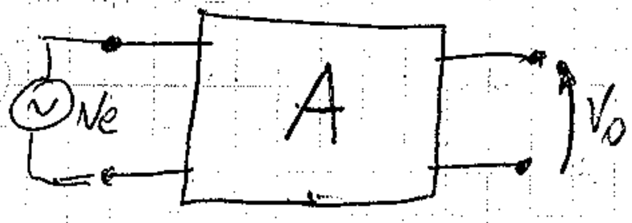
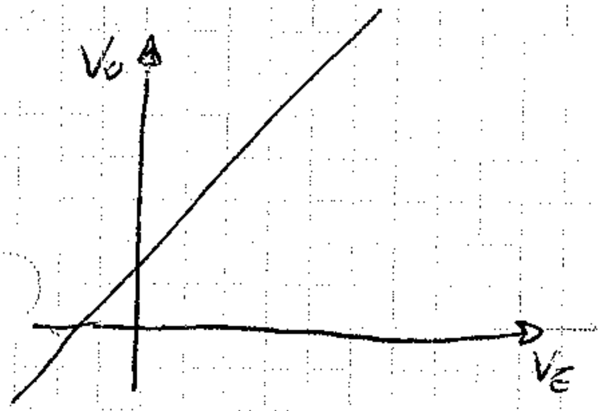
AMPLIFICATORI DI SEGNALE



$V_0 = A V_e + K$

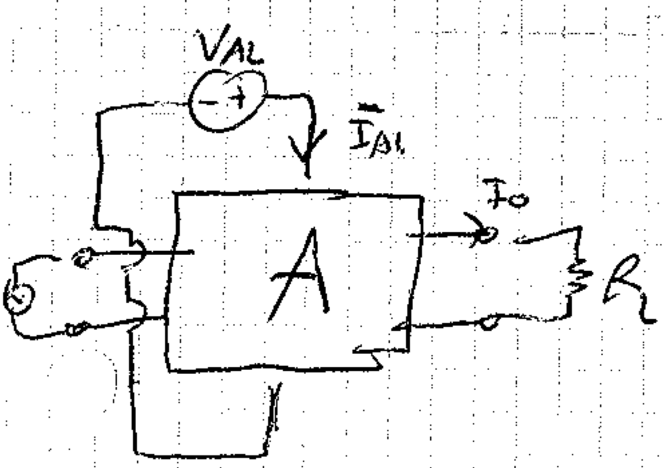


$A > 1$ amplificatore

$A = 1$ ripetitore

$A < 1$ attenuatore

$P_0 >> P_i \simeq 0$



$I_{AL} = I_{PS} + I_0$

→ per far funzionare l'amplificatore.

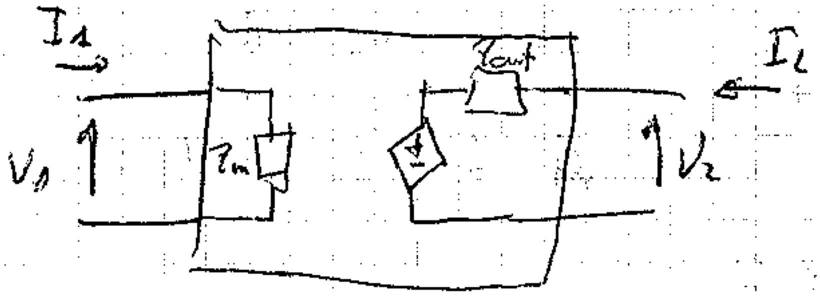
L'informazione si propaga dall'ingresso all'uscita, ma non viceversa

Sotto ipotesi di linearità

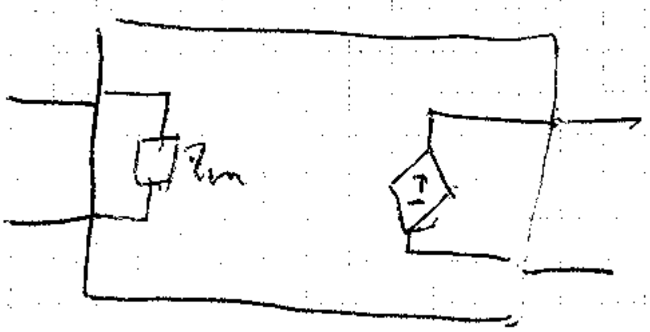
$$\begin{cases} i_1 = y_{11} v_1 + y_{12} v_2 \\ i_2 = y_{21} v_1 + y_{22} v_2 \end{cases}$$

Se il segnale si propaga dall'ingresso all'uscita, ma non viceversa vuol dire che $y_{12} = 0$. I circuiti amplificatori sono <u>non reciproci</u>.

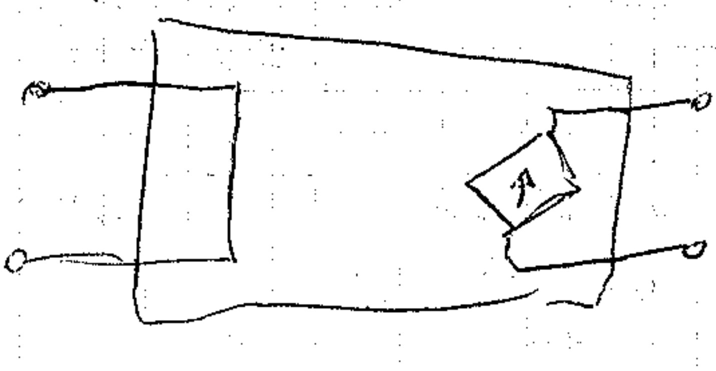
Alla base c'è l'ipotesi di linearità del doppio bipolo.



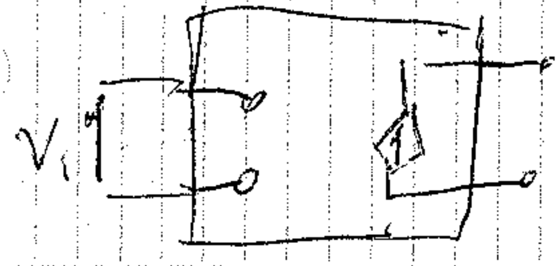
Amplificatore id. di tensione



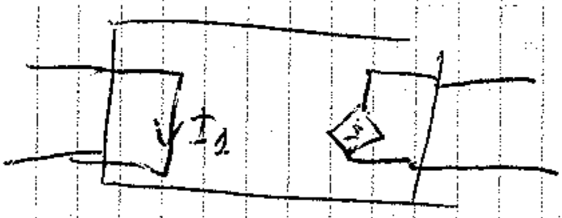
Ampl. id. di corrente



Amplificatore ideale di TRANSCONDUTTANZA



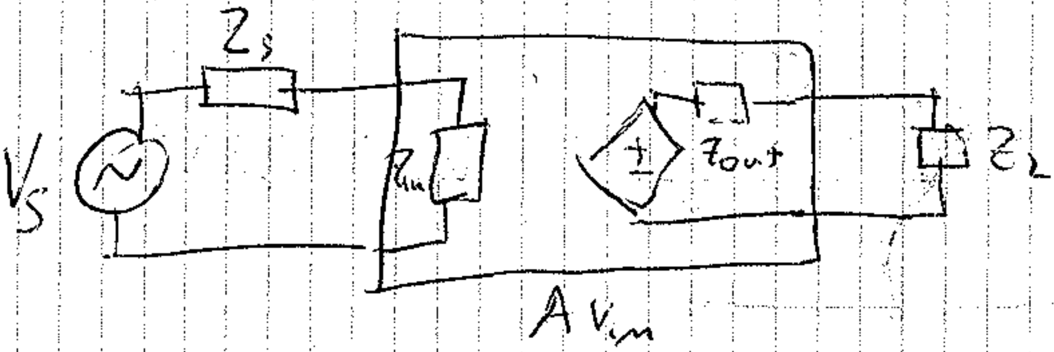
Amplif. ideale di TRANSRESISTENZA



$$V = R_M \cdot I_1$$

Per identificare un amplificatore si utilizzano i parametri:

$$\boxed{Z_{in},\ Z_{out},\ A_v}$$



$$A_v^* = \frac{V_o}{V_s}$$

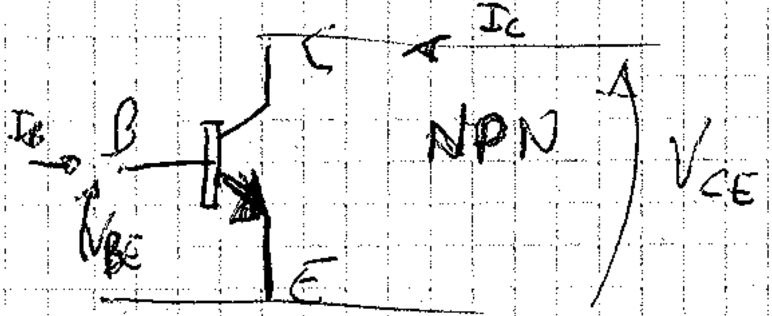
$$V_0 = \frac{Z_L}{Z_L + Z_{out}} \cdot A_V V_{in}$$

$$V_{in} = \frac{Z_{in}}{Z_{in} + Z_S} V_S$$

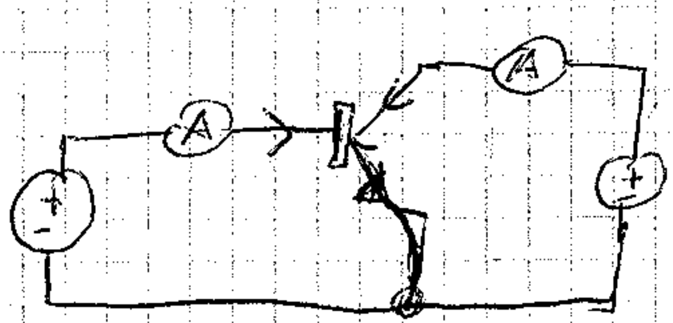
$$A_V^* = \frac{V_0}{V_S} = \frac{Z_{in}}{Z_{in} + Z_S} \cdot \frac{Z_L}{Z_L + Z_{out}} \cdot A_V$$

coeff. di amplif.

$\boxed{\text{TRANSISTORI}}$ (bipolari)



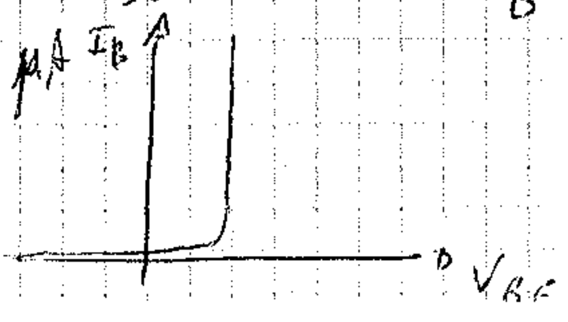
$$I_E = I_C + I_B$$



$$V_{CE} > 0{,}2\,V$$

$$V_{CE1} = 1V$$

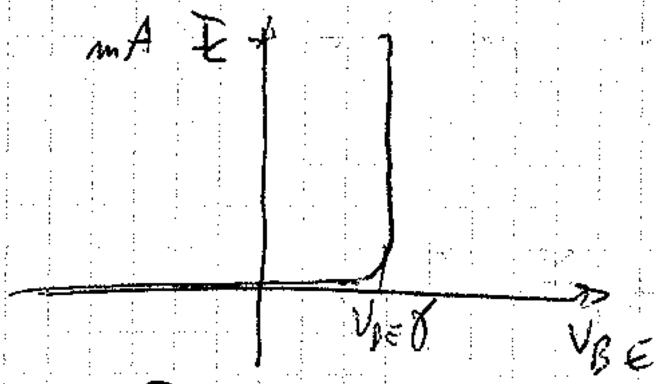
$$I_B = f(V_{BE})$$



$$I_B = I_{BO} \exp\left(\frac{V_{BE}}{\eta V_T}\right)$$

$$\eta \simeq 1 \qquad V_T = \frac{k_B T}{q}$$

$$I_C = f(V_{BE})$$



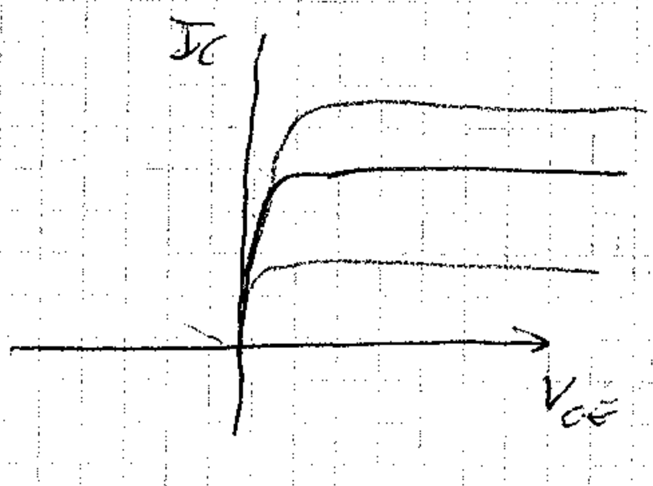
$$I_C = I_{CO} \exp\left(\frac{V_{BE}}{\eta V_T}\right)$$

$$\beta_F \doteq \frac{I_C}{I_B} \simeq \text{costante} \gg 1$$

$$10 < \beta_F < 1000$$

$$V_{BEQ} > V_{BE,\gamma}$$

$$I_C = f(V_{CE})$$

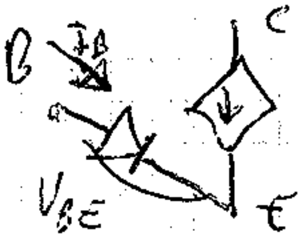


$$V_{BE} = V_{BEQ}$$

I_C è costante al variare di V_{CE}

spec. se $V_{CE} > V_{CE SAT} \simeq 0,2$ V

Tra collettore ed emettitore il transistor si comporta come

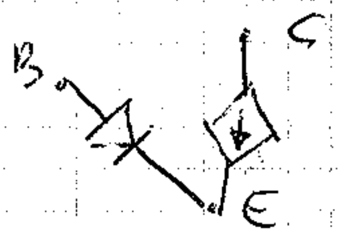


pilotata da V_{BE}

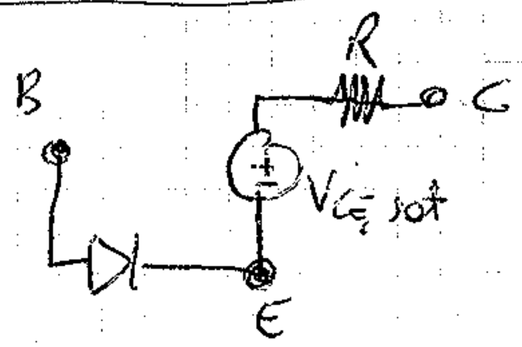
$$I_E = (\beta_F + 1) I_B \simeq I_C$$

Quindi se $\begin{cases} V_{CE} > V_{CE,SAT} \\ V_{BE} > V_{BE,\gamma} \end{cases}$ il transistor

è in regione attiva diretta ed è descritto dal modello di EBERS - MOLL

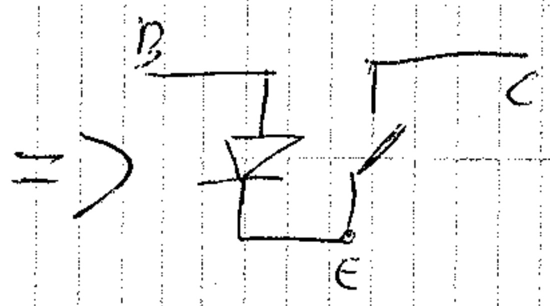


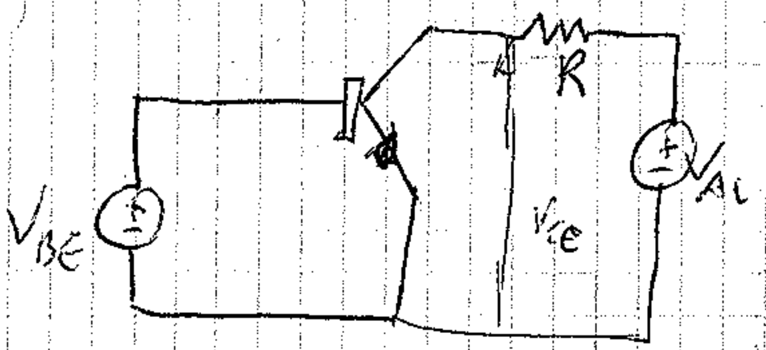
Funzionamento del transistore nella regione di saturazione ($V_{CE} < V_{CE,sat}$)



Regione di interdizione

$V_{BE} < V_{BE,\gamma} \Rightarrow$

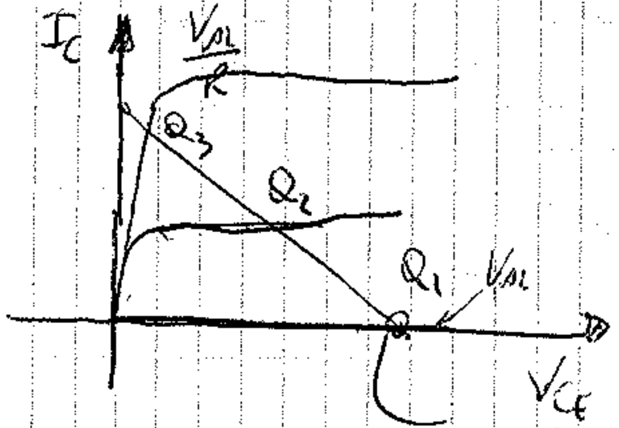




$V_{AL} = 10\ V$

$R = 1k\Omega$

$V_{BE,\gamma} = 0{,}6V$



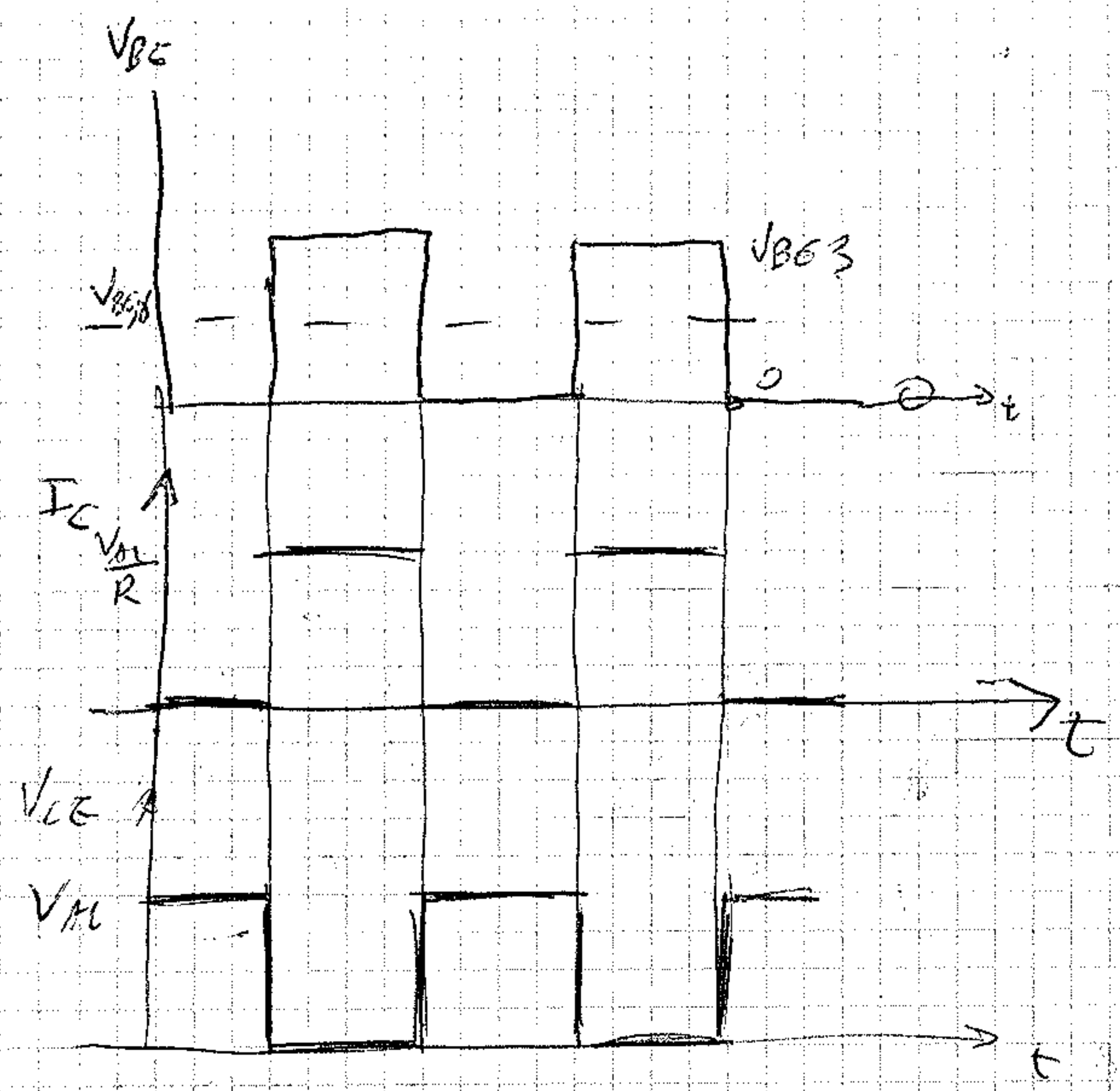
$$I_C = \frac{V_{AL} - V_{CE}}{R}$$

retta di carico del circuito

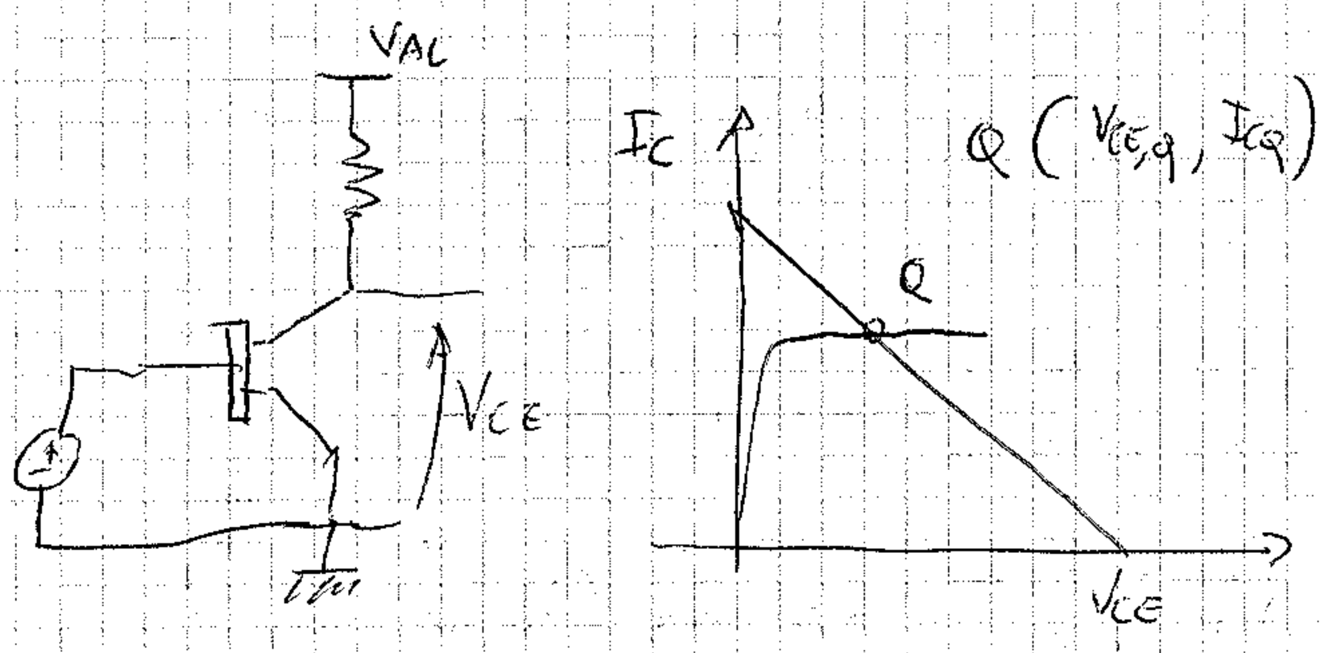
$Q_1\ (V_{AL},\ 0)$ se $V_{BE} < V_{BE,\gamma}$

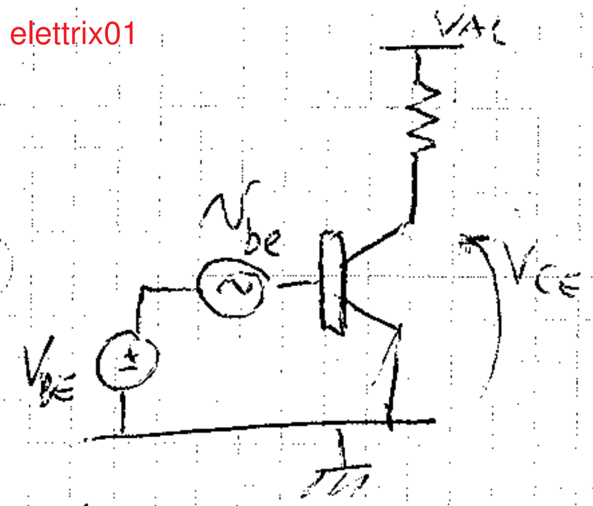
$$\begin{cases} V_{BE} > V_{BE,\gamma} \\ V_{CE} > V_{CE,sat} \end{cases} \Rightarrow Q_2\,(V_{CE,2},\ I_{C2})$$

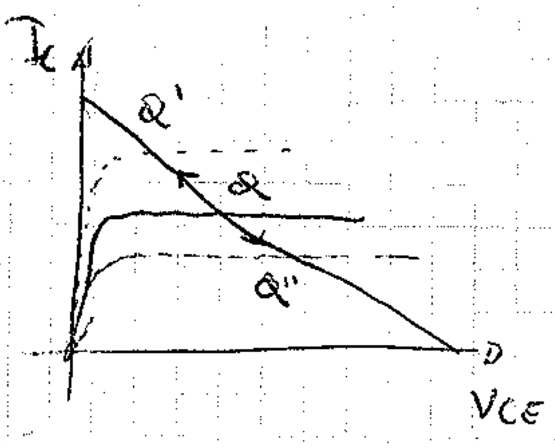
$$\begin{cases} V_{CE} < V_{CE\,sat} \\ V_{BE} > V_{BE,\gamma} \end{cases} \Rightarrow Q_3\,(V_{CE,sat} \overset{\simeq 0}{}, \ I_{C3} \overset{\simeq \frac{V_{AL}}{R}}{})$$

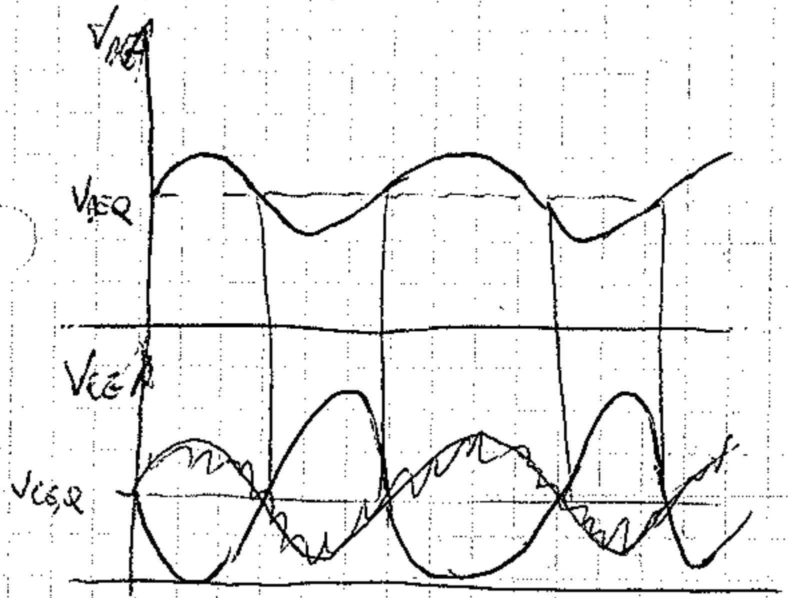


Il transistore può anche essere usato per gli amplificatori:

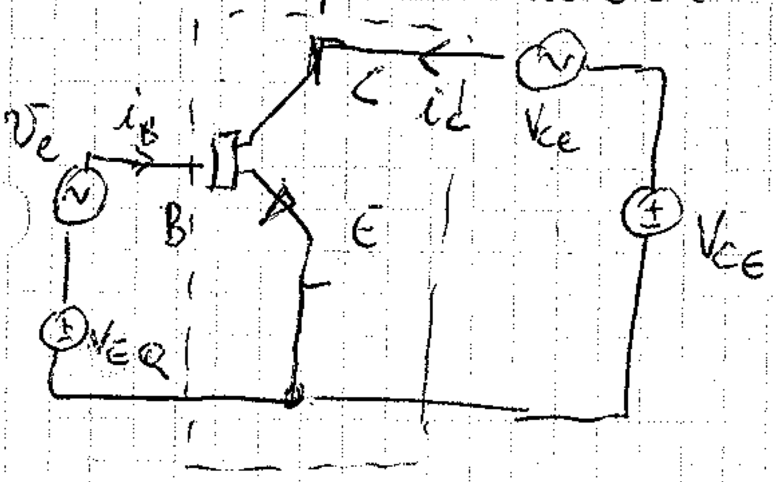








Modello per transistore bipolare

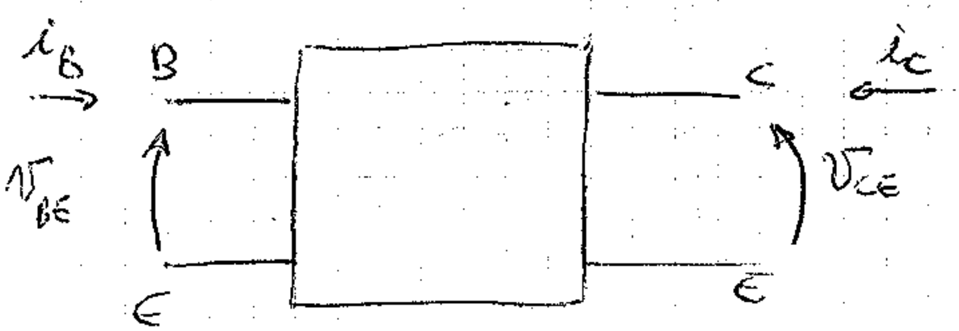


V_{BEQ}, V_{CEQ} sono tali che BJT sia in regione attiva

$i_B = I_{BQ} + i_b$

$i_C = I_{CQ} + i_c$

Il transistor può essere descritto come



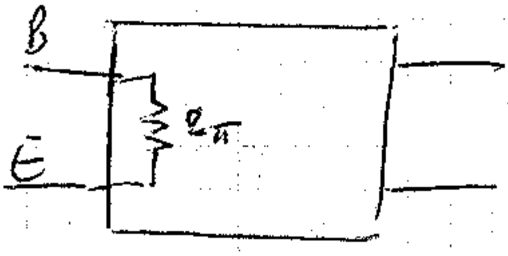
Modello di piccolo segnale

$$\begin{bmatrix} i_B \\ i_C \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} v_{BE} \\ v_{CE} \end{bmatrix}$$

$$y_{11} = \left.\frac{i_B}{v_{BE}}\right|_{v_{CE}=0} = \left.\frac{\partial i_B}{\partial v_{BE}}\right|_{v_{CE}=\text{cost}}$$

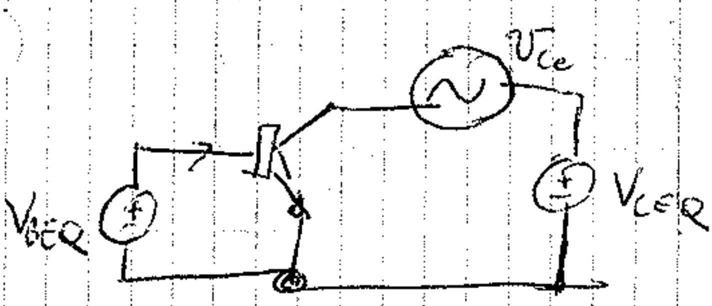
$$i_B = I_{BO} \exp\left(\frac{v_{BE}}{\eta V_T}\right)$$

$$\frac{\partial i_B}{\partial v_{BE}} = \frac{I_{BO}}{\eta V_T} \exp\left(\frac{V_{BE}}{\eta V_T}\right) = \frac{I_{B0}}{\eta V_T}$$



$$r_\pi = \frac{1}{y_{11}}$$

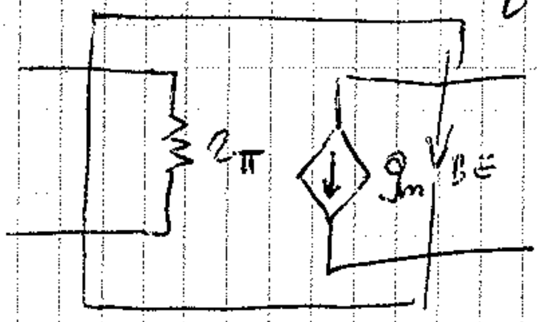
$$y_{12} = \frac{i_B}{v_{CE}}\bigg|_{v_{BE}=0} = \frac{\partial i_B}{\partial v_{CE}}\bigg|_{V_{BE}=cost} = 0$$



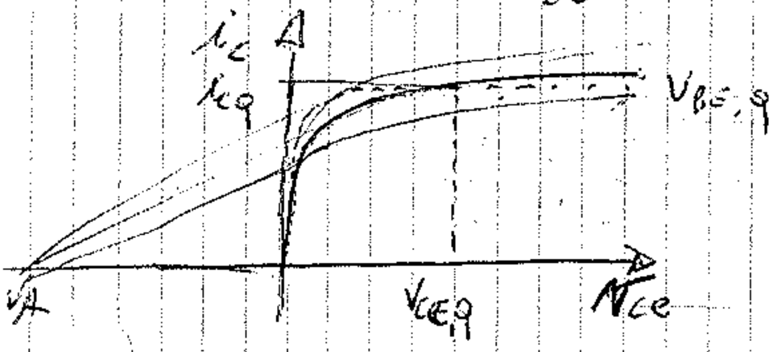
$$y_{21} = \frac{i_c}{v_{BE}}\bigg|_{v_{ce}=0} = \frac{\partial i_c}{\partial v_{BE}}\bigg|_{V_{CE}=cost} = \underbrace{\frac{i_{c,q}}{\eta V_T}}$$

g_m transconduttanza del transistore

$$i_c = i_{co} \exp\left(\frac{V_{BE}}{\eta V_T}\right)$$

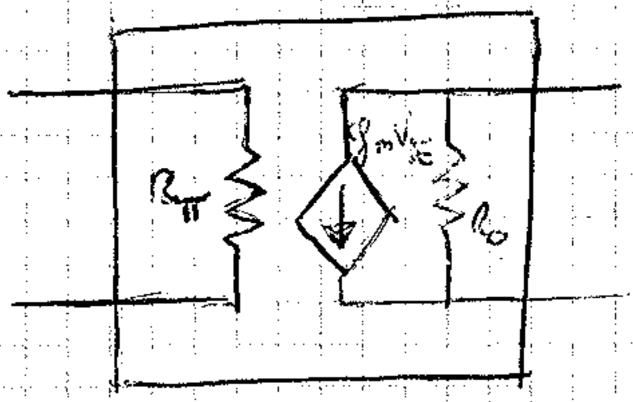


$$y_{22} = \frac{i_c}{v_{CE}}\bigg|_{v_{be}=0} = \frac{\partial i_c}{\partial V_{CE}}\bigg|_{V_{BE}=cost} = \frac{I_{cq}}{|V_A| + V_{CEQ}}$$



V_A tensione di EARLY

Circuito equivalente di piccolo segnale

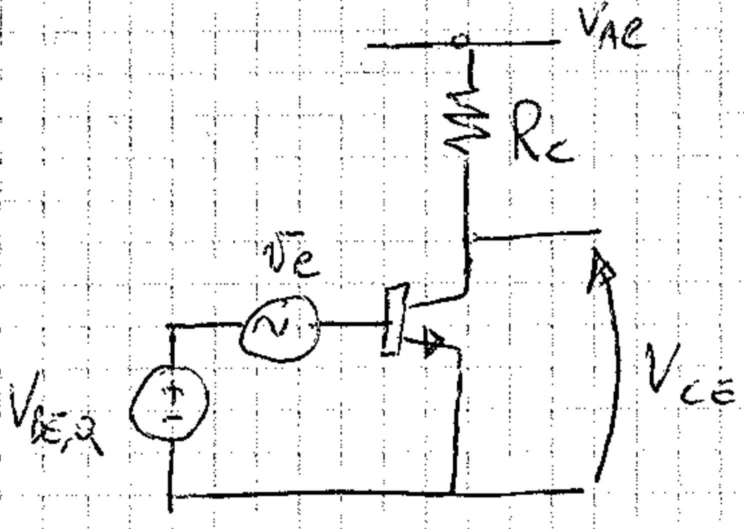


$$r_o = \frac{1}{y_{22}}$$

$$r_\pi = \frac{1}{y_{11}}$$

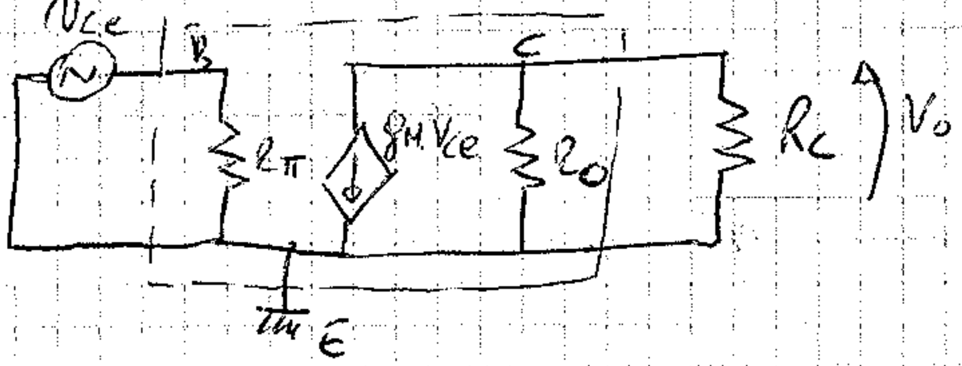
$$g_m = \frac{i_{CQ}}{\eta V_T}$$

Consideriamo il circuito.



Se $V_{BE,Q}$ è tale che $V_{CEQ} > V_{CE,SAT}$

Circuito equivalente x le variazioni:

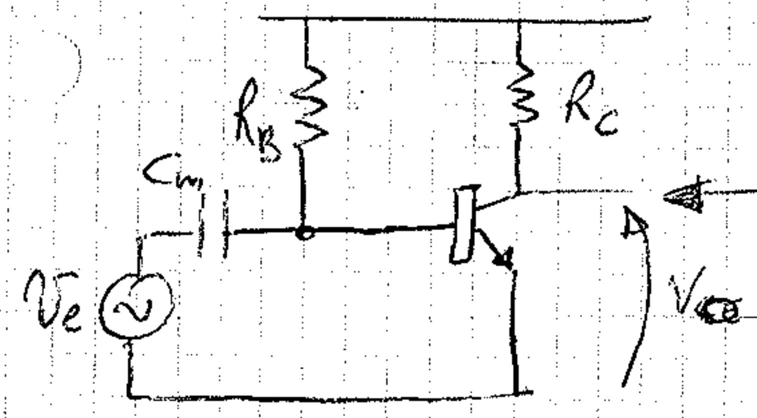


$$v_{be} = v_\pi = v_e$$

$$v_o = -g_m v_\pi (R_o \parallel R_C)$$

$$A_V = \frac{V_o}{v_e} = -g_m R_C \quad (\text{ipotesi che } R_o \gg R_C)$$

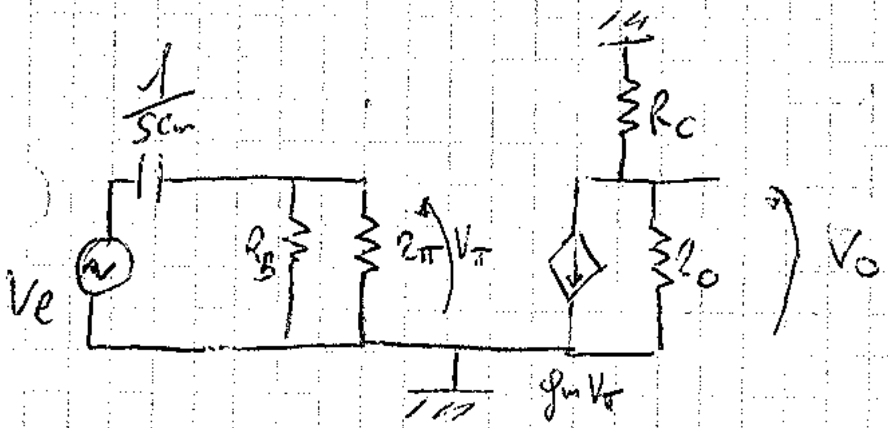
Una sola tensione di alimentazione



$$V_{BEQ} = V_{AL} - R_B I_B$$

Emettitore comune

Circuito eq. di piccolo segnale



$$v_o = -g_m v_\pi (r_o \parallel R_C)$$

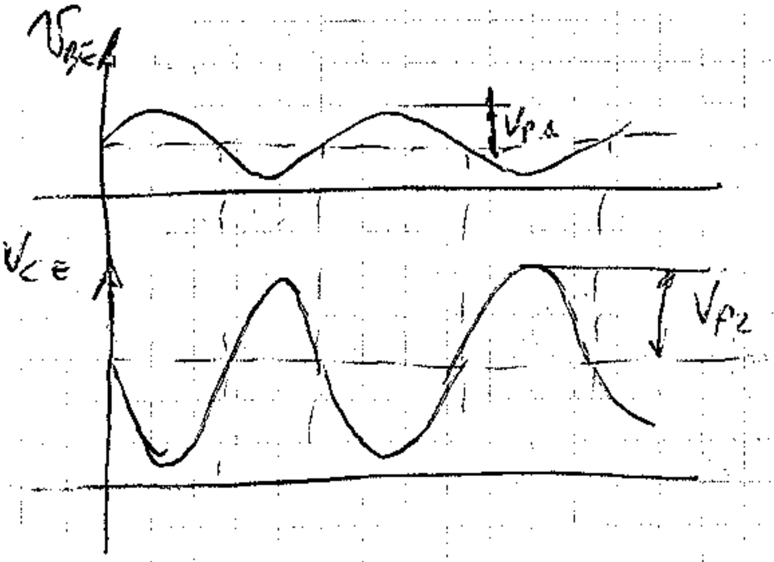
$$V_\pi = \frac{r_\pi \parallel R_B}{\frac{1}{sC_{in}} + R_B \parallel R_\pi}$$

$$A_1 = \frac{v_o}{v_e} = \frac{-g_m (r_o \parallel R_C) \cdot s C_{in} (R_B \parallel r_\pi)}{1 + s C_{in} (R_B \parallel r_\pi)}$$

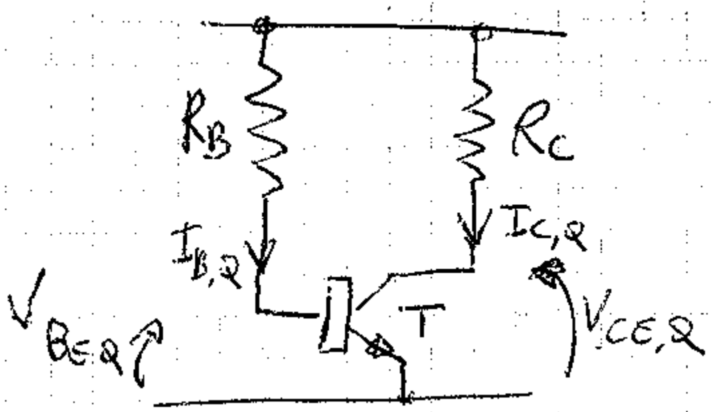
$s = j\omega = j2\pi f$

$A_V(\omega) = -g_m (R_C \parallel r_o) \simeq$ se $\omega \gg \dfrac{1}{C_m (R_B \parallel R_\pi)}$

$\simeq -g_M R_C$



$\dfrac{V_{p2}}{V_{p1}} = A_V$



$I_{BQ} = \dfrac{V_{AL} - V_{BEQ}}{R_B}$ se T è in regione ATTIVA

$I_{CQ} = \beta_F I_{BQ}$

$V_{CEQ} = V_{AL} - R_C I_{CQ} = V_{AL} - R_C \beta_F \dfrac{V_{AL} - V_{BEQ}}{R_B}$

Se $V_{BEQ} \simeq V_{BE\gamma}$ allora

$$\cancel{V_{BEQ}} = I_{BQ} = \frac{V_{AL} - V_{BE\gamma}}{R_B}$$

$$I_{CQ} = \beta_F I_{BQ}$$

$$V_{CEQ} = V_{AL} - \frac{R_C}{R_B}(V_{AL} - V_{BE\gamma})\beta_F$$

Ricordiamoci che $10 < \beta_F < 1000$
il parametro β_F è affetto da forti variabilità da esemplare ad esemplare.

β_F dipende dalla Temp. (cresce 1% al grado)

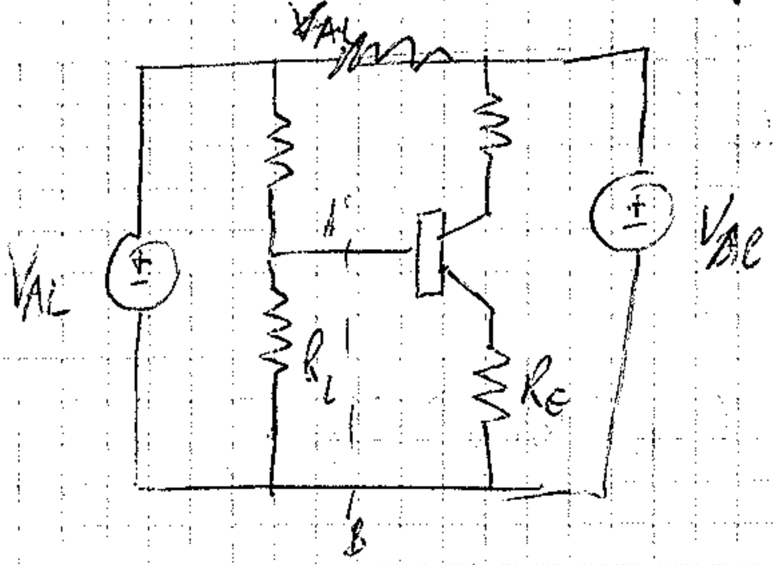
$$\frac{\partial V_{BE\gamma}}{\partial T} = -2 \frac{mV}{°C}$$

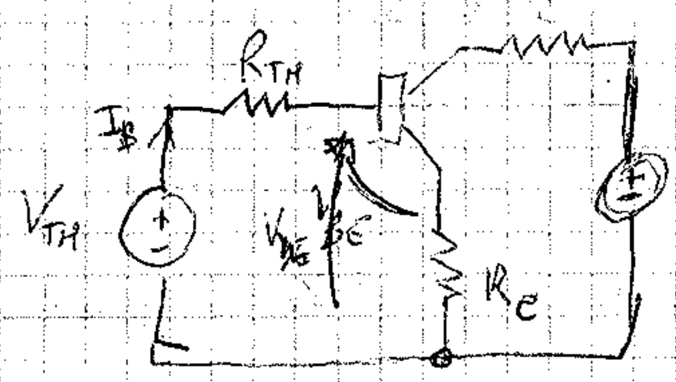
$$A_V = -g_m R_C$$

$g_m = \dfrac{I_{CQ}}{\eta V_T}$ quindi dipende da β_F

A seconda del valore di β_F il transistore può non essere più in zona attiva e allora non vale più il modello.

Altro circuito di polarizzazione.





$$V_{TH} - R_{TH} I_B - V_{BE} - R_E I_E = 0$$

$$V_{TH} - V_{BE} = \left[R_{TH} + R_E (1 + \beta_F) \right] I_B$$

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (1 + \beta_F) R_E}$$

$$I_C = \beta_F \frac{V_{TH} - V_{BE}}{R_{TH} + (1 + \beta_F) R_E}$$ se $R_{TH} << (1+\beta_F) R_E$ allora

$$I_C \simeq \frac{\cancel{\beta_F}}{\cancel{1+}\beta_F} \frac{V_{TH} - V_{BE\gamma}}{R_E}$$

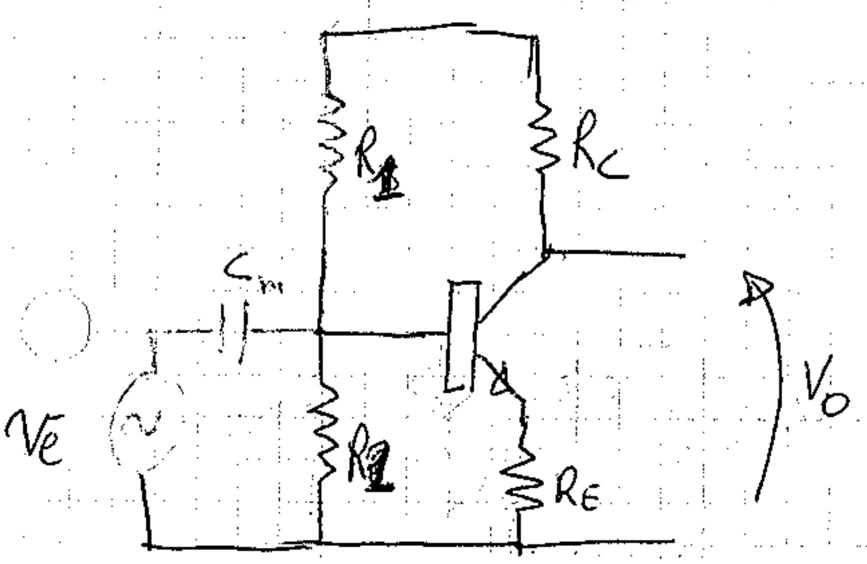
$\beta_F >> 1$

In particolare questo circuito non dipende da β_F

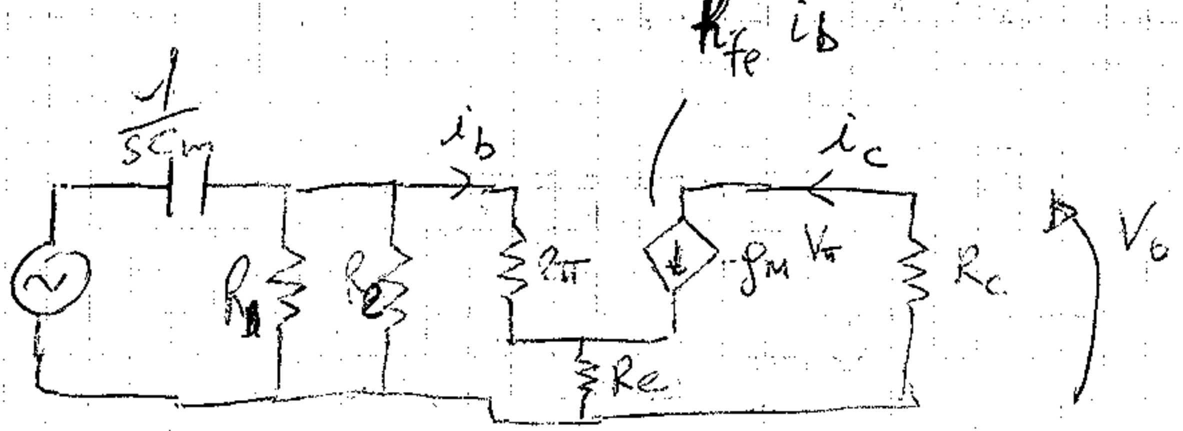
21

Consideriamo il circuito

(Configurazione mista)

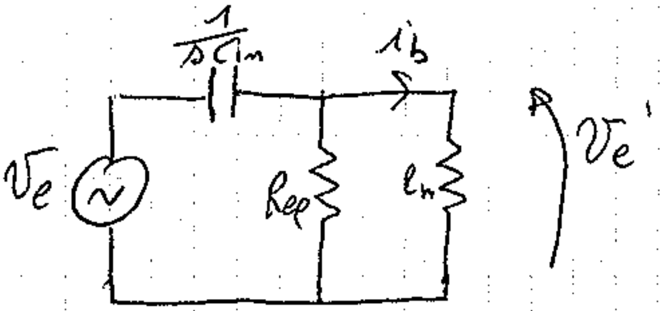


$$A_V = \frac{V_0}{V_e}$$



$$V_0 = -R_C\, I_C = -R_C\, h_{fe}\, i_b$$

$$R_{eq} = R_1 \parallel R_2$$

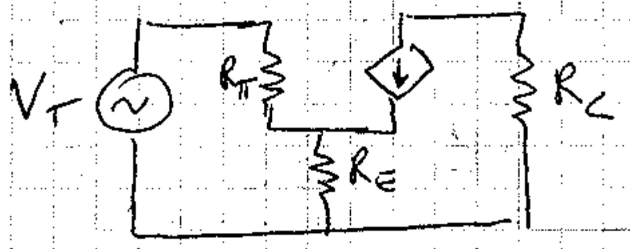


$$v_e' = \frac{(R_{eq} \parallel R_{in})}{\frac{1}{sC_{in}} + (R_{eq} \parallel R_{in})} v_e$$

$$\omega > \frac{1}{C_{in}(R_{eq} \parallel R_{in})} \Rightarrow v_e' = v_e$$

$$i_b = \frac{v_e}{R_{in}}$$

Valutiamo R_{in}



$$V_T = r_\pi i_b + R_E (1 + h_{fe}) i_B$$

$$R_{in} = r_\pi + R_E (1 + h_{fe})$$

$$V_o = - R_c h_{fe} \frac{v_e}{r_\pi + (1 + h_{fe}) R_E}$$

$$A_V = \frac{V_o}{V_e} = - R_c h_{fe} \frac{1}{r_\pi + (1 + h_{fe}) R_E}$$

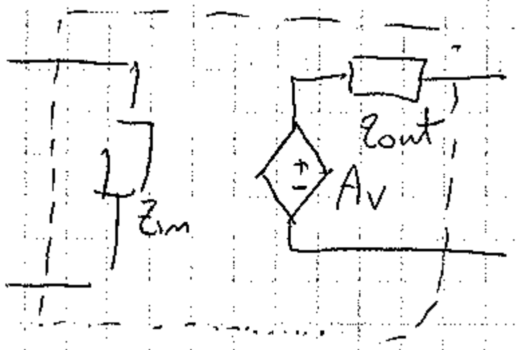
Se $\left.\begin{array}{l} r_\pi < (1 + h_{fe}) R_E \\ h_{fe} \gg 1 \end{array}\right\}$ allora

$$A_V \simeq - \frac{R_C}{R_E}$$

$$Z_{in} = \frac{1}{sC_{in}} + R_1 \parallel R_2 \parallel [r_\pi + R_E (1 + h_{fe})]$$

$$Z_{out} = R_C$$

Configurazione ad ~~collettore~~ emettitore comune

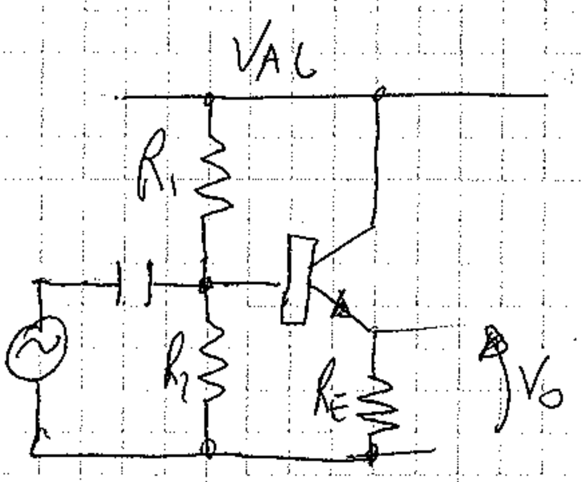


$$Z_{in} = \frac{1}{sC_{in}} + R_1 // R_2 // r_\pi$$

$$Z_{out} = R_C$$

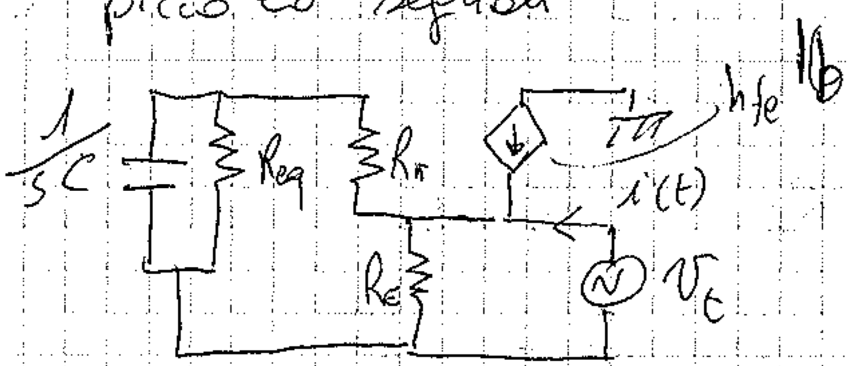
$$A_V = -g_m R_C$$

CONFIGURAZIONE A COLLETTORE COMUNE



$$\boxed{Z_{in} = \frac{1}{sC_{in}} + R_1 // R_2 // (r_\pi + (1+h_{fe})}$$

Per trovare $\underline{Z_{out}}$ utilizzo circ. eq. di piccolo segnale



Hp: $\omega \gg \frac{1}{C_{in}(R_{eq} // [r_\pi + (1+h_{fe}) R_E]}$

$\Downarrow$

C si comporta come un corto circuito

$$i_t = -h_{fe} i_b - i_b + i_E = -(1+h_{fe}) i_b + i_E =$$

$$= -(1+h_{fe})\left(-\frac{V_T}{r_\pi}\right) + \frac{V_T}{R_E}$$

$$\Downarrow$$

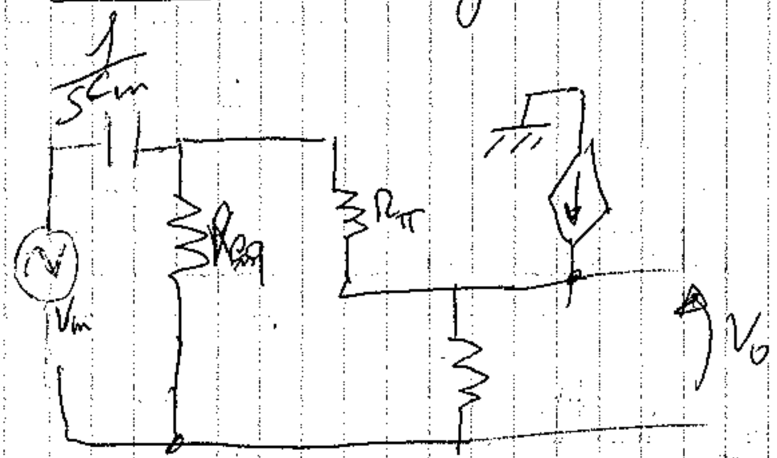
$$Z_{out} = \frac{V_T}{i_T} = \frac{1}{\dfrac{1}{R_E} + \dfrac{1+h_{fe}}{r_\pi}}$$

$$g_m r_\pi = h_{fe} \gg 1$$

$$\Downarrow$$

$$\boxed{Z_{out} = \frac{1}{\dfrac{1}{R_E} + g_m} \simeq \frac{1}{g_m}}$$

<u>calcolo del guadagno</u>



$$V_o = R_E\, i_e = R_E (1+h_{fe})\, i_b$$

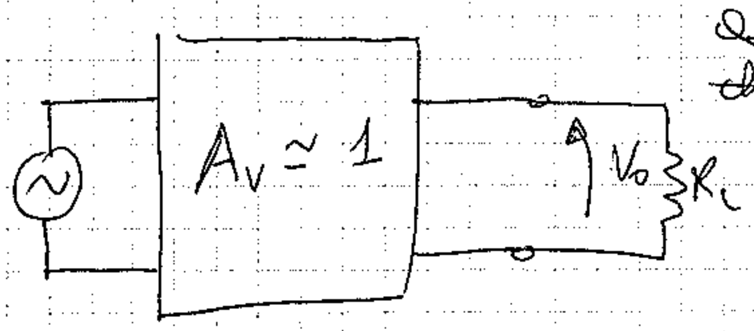
$$i_b = \frac{R_{eq} \parallel R_{in}}{\dfrac{1}{sC_{in}} + R_{eq} \parallel R_{in}} V_{in} \cdot \frac{1}{R_{in}} \simeq \frac{V_{in}}{R_{in}}$$

$$A_V = \frac{V_o}{V_{in}} = R_E (1+h_{fe}) \frac{V_{in}}{R_{in}} = \frac{R_E (1+h_{fe})}{r_\pi + (1+h_{fe}) R_E} < 1$$

Quindi il circuito più che un amplificatore è un <u>ATTENUATORE</u> 26

In particolare, poiché $r_\pi << (1 + h_{fe})R_E$ si ha che $A_V \simeq 1$

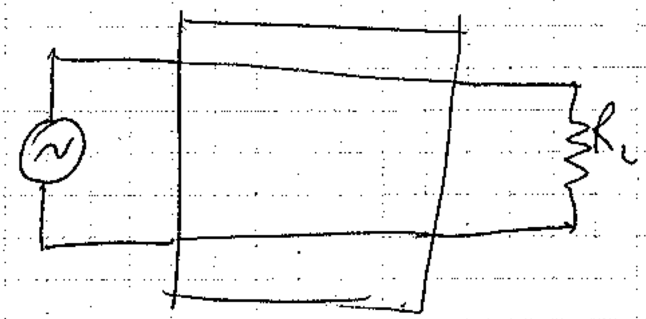
(A)



~~Questo fa in modo che al [illegible]~~

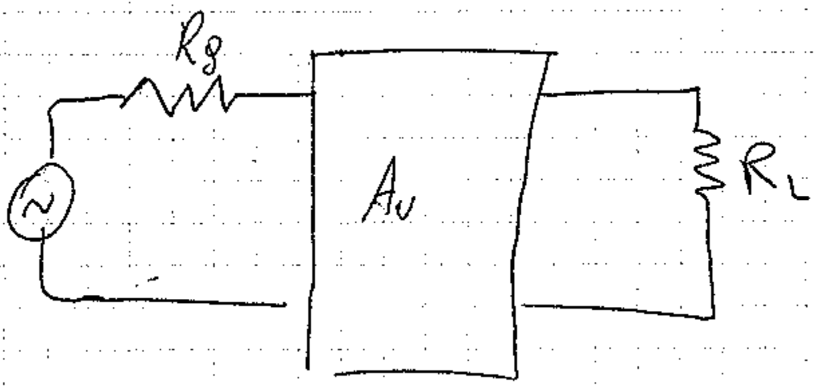
In A la corrente viene presa dall'alimentatore
In B viene fornita direttamente.

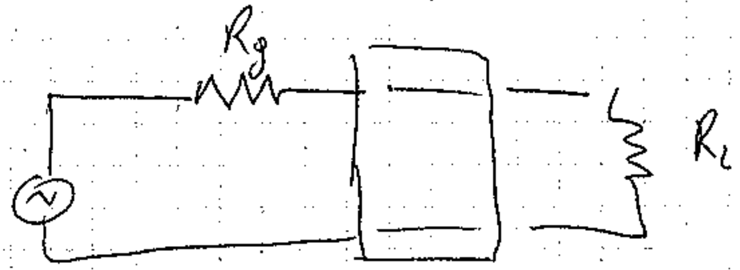
(B)



Disaccoppiare ~~[illegible]~~ l'informazione dalla potenza

(A)





Caso A: $\begin{cases} \text{se} & R_g \ll R_{in} \\ \text{se} & R_{out} \ll R_L \end{cases}$

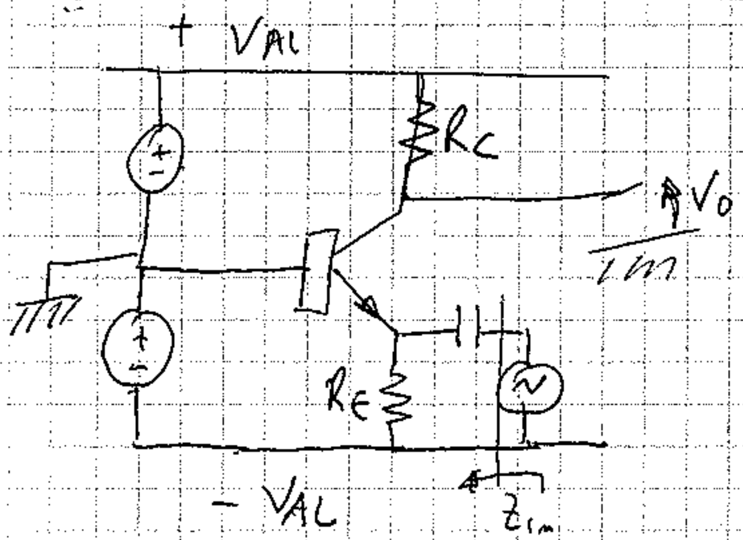
$\rightarrow$

$$V_0 \simeq V_{out}$$

Caso B: $V_0 = \dfrac{R_L}{R_L + R_g} V_{in}$

Un amplificatore a collettore comune è anche detto disaccoppiatore di impedenze.

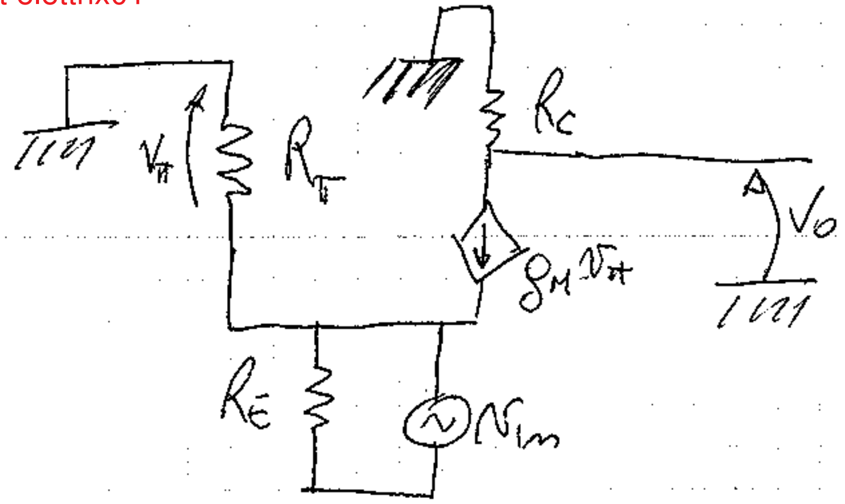
CONFIGURAZIONE A BASE COMUNE



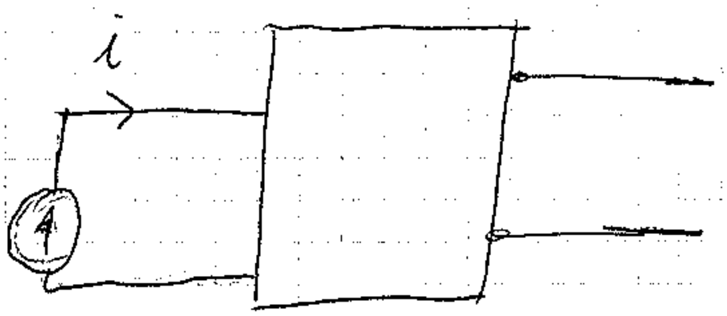
$$Z_{in} = \frac{1}{S C_{in}} + R_E // \left(\frac{1}{g_M}\right) \simeq \frac{1}{g_M}$$

se $\omega \gg \dfrac{1}{C_{in}\left[R_E // \dfrac{1}{g_M}\right]}$

$$Z_{out} = R_C$$



$$\frac{V_o}{V_{in}} = -\frac{g_M R_C v_\pi}{V_{in}} = \frac{R_C g_M \cancel{V_{in}}}{\cancel{V_{in}}} = R_C g_M$$



Poiché Z_m è bene può essere utilizzato come amplificatore di trans resistente ed essere alimentato con generatore di corrente.

Presente di polinomi complessi:

$$H(s) = \frac{N(s)}{D(s)} = \frac{\prod_{i=1}^{N}\left(1+\frac{s}{s_{z_i}}\right)}{\prod_{k=1}^{M}\left(1+\frac{s}{s_{pk}}\right)}$$

$$H(s) = \mathrm{Re}\{H\} + j\,\mathrm{Im}\{H\} = |H(s)|\, e^{j\angle H}$$

$$s = j\omega \quad , \quad \sigma = 0$$

$$|H(j\omega)| = \sqrt{\mathrm{Re}^2\{H\} + \mathrm{Im}^2\{H\}}$$

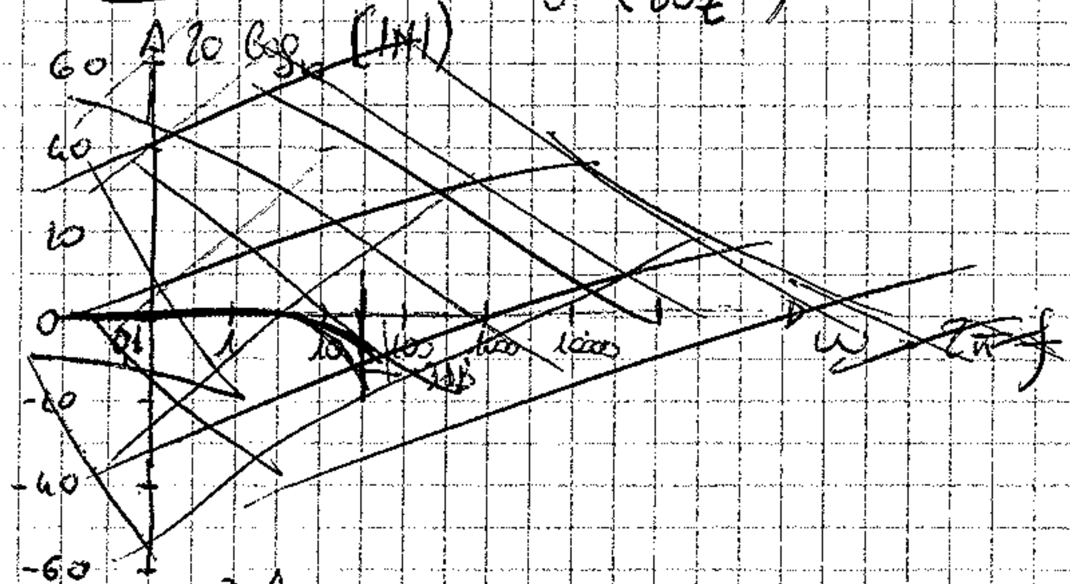
$$\angle H = \arctan \frac{\mathrm{Im}\{H\}}{\mathrm{Re}\{H\}}$$

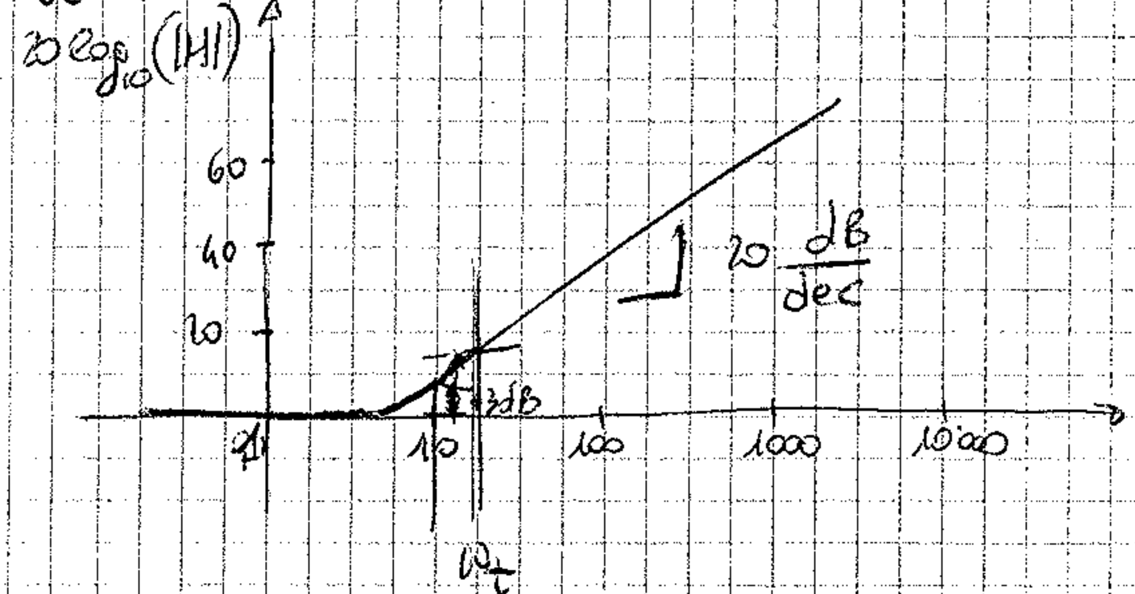
$$H(s) = 1 + \frac{s}{s_z} \qquad s_z \in \mathbb{R}$$

$$|s_z| = \omega_z$$

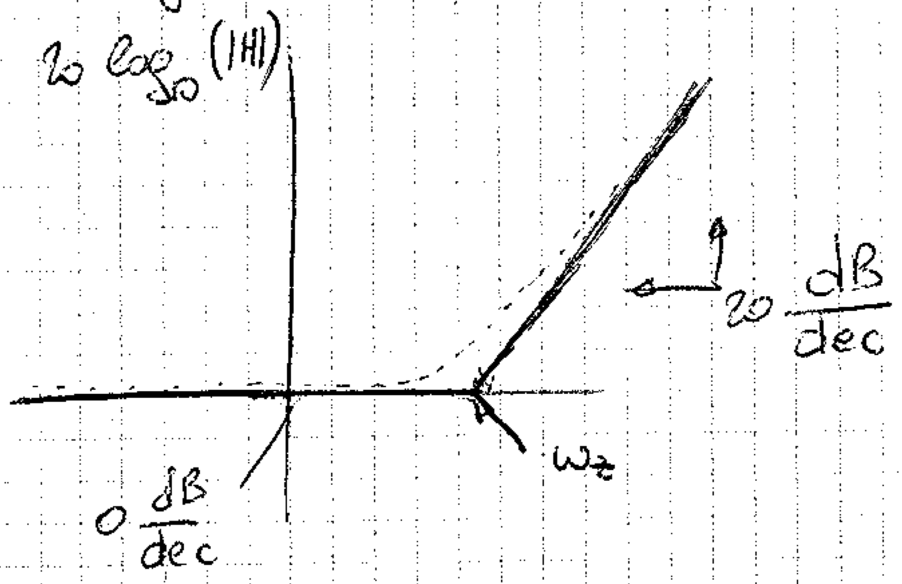
$$|H(j\omega)| = \sqrt{1 + \left(\frac{\omega}{\omega_z}\right)^2}$$

$$\angle H(j\omega) = \arctan\left(\frac{\omega}{\omega_z}\right)$$

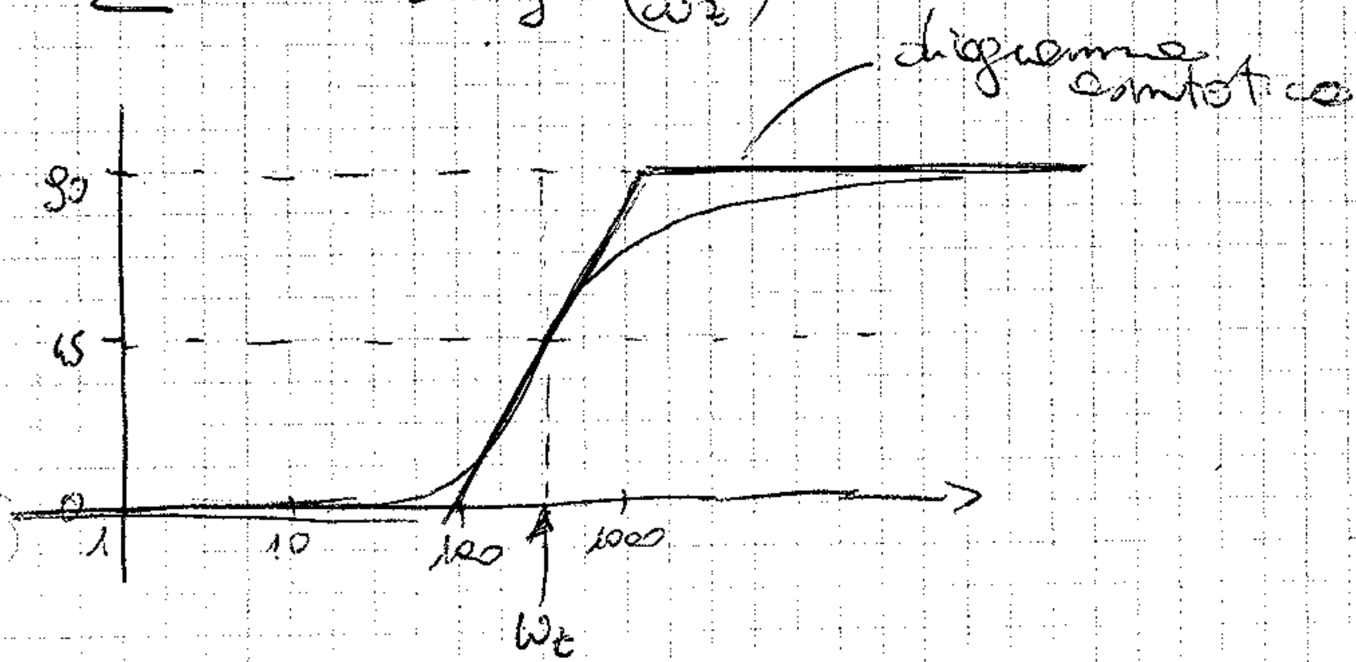




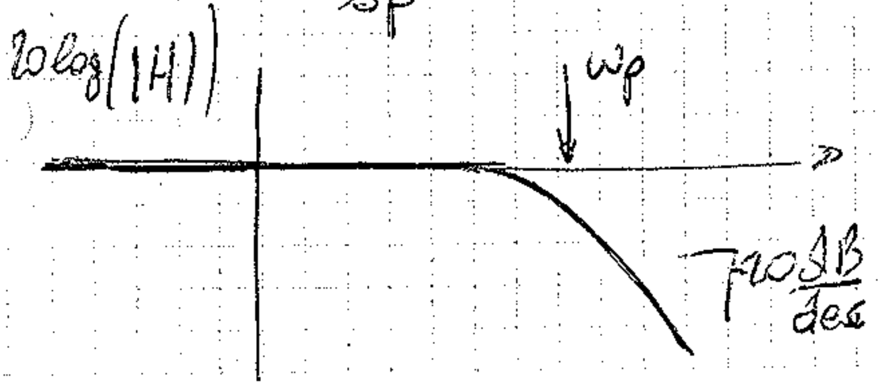
Diagrammi di Bode

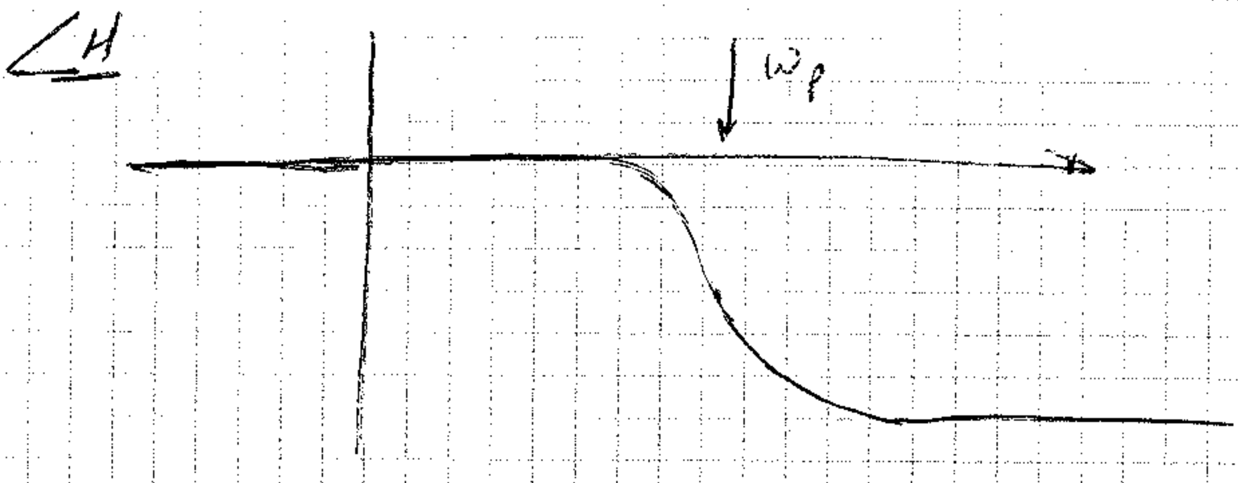


$$\angle H = \operatorname{arctg}\left(\frac{\omega}{\omega_z}\right)$$



$$H_s = \frac{1}{1 + \frac{s}{s_p}}$$

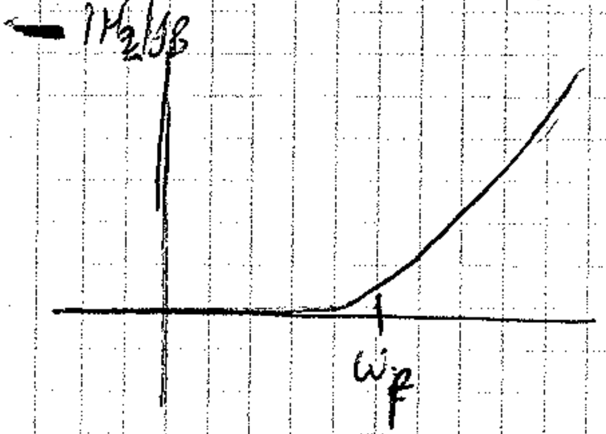


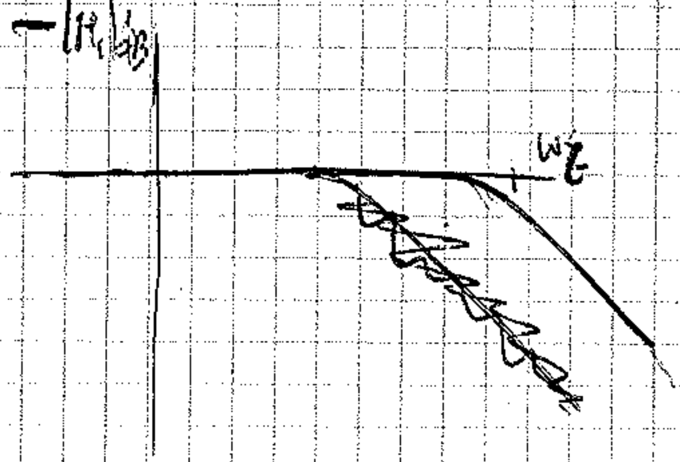


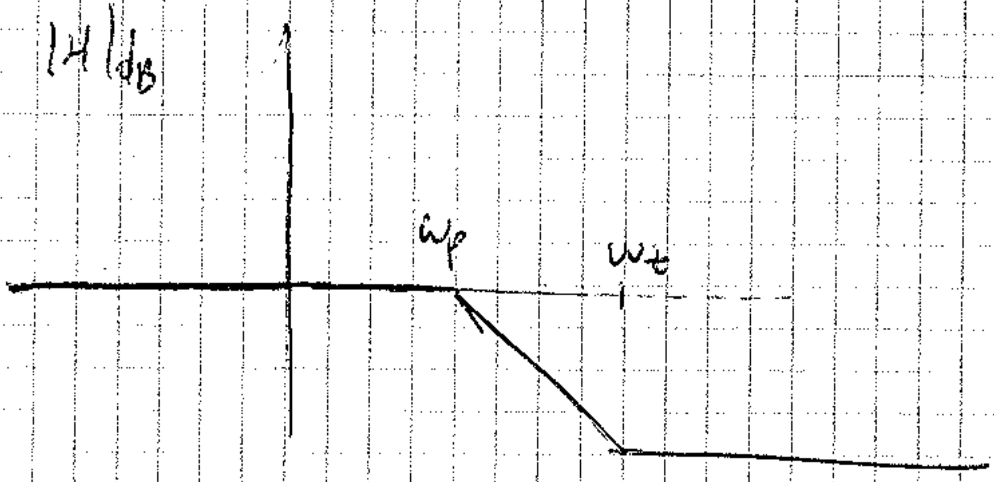
Esempio:

$$H(s) = \frac{1+\frac{s}{s_z}}{1+\frac{s}{s_p}} \quad ; \quad |H| = 20\log_{10}\left(\left|1+\frac{s}{s_z}\right|\right) + 20\log_{10}\left(\left|\frac{1}{1+\frac{s}{s_p}}\right|\right)$$

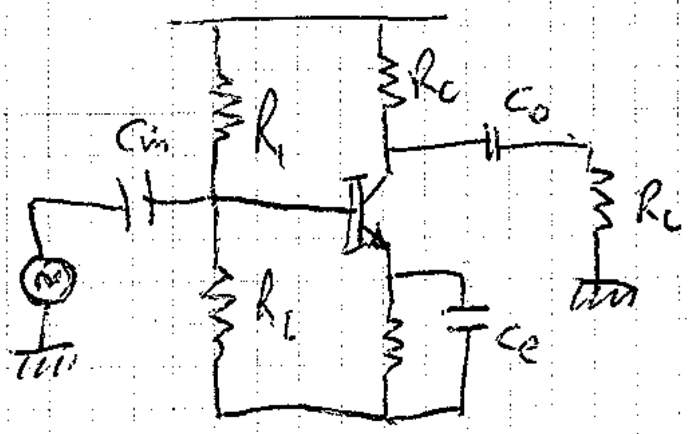
con $|s_z| > |s_p|$



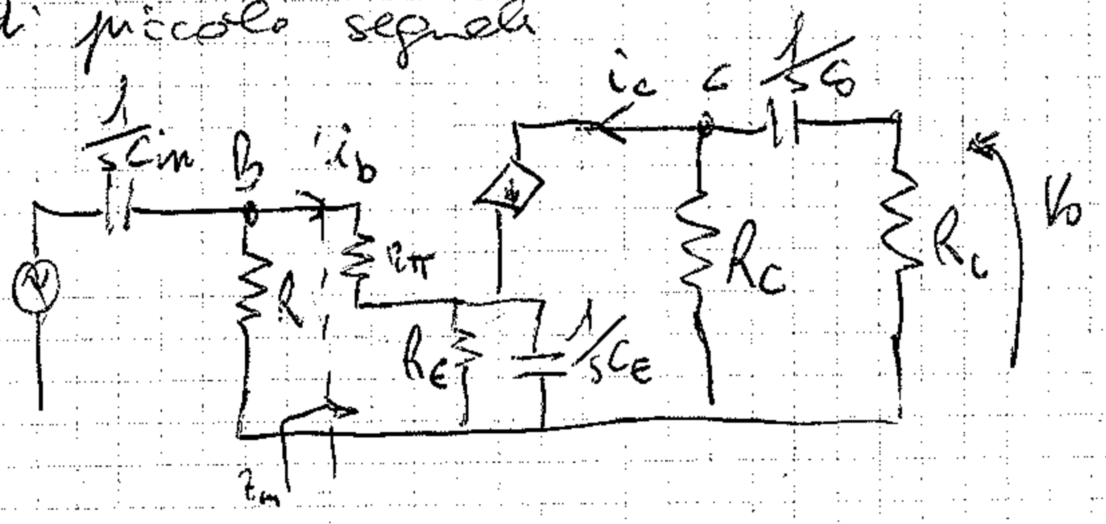




Risposta in frequenza del circuito



Per analizzare utilizziamo il circuito eq. di piccolo segnale



$$A_v(s) = \frac{v_o}{v_{in}}$$

$$v_o = -R_L \frac{R_C}{R_C + R_L + \frac{1}{sC_o}} \cdot h_{fe}\, i_b$$

cerchiamo i_b

$$i_b = \frac{v_B}{z_{in}} \qquad \frac{\cancel{\frac{1}{sC_{in}}}\, Z_{in} /\!/ R}{\frac{1}{sC_{in}} + R /\!/ Z_{in}}\, v_{in} = v_b$$

$$= \frac{R\, Z_{in}\, C_{in}\, s}{s\, C_{in} R Z_{in} + R + Z_{in}} V_{in}$$

$$i_b = \frac{1}{\cancel{Z_{in}}} \cdot \frac{R\, \cancel{Z_{in}}\, C_{in}\, s}{s\, C_{in} R Z_{in} + R + Z_{in}} V_{in}$$

$$\frac{V_o}{V_{in}} = -R_L \frac{R_C}{R_C + R_L + \frac{1}{sC_o}} \cdot h_{fe} \frac{R\, C_{in}\, s}{R + Z_{in} + s C_{in} R Z_{in}}$$

$$Z_{in} = r_\pi + (1 + h_{fe})\, R_E \parallel \frac{1}{sC_E} =$$

$$= r_\pi + (1 + h_{fe}) \frac{R_E}{1 + s C_E R_E}$$

$$A_v(s) = -\frac{R_L R_C}{R_C + R_L + \frac{1}{sC_o}} \cdot h_{fe} \frac{R\, C_{in}\, s}{R + r_\pi + (1 + h_{fe}) \frac{R_E}{1 + sC_E R_E} + s C_{in} R \left(r_\pi + (1 + h_{fe}) \frac{R_E}{1 + sC_E R_E}\right)} =$$

$$= -\frac{R_L R_C\, s C_o\, h_{fe}}{(R_C + R_L) C_o s + 1} \cdot \frac{(R C_{in} s)(1 + s C_E R_E)}{(R + r_\pi)(1 + s C_E R_E) + (1 + h_{fe}) R_E + s C_{in} R \left(r_\pi (1 + s C_E R_E) + (1 + h_{fe}) R_E\right)}$$

$$\frac{V_o}{V_{in}} = K \frac{s^2\left(1+\frac{s}{s_z}\right)}{\left(1+\frac{s}{s_{p1}}\right)\left(1+\gamma s+\xi s^2\right)}$$ 3 zeri 3 poli.

(30)

$$S_{z_1} = -\frac{1}{R_E C_E} \in \mathbb{R} \qquad S_{p_1} = -\frac{1}{(R_L+R_C)C_o} \in \mathbb{R}$$

$$s = j\omega \qquad A_b = H(j\omega) = \frac{V_o}{V_{in}}(j\omega)\Big|_{\omega\to\infty} \simeq$$

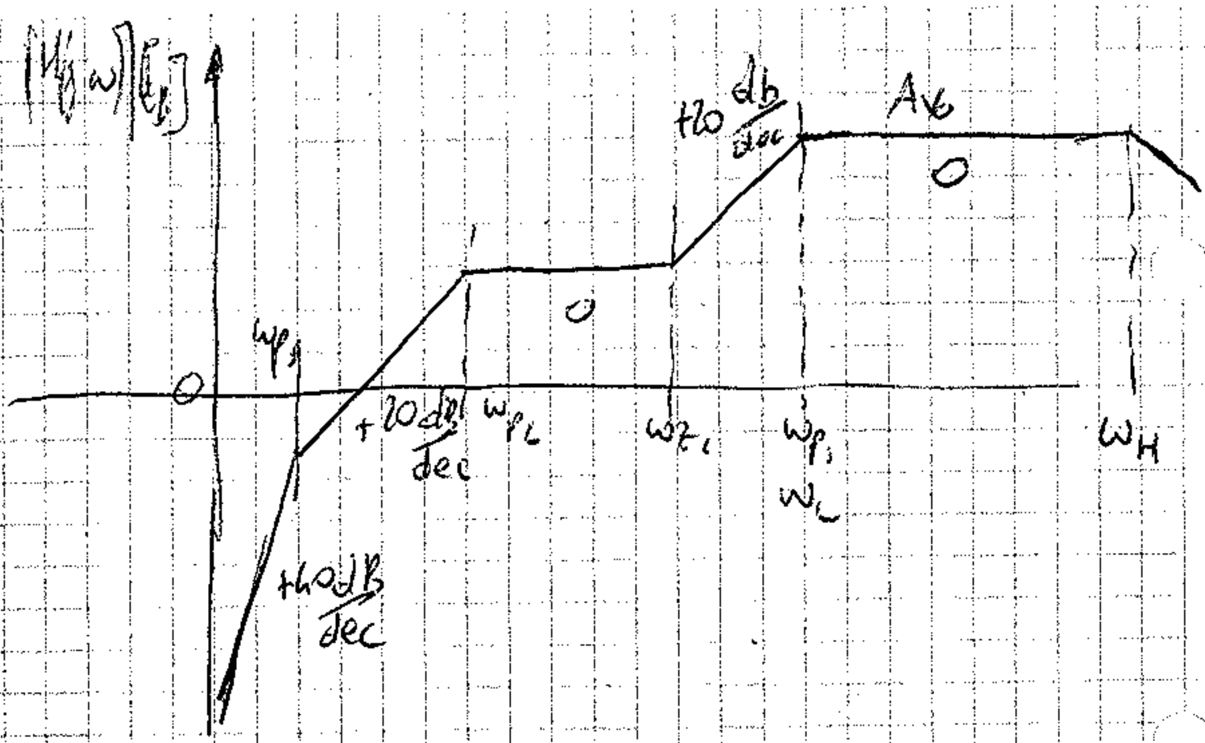
$$\simeq \left[\frac{R_L R_C \cancel{j\omega C_o}\, h_{fe}}{(R_L+R_C)\cancel{C_o j\omega}}\right] \frac{\cancel{R_{C_{in}}}\ \cancel{C_E R_E}\ \cancel{(j\omega)^2}}{\cancel{(j\omega)^2}\ C_{in} R_{1_{eq}}\ \cancel{C_E R_E}}$$

$$= -\frac{R_L R_C}{R_L+R_C}\ \underbrace{h_{fe}\ \frac{1}{2\pi}}_{g_M} = -g_M \frac{R_L R_C}{R_L+R_C}$$

se $\omega \to \infty$ si ha la configurazione ad emettitore comune !!

$$\frac{V_o}{V_{in}}\Big|_{\omega\to\infty} = -g_M\, R_C /\!/ R_L$$

$$|H(j\omega)|\Big|_{\omega\to\infty} >> \frac{R_C /\!/ R_L}{R_E}$$



Viene fornito anche un dato molto importante: banda di funzionamento

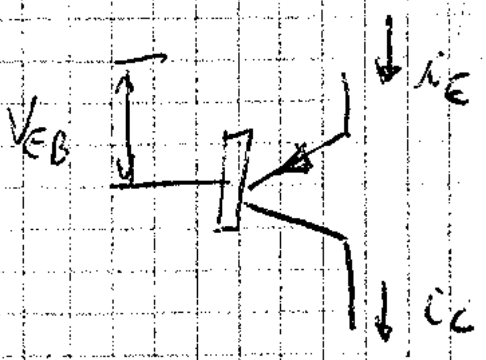
$\omega_L < \omega < \omega_H$.

ω_L e ω_H sono tali per cui

$A_V(\omega_L) = \frac{A_{V0}}{\sqrt{2}}$

Di solito ω_H viene imposto da un condensatore in uscita dall'emettitore.

Transistor PNP



$V_{EB} > V_{EB,\gamma}$

$V_{EC} > V_{EC,sat} \simeq 0{,}2\ V$