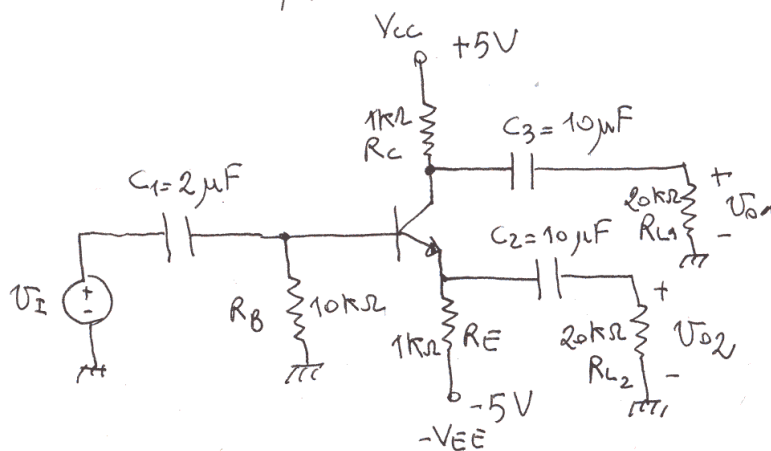


1° Esercizio 3° homework 9.69 pag 530 (Jaeger-Blalock) (1/5)

Il circuito di figura è chiamato invertitore di fase. Calcolare i due guadagni $A_{v1} = v_{o1}/v_i$ e $A_{v2} = v_{o2}/v_i$.

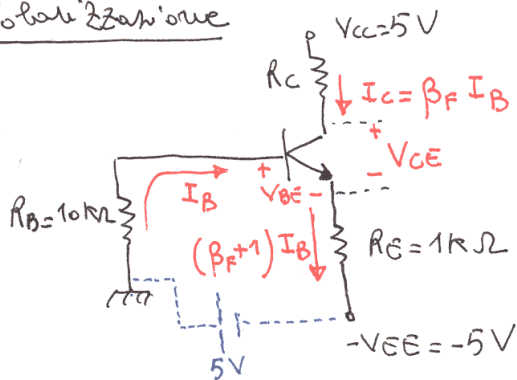
Qual'è il massimo segnale dc che si può trovare all'uscita v_{o1} in questo circuito?

Assumere $\beta_F = 100$



Soluzione

Polarizzazione



HP: zona attiva

$$I_B = \frac{V_{EE} - V_{BE}}{R_B + (\beta_F + 1)R_E} \quad \left[\frac{V}{k\Omega} = mA \right]$$

$$= \frac{5 - 0.7}{10 + (100 + 1) \cdot 1} = 0.0387 \text{ mA}$$

$$I_C = \beta_F I_B = 100 \cdot 0.0387 = 3.87 \text{ mA}$$

$$V_{CE} = (V_{CC} + V_{EE}) - R_C I_C - R_E I_C \left(1 + \frac{1}{\beta_F}\right)$$

$$= 10 - 1 \cdot 3.87 - 1 \cdot 3.87 \left(1 + \frac{1}{100}\right)$$

$$= 2.22 \text{ V} > 0.2 \text{ V OK.}$$

Parametri di piccoli segnali

$$g_m = \frac{I_C}{V_T} = 40 I_C = 40 \cdot 3.87 = 154.8 \frac{\text{mA}}{\text{V}}$$

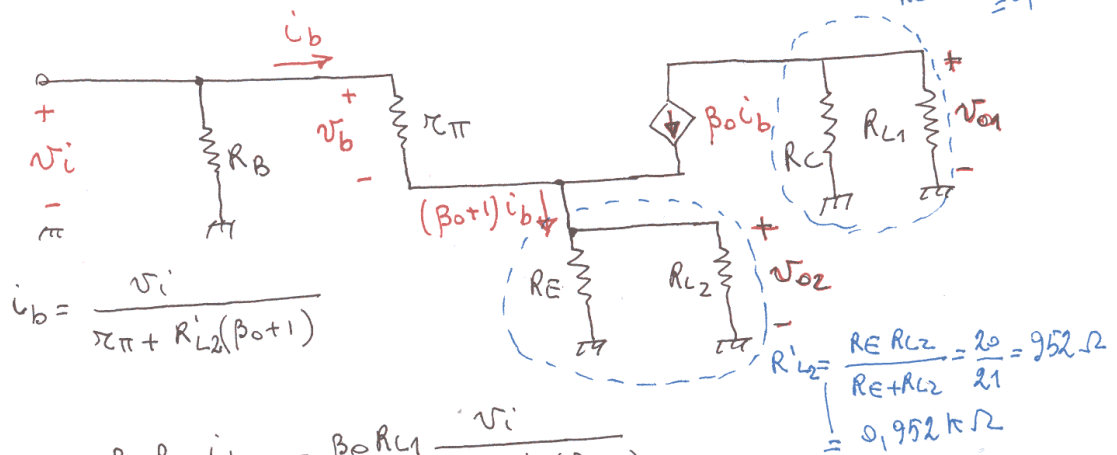
$$r_{\pi} = \frac{\beta_0}{g_m} = \frac{100}{154.8 \frac{\text{mA}}{\text{V}}} = 646 \Omega$$

Assumendo $\beta_0 = \beta_F$

Si trascura effetto Early
per cui
 $r_{o0} = \infty$

(2/6)

Circuito equivalente in dc



$$v_{o1} = -\beta_0 R_{L1} i_b = -\beta_0 R_{L1} \frac{v_i}{r_{\pi} + R'_{L2}(\beta_0 + 1)}$$

$$A_{v1} = \frac{v_{o1}}{v_i} = -\frac{\beta_0 R'_{L1}}{r_{\pi} + R'_{L2}(\beta_0 + 1)} = -\frac{100 \cdot 0.952}{0.646 + 0.952(100 + 1)} = -0.983$$

$$v_{o2} = (\beta_0 + 1) R'_{L2} i_b = (\beta_0 + 1) R'_{L2} \frac{v_i}{r_{\pi} + R'_{L2}(\beta_0 + 1)}$$

$$A_{v2} = \frac{v_{o2}}{v_i} = \frac{(\beta_0 + 1) R'_{L2}}{r_{\pi} + R'_{L2}(\beta_0 + 1)} = \frac{(100 + 1) \cdot 0.952}{0.646 + 0.952(100 + 1)} = 0.993$$

Calcolo del massimo segnale v_{o1}

$$\begin{cases} i_c = I_s e^{\frac{(V_{BE} + v_b)/V_T}{}} = I_s e^{\frac{V_{BE}/V_T}{}} e^{\frac{v_b/V_T}{}} = I_c \cdot \left(1 + \frac{v_b}{V_T} + \frac{v_b^2}{2V_T^2} + \dots\right) = I_c + I_c(\dots) \\ \frac{v_b^2}{2V_T^2} \ll \frac{v_b}{V_T} \quad v_b \ll 2V_T = 50 \text{ mV} \rightarrow v_b \leq 5 \text{ mV} \end{cases}$$

Per la linearità

$$v_b = v_i - v_{o2} = v_i - A_{v2} v_i = (1 - A_{v2}) v_i$$

$$v_i = \frac{v_b}{1 - A_{v2}} \leq \frac{5 \text{ mV}}{1 - 0.993} \approx 0.714 \text{ V}$$

Deve essere anche $v_{CB} = v_C - v_B \geq 0$ affinché il BJT sia in zona attiva (guinzagone base-collettore in inversa)

$$v_C = V_{CC} - R_C I_C = 5 - 1 \text{ k}\Omega \cdot 3.87 \text{ mA} = 1.13 \text{ V}; \quad v_B = -R_B I_B = 10 \text{ k}\Omega \cdot 0.0387 \text{ mA} = -0.387 \text{ V}$$

$$v_C = V_C + v_{o1} = V_C - 0.983 v_i$$

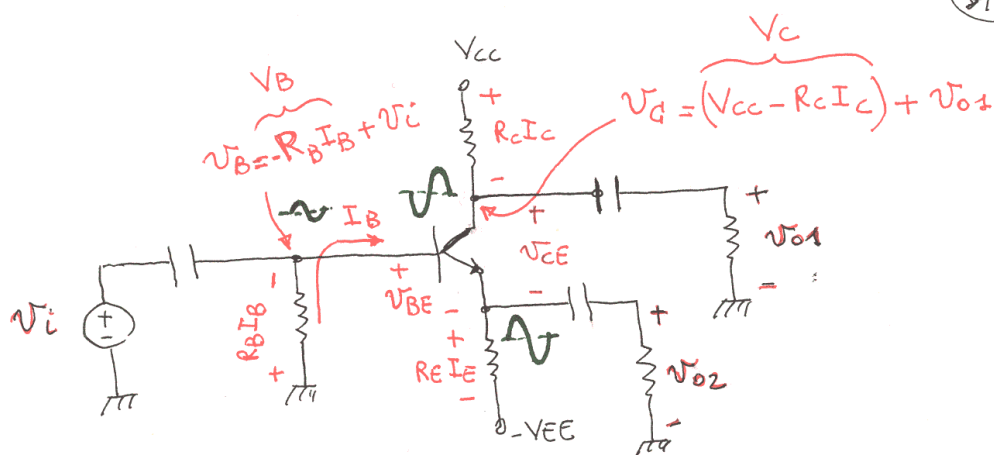
$$v_B = V_B + v_i$$

$$v_{CB} = (V_C - 0.983 v_i) - (V_B + v_i) \geq 0$$

$$1.517 - 1.983 v_i \geq 0$$

$$v_i \leq \frac{1.517}{1.983} = 0.765 \text{ V}$$

$$v_{i_{max}} = \min(0.714; 0.765)$$



Nella figura sono rappresentati i segnali che influiscono nella determinazione di V_C e V_B .

Alternativamente si sarebbe potuto scrivere

$$V_C = V_{CE} + R_E I_E - V_{EE} + V_{o1}$$

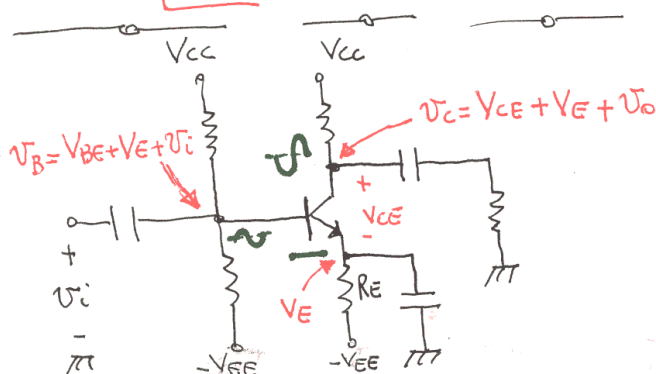
$$V_B = V_{BE} + R_E I_E - V_{EE} + V_i$$

$$V_{CB} = V_C - V_B = (V_{CE} - V_{BE}) + V_{o1} - V_i \geq 0 \quad (\text{se z. attiva})$$

$$(V_{CE} - V_{BE}) \geq (V_i - V_{o1}) = (1 - A_{v1}) V_i$$

$$V_i \leq \frac{V_{CE} - V_{BE}}{1 - A_{v1}} = \frac{2,22 - 0,7}{1 - (-0,983)} \cong 0,766$$

$$V_{o1 \max} = |A_{v1}| \cdot V_{i \max} = 0,983 \cdot 0,714 \cong 0,702 \text{ V}$$



Nel caso di emettitore a massa per i segnali si ha

$$V_{CB} = V_C - V_B = (V_{CE} - V_{BE}) + V_o - V_i \geq 0$$

$$V_{CE} - V_{BE} \geq V_i - V_o = (1 - A_v) V_i$$

In questo caso

$$A_v = -g_m R_{L1} = -154,8 \cdot 0,952 \cong -147$$

$$V_i \leq \frac{V_{CE} - V_{BE}}{1 - A_v} = \frac{2,22 - 0,7}{1 - (-147)} \cong 0,01 \text{ V}$$

$$\text{risulta } (1 - A_v) V_i \cong -A_v V_i = -V_o$$

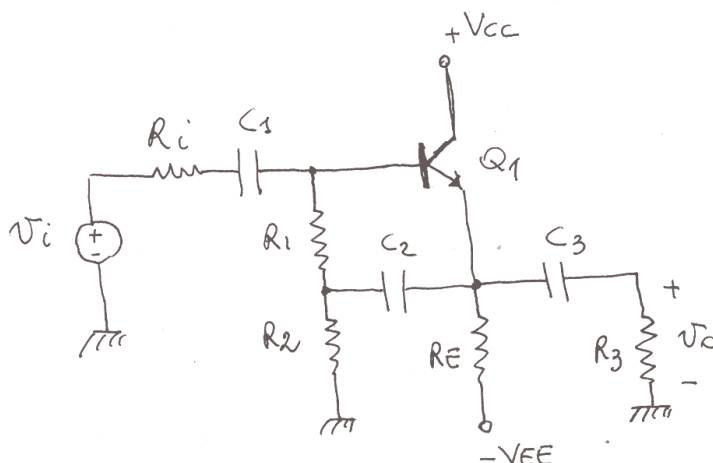
$$V_{CE} - V_{BE} \geq -V_o$$

$$-V_{o \max} = V_{CE} - V_{BE} = 2,22 - 0,7 = 1,52 \text{ V}$$

2° Esercizio 3° homework pag. 530 (Jaeger-Blalock) 9.74 a)

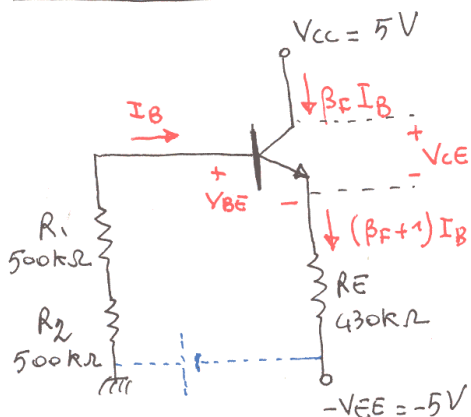
Calcolare i valori A_v , R_{in} , R_{out} per l'amplificatore di figura se $R_i = 500 \Omega$, $R_1 = 500 k\Omega$, $R_2 = 500 k\Omega$, $R_3 = 500 k\Omega$, $R_E = 430 k\Omega$ e $V_{CC} = V_{EE} = 5V$. Usare $\beta_F = 100$ e $V_A = 60V$

(4/6)



Soluzione

Polarizzazione



HP: 2.341V2

$$I_B = \frac{V_{EE} - V_{BE}}{R_1 + R_2 + (\beta_F + 1)R_E} \quad \left[\frac{V}{k\Omega} \right]$$

$$= \frac{5 - 0,7}{500 + 500 + (100 + 1)430} = 96,78 \mu A$$

$$I_C = \beta_F I_B = 100 \cdot 96,78 \mu A \approx 9,68 \mu A$$

$$V_{CE} = V_{CC} - (-V_{EE}) - R_E I_C \left(1 + \frac{1}{\beta_F} \right)$$

$$= 10 - 430 \cdot 9,68 \cdot 10^{-3} \left(1 + \frac{1}{100} \right)$$

$$= 5,8 V$$

Parametri ai piccoli segnali

$$g_m = \frac{I_C}{V_T} = 40 I_C = 40 \cdot 9,68 \mu A / V = 0,387 \frac{mA}{V}$$

$$r_{\pi} = \frac{\beta_0}{g_m} = \frac{100}{0,387 \frac{mA}{V}} \approx 258 k\Omega$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{(60 + 5,8) V}{9,68 \mu A}$$

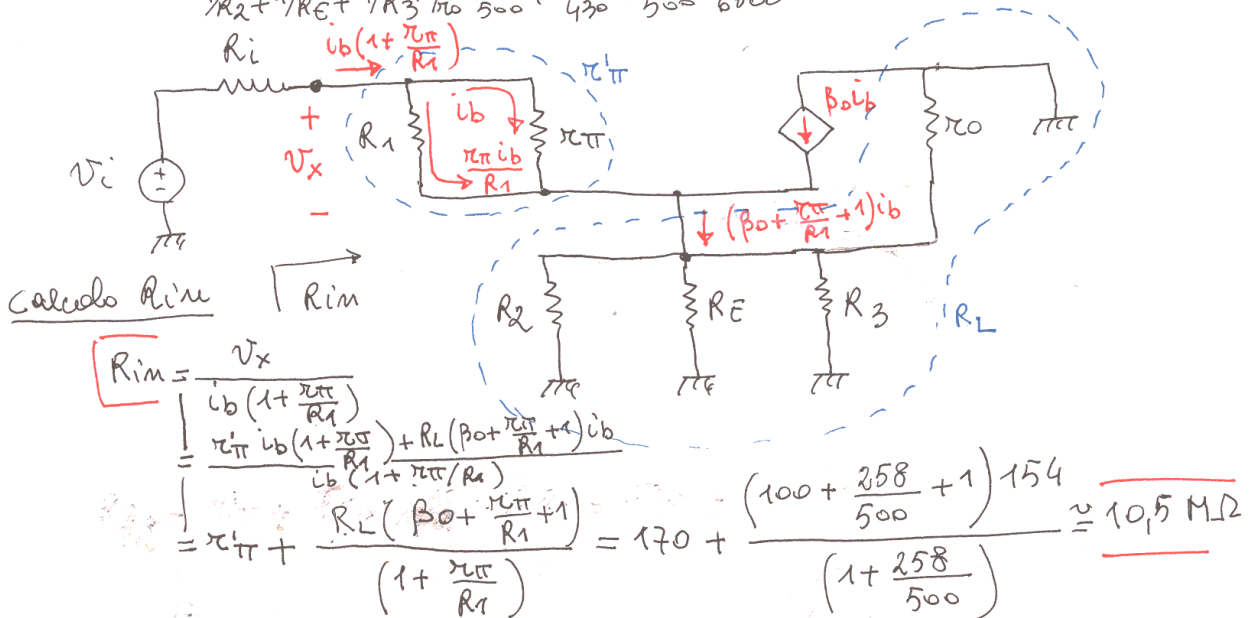
$$= 6,8 M\Omega$$

Circuito equivalente ai piccoli segnali

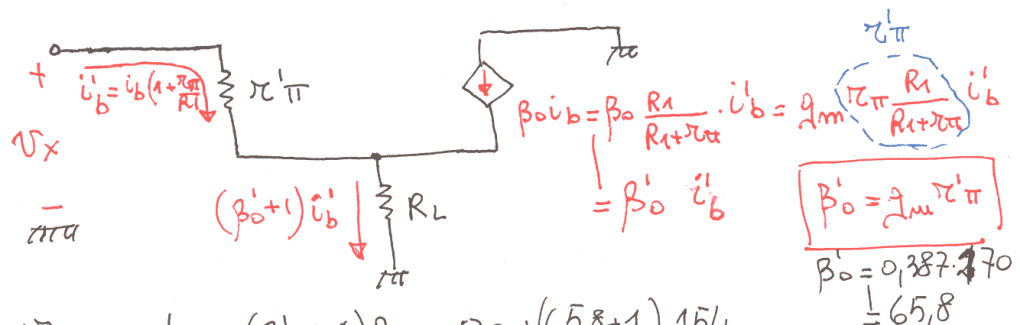
(5/6)

$$r_{\pi} = \frac{R_1 \cdot r_{\pi}}{R_1 + r_{\pi}} = \frac{500 \cdot 258}{500 + 258} \approx 170 \text{ k}\Omega$$

$$R_L = \frac{1}{\frac{1}{R_2} + \frac{1}{R_E} + \frac{1}{R_3} + \frac{1}{R_L}} = \frac{1}{\frac{1}{500} + \frac{1}{470} + \frac{1}{500} + \frac{1}{6800}} \approx 154 \text{ k}\Omega$$



in alternativa

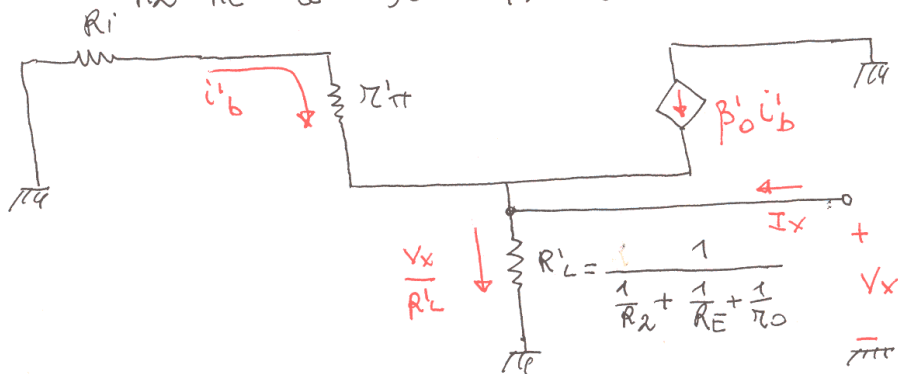


$$R_{in} = \frac{v_x}{i'_b} = r_{\pi} + (\beta'_0 + 1) R_L = 170 + (65,8 + 1) \cdot 154 = 10,5 \text{ M}\Omega$$

calculo R_{out}

$$R'_L = \frac{1}{\frac{1}{R_2} + \frac{1}{R_E} + \frac{1}{r_o}} = \frac{1}{\frac{1}{500} + \frac{1}{430} + \frac{1}{6800}} \approx 224 \text{ k}\Omega$$

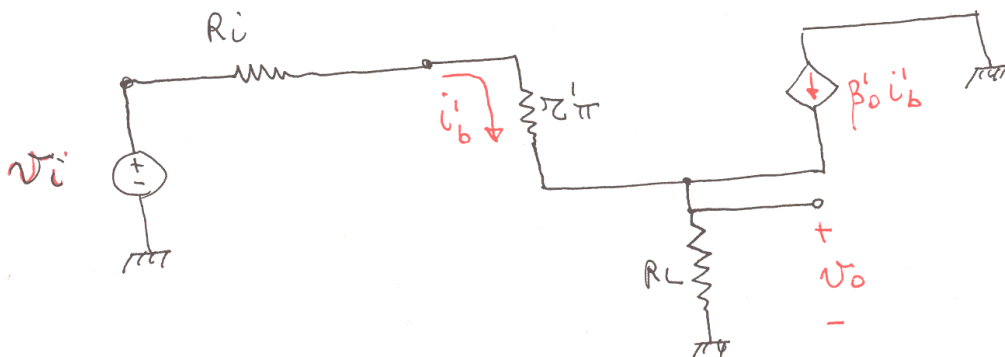
(6/6)



$$R_{out} = \frac{V_x}{\frac{V_x}{R'_L} + \frac{V_x}{r_{\pi} + R_i} + \beta'_0 \frac{V_x}{R_i + r_{\pi}}} = \frac{1}{\frac{1}{R'_L} + \frac{(1 + \beta'_0)}{r_{\pi} + R_i}}$$

$$= \frac{R'_L (r_{\pi} + R_i)}{(R_i + r_{\pi}) + (\beta'_0 + 1) R'_L} = \frac{224 \cdot (170 + 0,5)}{(170 + 0,5) + (65,8 + 1) \cdot 224} \approx 2,52 \text{ k}\Omega$$

calculo A_v



$$v_o = R_L (\beta'_0 + 1) i'_b$$

$$i'_b = \frac{v_i}{R_i + r_{\pi} + R_L (\beta'_0 + 1)}$$

$$A_v = \frac{v_o}{v_i} = \frac{R_L (\beta'_0 + 1)}{R_i + r_{\pi} + R_L (\beta'_0 + 1)}$$

$$A_v = \frac{154 (65,8 + 1)}{0,5 + 170 + 154 (65,8 + 1)} \approx 0,984$$