Circuito di p.s.



$$\frac{v_{u1}}{v_d} = -\frac{\left(R_c \parallel \frac{1}{h_{oe}}\right) h_{fe}}{h_{ie}} \sim -\frac{R_c h_{fe}}{h_{ie}}$$

(se $h_{oe} = 0$)
$\left(\frac{1}{h_{oe}} \gg R_c\right)$

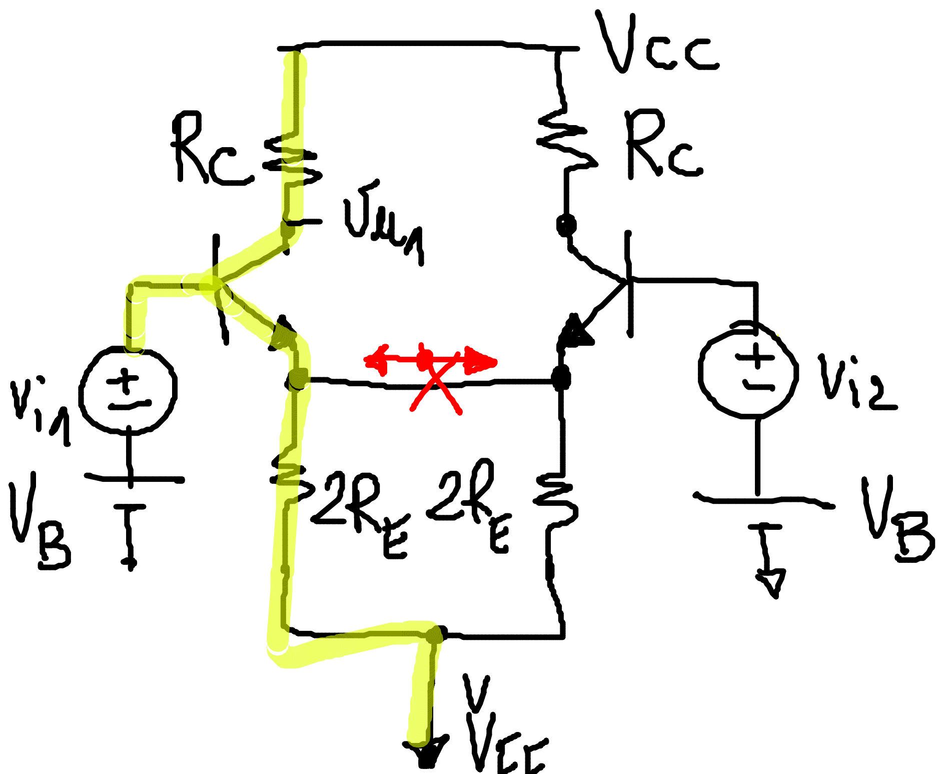
$$A_d \triangleq \frac{v_{u1}}{2v_d} = -\frac{R_c h_{fe}}{h_{ie}}$$

$2v_d = (v_{i1} - v_{i2})$ ← tensione differenziale di ingresso

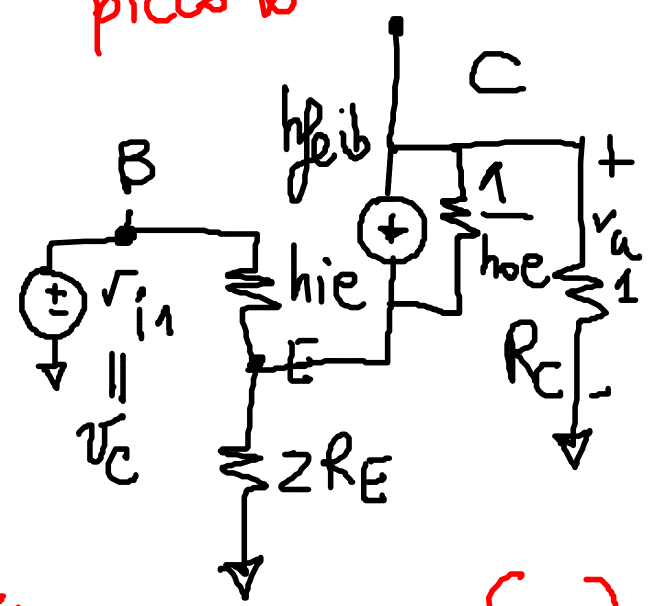
A_d: Amplificazione differenziale

Funzionamento in MODO COMUNE

$$v_{i1} = v_{i2} = v_C$$



Circuito eq. piccolo



Stadio CE con R_E ($2R_E$)

$$A_c \triangleq \frac{v_{u1}}{v_c} = \frac{-h_{fe}' R_c}{h_{ie} + 2R_E h_{fe}'} \simeq \frac{-h_{fe} R_c}{h_{ie} + 2R_E h_{fe}}$$

A_c ↑ amplificazione di modo comune

$h_{oe} \simeq 0$

$$h_{fe}' = \frac{h_{fe} - 2R_E h_{oe}}{1 + h_{oe} R_c}$$

se $\frac{1}{h_{oe}} \gg R_E, R_c \Rightarrow h_{fe}' = h_{fe}$

$$v_{u_1} = a_1 v_{i_1} + a_2 v_{i_2}$$ ← perchè il circuito è lineare

$$v_{u_1} = \left(\frac{a_1 - a_2}{2}\right)(v_{i_1} - v_{i_2}) + (a_1 + a_2)\left(\frac{v_{i_1} + v_{i_2}}{2}\right)$$

$$v_{u_1} = A_d v_d + A_c v_c$$

$$a_1 = A_d + \frac{A_c}{2} \qquad a_2 = -A_d + \frac{A_c}{2}$$

$$v_{u_1} = \left(A_d + \frac{A_c}{2}\right) v_{i_1} + \left(-A_d + \frac{A_c}{2}\right) v_{i_2}$$

Amplificatore differenziale se $A_c \ll A_d$

$$v_{u_1} = A_d v_d + A_c v_c \sim A_d v_d$$

l'uscita dipende (quasi) solo dalla tensione differenziale

CMRR Common Mode Rejection Ratio

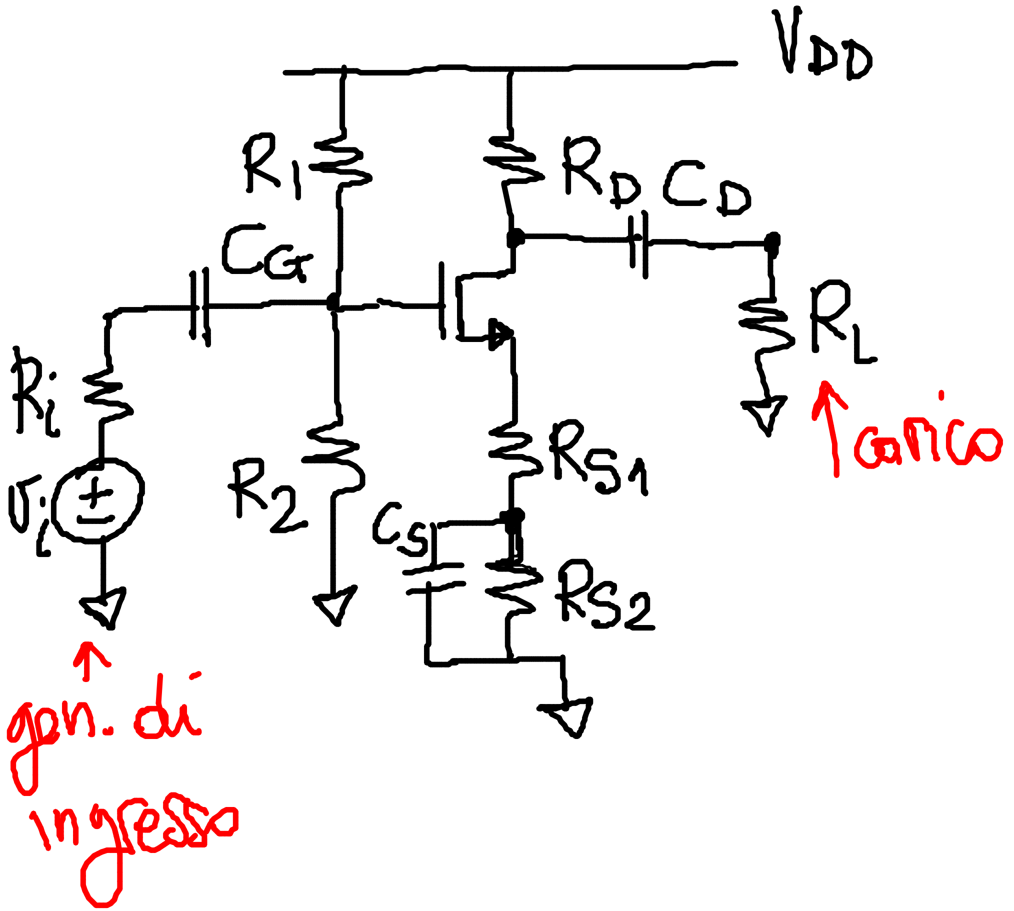
↳ Rapporto di reiezione del modo comune

$$CMRR = \frac{A_d}{A_c}$$

tipicamente CMRR $10^3 \div 10^7$

Stadi amplificatori con FET

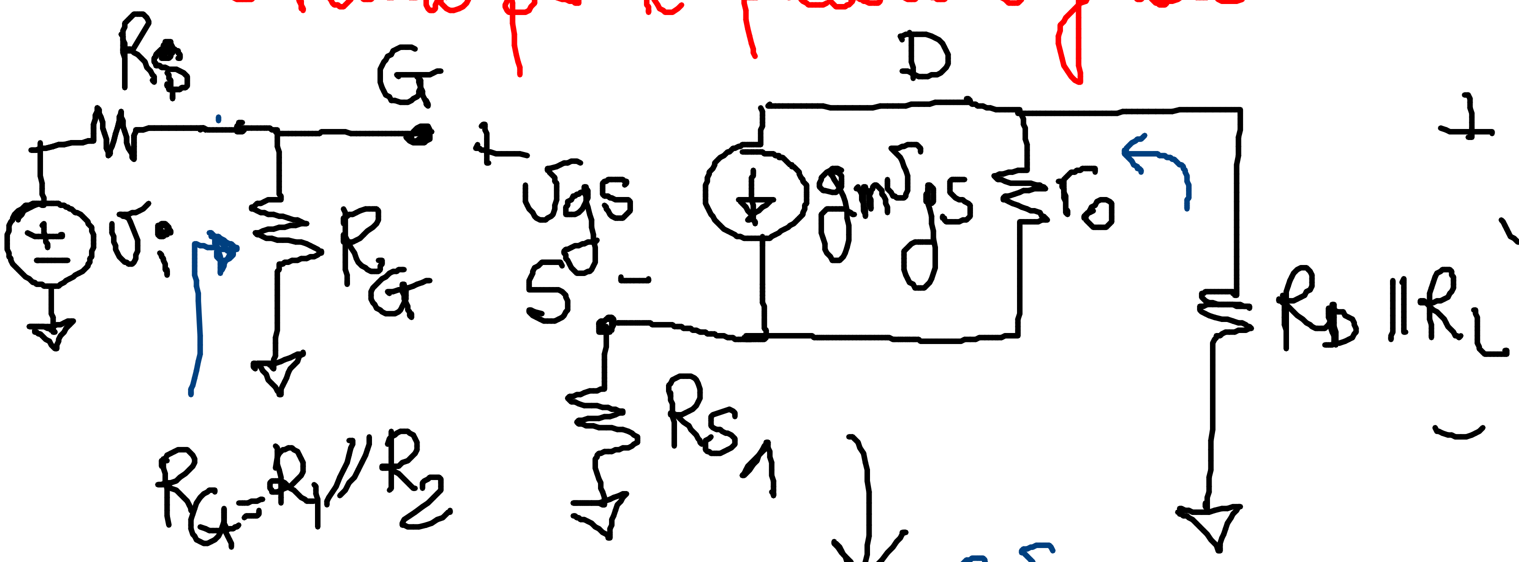
Stadio Common Source con R_S



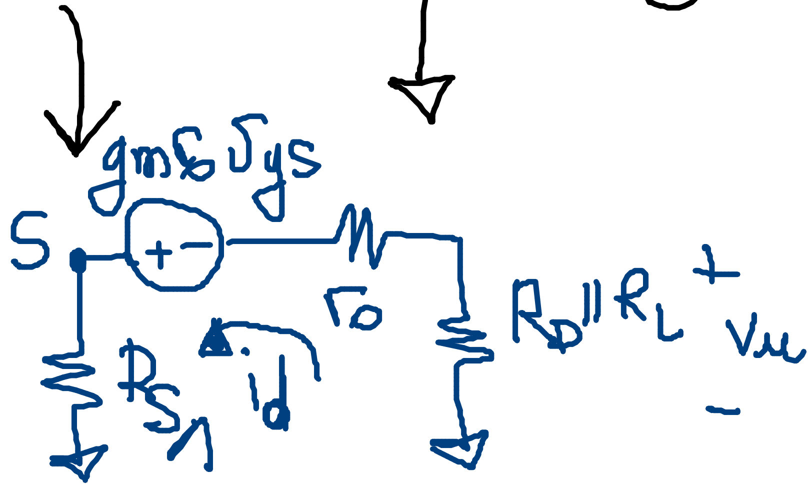
C_G, C_D capacità di accoppiamento

C_S capacità di bypass

circuito per il piccolo segnale



$R_G = R_1 // R_2$



$$v_g = v_i \frac{R_G}{R_G + R_i}$$

$$i_d = \frac{g_m v_{gs} r_o}{R_{S1} + r_o + R_D // R_L}$$

$$v_{gs} = v_g - R_{S1} i_d$$

$$i_d\left(R_{S_1} + r_o + R_D \| R_L\right) = g_m r_o\left(v_g - R_{S_1} i_d\right)$$

$$i_d = \frac{g_m r_o}{R_{S_1}\left(1 + g_m r_o\right) + r_o + R_D \| R_L} v_g$$

$$v_u = -i_d\left(R_D \| R_L\right)$$

$$A_v = \frac{v_u}{v_i} = \frac{-g_m r_o\left(R_D \| R_L\right)}{R_{S_1}\left(1 + g_m r_o\right) + r_o + R_D \| R_L} \cdot \left[\frac{R_G}{R_G + R_i}\right]$$

se R_{S_1} non è troppo piccola

cioè se $g_m r_o R_{S_1} \gg R_{S_1} + r_o + R_D /\!/ R_L$

allora $A_V \simeq -\dfrac{R_D /\!/ R_L}{R_{S_1}} \left(\dfrac{R_G}{R_G + R_i}\right)$

RICORDA stadio CE con R_E

$$A_V \simeq \frac{-h_{fe}'(R_C /\!/ R_L)}{R_B /\!/ R_S + h_{ie} + (h_{fe}'+1)R_E} \left(\frac{R_B}{R_B + R_S}\right) \simeq -\frac{R_C /\!/ R_L}{R_E} \left(\frac{R_B}{R_B + R_S}\right)$$

↑ se R_E NON è troppo piccola

Se bypassiamo completamente R_S $(R_{S_1} = 0)$

allora $A_V = \dfrac{-g_m r_o (R_D // R_L)}{r_o + R_D // R_L} \left(\dfrac{R_G}{R_G + R_i} \right)$

$$A_V = -g_m \left[r_o // R_D // R_L \right] \frac{R_G}{R_G + R_i}$$

$\underline{R_{in}} = R_G$ →

Resistenza di uscita

$$R_{out} = \frac{V_{u0}}{i_{ucc}} =$$

$$V_{u0} = A_v \Big|_{R_L \to \infty} v_i$$

$$i_{ucc} = \lim_{R_L \to 0} \left[\frac{v_u}{R_L} \right] = \lim_{R_L \to 0} \left[\frac{A_v}{R_L} \right] v_i$$

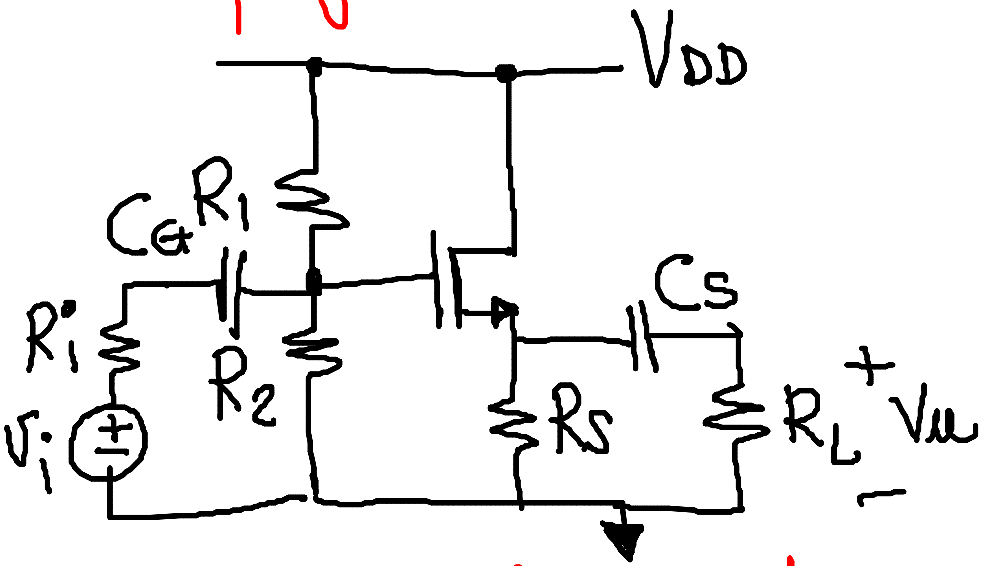
$$R_{out} = \frac{\ominus\, g_m r_o R_D}{R_{S_1}(1+g_m r_o)+r_o+R_D} \cdot \lim_{R_L \to 0} \left[\frac{R_{S_1}(1+g_m r_o)+r_o+R_L}{\ominus\, g_m r_o R_L} \cdot R_L \right]$$

$$R_{out} = R_D \parallel \left[R_{S_1}(1+g_m r_o) + r_o \right]$$

NOTA $R_{S_1} \uparrow \rightarrow R_{out} \uparrow$

se $R_{S_1} = 0 \rightarrow R_{out} = R_D \parallel r_o$

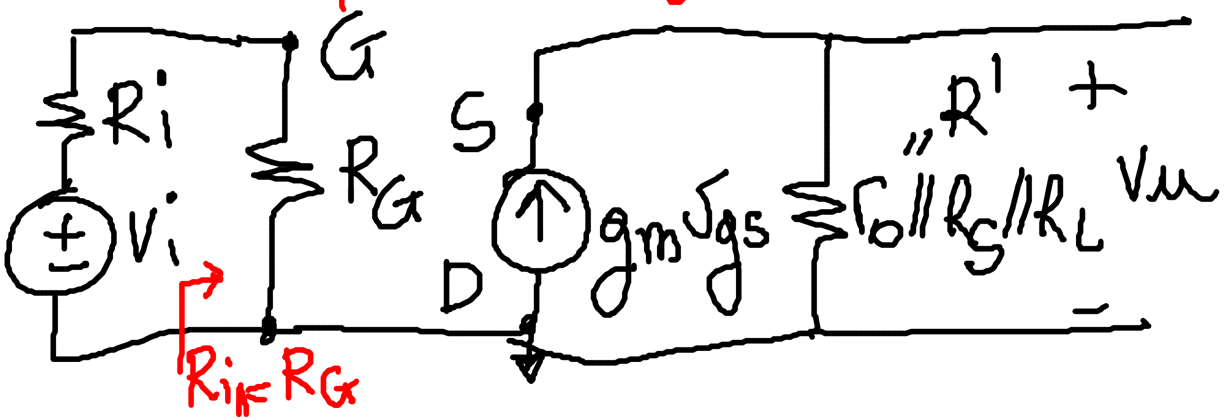
Amplificatore Common Drain (CD)



$$v_g = v_i \frac{R_G}{R_G + R_i}$$

$$v_u = v_s = g_m v_{gs} R'$$

circuito di piccolo segnale



$$v_u = g_m R' (v_g - v_u) \rightarrow v_u = \frac{g_m R'}{1 + g_m R'} v_g$$

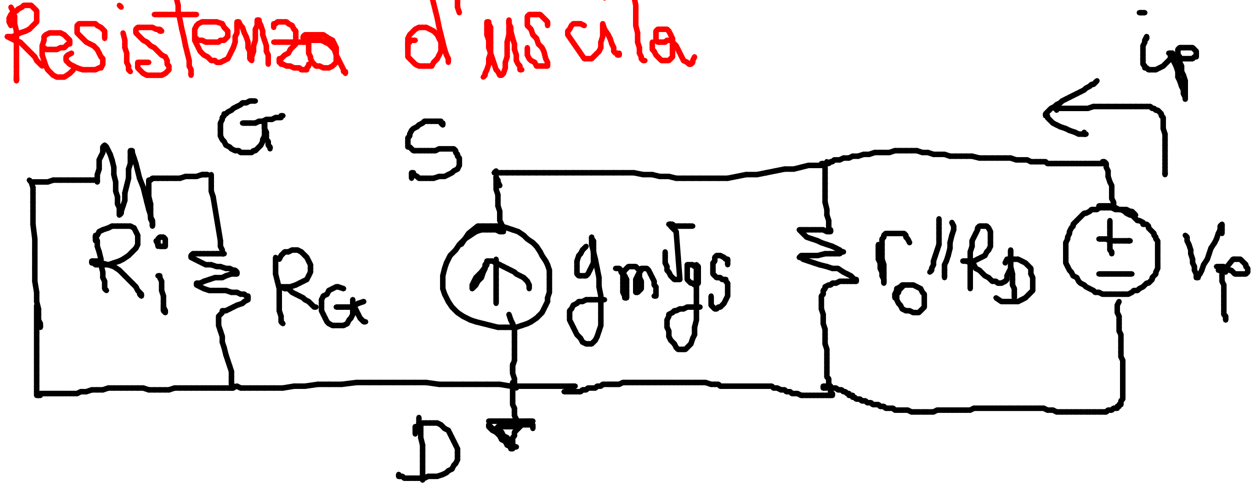
$$A_V = \frac{v_u}{v_i} = \frac{g_m R'}{1 + g_m R'} \cdot \frac{R_G}{R_G + R_i}$$

$$(R' = r_o \,//\, R_S \,//\, R_L)$$

$$0 < A_V < 1$$

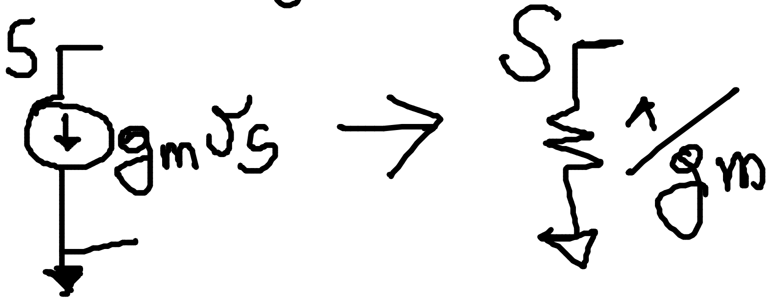
Se $A_V \approx 1$ si chiamo insequitore di source
"source follower"

Resistenza d'uscita



$$\frac{v_p}{i_p}$$

$$v_g = 0 \rightarrow v_{gs} = -v_s$$



$$R_{out} = \frac{1}{g_m} // r_o // R_D \simeq \frac{1}{g_m}$$

	Av	Rout	Rin
CS	<0 alta	media	
CS con Rs	<0 media	alta	alta (R_G)
CD	>0 bassa ($0 < A_v < 1$)	bassa	