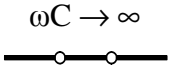
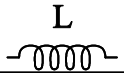
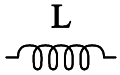
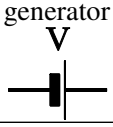
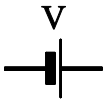
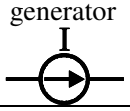
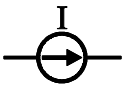
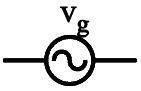
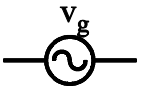
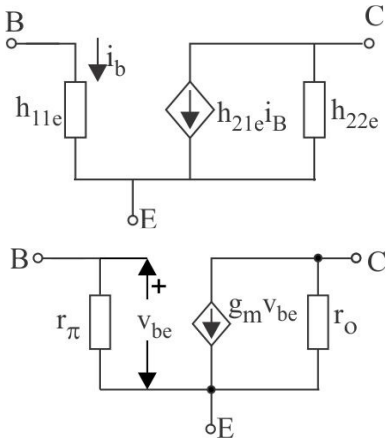
ANALIZA POJAČAVAČA SA BIPOLARNIM TRANZISTORIMA

Element	Jednosmerni model (DC)	Naizmenični model (AC)	
		Opšti slučaj	Srednje frekvencije
Otpornik			
Kondenzator 			
Kalem 			
Jednosmerni naponski generator 			
Jednosmerni strujni generator 			
Naizmenični naponski generator 			



$$h_{11e} = \frac{V_T}{I_B} \quad h_{21e} = \beta \quad h_{22e} = \frac{I_C}{V_A}$$

$$g_m = \frac{I_C}{V_T} \quad r_\pi = \frac{I_B}{V_T} \quad r_o = \frac{V_A}{I_C}$$

Veza između „h“ parametara i parametara pi modela:

$$r_\pi = h_{11E} \quad g_m = \frac{h_{21E}}{h_{11E}} \quad r_o = \frac{1}{h_{22E}}$$

1. ZADATAK

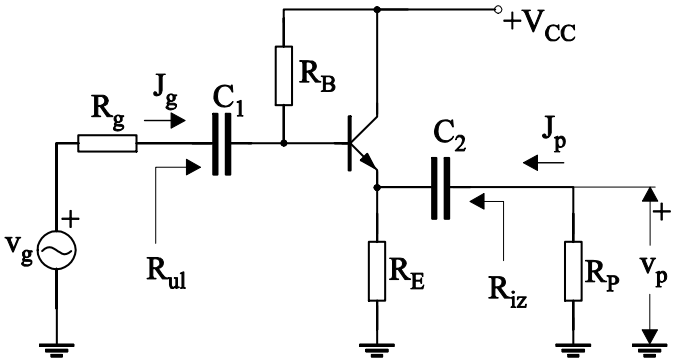
Na slici je prikazan pojačavač u spoju sa zajedničkim kolektorom. Poznati su parametri tranzistora: V_{BE}=0,6 V; h_{12E} = 0; β=h_{21E} = 80; h_{22E} = 0 S. Elementi kola: $R_p = R_E$ = 6 kΩ; R_g = 600 Ω; $C_1 = C_2 \rightarrow \infty$; R_B =335 kΩ; V_{CC}=12 V. Smatrati da je $R_B >> R_g$. Odrediti:

a) Dinamičke parametre tranzistora;

b) Ulaznu otpornost pojačvača R_{ul};

c) Izlaznu otpornost pojačavača R_{iz};

d) Naponsko pojačanje A = v_p/v_g.



Rešenje:

a)

$$-R_E \cdot I_B \cdot (1+\beta) - V_{BE} - R_B \cdot I_B + V_{CC} = 0$$

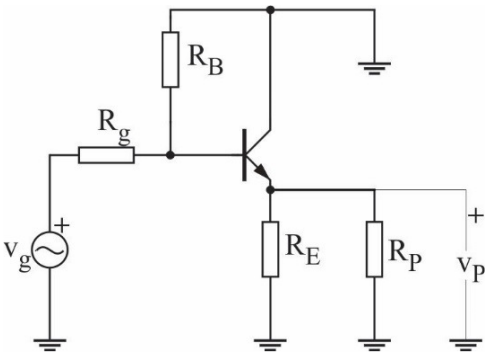
$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (1+\beta) \cdot R_E} = 14\ \mu A$$

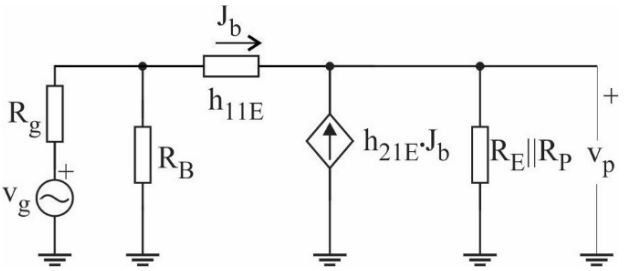
$$h_{ie} = h_{11e} = \frac{V_T}{I_B} = \frac{26mV}{14\mu A} = 1{,}85\ k\Omega$$

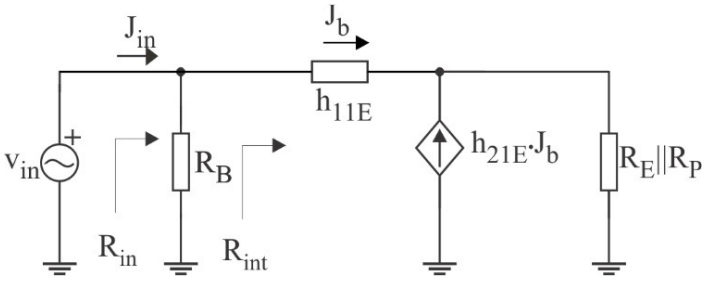
$$h_{fe} = h_{21e} = \beta = 80$$

b)

Šema za naizmeničnu struju







$R_E \parallel R_P = R_{EC}$

$(B) \qquad \frac{v_{in}}{R_B} + i_b - i_{in} = 0$

(E) $\qquad -i_b - h_{21E} \cdot i_b + \frac{v_e}{R_{EC}} = 0$

$i_b = \frac{v_{in} - v_e}{h_{11e}}$

(E) $\qquad v_e = R_{EC} \cdot i_b \cdot (1 + h_{21e})$

$i_b = \frac{v_{in} - R_{EC} \cdot J_b \cdot (1 + h_{21e})}{h_{11e}}$

$i_b = \frac{v_{in}}{h_{11e} + R_{EC} \cdot (1 + h_{21e})}$

$R_{int} = \frac{v_{in}}{i_b} = h_{11e} + R_{EC} \cdot (1 + h_{21e}) = 244{,}8\ k\Omega$

(B) $\qquad i_{in} = \frac{v_{in}}{R_B} + \frac{v_{in}}{h_{11e} + R_{EC} \cdot (1 + h_{21e})}$

$$\frac{1}{R_{in}} = \frac{i_{in}}{v_{in}} = \frac{1}{R_B} + \frac{1}{h_{11e}+R_{EC}\cdot(1+h_{21e})}$$

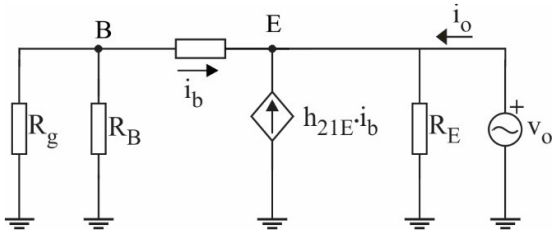
$R_{in} = 133{,}8\ k\Omega$

Ulazna otpornost može da izrazi i na sledeći način:

$$\frac{1}{R_{in}} = \frac{1}{R_B} + \frac{1}{R_{int}}$$

$$R_{in} = R_B \parallel R_{int}$$

c)



$$R_B \parallel R_g = R_{BC}$$

$$(B) \qquad \frac{v_b}{R_{BC}} + i_b = 0$$

$$\text{(E)} \qquad -i_o - h_{21E}\cdot i_b - i_b + \frac{v_o}{R_E} = 0$$

$$i_b = \frac{v_b - v_o}{h_{11e}}$$

$$\text{(B)} \quad v_b = -i_b \cdot R_{BC}$$

$$i_b = \frac{-i_b \cdot R_{BC} - v_o}{h_{11e}}$$

$$i_b = -\frac{v_o}{h_{11e} + R_{BC}}$$

(E)

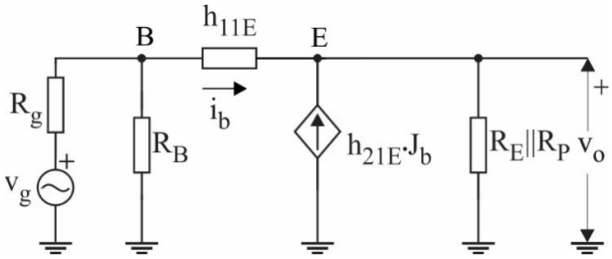
$$i_o = -(h_{21E}+1)\cdot i_b + \frac{v_o}{R_E} = (h_{21E}+1)\cdot\frac{v_o}{h_{11e}+R_{BC}} + \frac{v_o}{R_E}$$

$$\frac{1}{R_o} = \frac{i_o}{v_o} = \frac{1+h_{21e}}{h_{11e}+R_{BC}} + \frac{1}{R_E}$$

$R_o = 30\ \Omega$

$$R_o = R_E \parallel R_{ot} \approx R_{ot} = \frac{h_{11e}+R_{BC}}{1+h_{21e}}$$

d)
I način primenom metoda potencijala čvorova



$R_E \parallel R_P = R_{EC}$

$(B) \qquad \frac{v_b}{R_B} + i_b + \frac{v_b - v_g}{R_g} = 0$

(E) $\qquad -i_b - h_{21E} \cdot i_b + \frac{v_o}{R_{EC}} = 0$

$i_b = \frac{v_b - v_o}{h_{11e}}$

(B) $\quad v_b = v_g \cdot \frac{R_B}{R_g + R_B} - i_b \cdot \frac{R_B \cdot R_g}{R_g + R_B}$

(E) $\quad v_o = R_{EC} \cdot i_b \cdot (1 + h_{21e})$

$v_b = h_{11e} \cdot i_b + v_o$

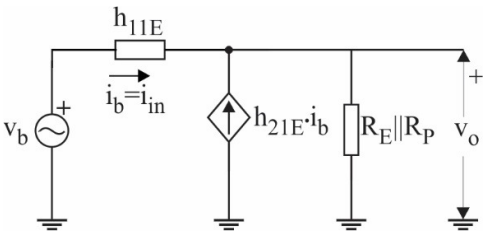
$$i_b = v_g \cdot \frac{\frac{R_B}{R_B + R_g}}{h_{11E} + \frac{R_B \cdot R_g}{R_g + R_B} + (1 + h_{21E}) \cdot R_{EC}}$$

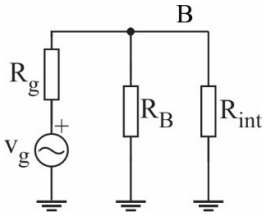
Zamenom izraza za struju baze u (E) dobija se:

$$A_n = \frac{v_o}{v_g} = \frac{R_{EC} \cdot (1 + h_{21e}) \cdot \frac{R_B}{R_B + R_g}}{h_{11E} + \frac{R_B \cdot R_g}{R_g + R_B} + (1 + h_{21E}) \cdot R_{EC}}$$

$$A_n = 0{,}99$$

II načine
Primenom teoreme o kompoenzaciji.





$R_E \parallel R_P = R_{EC}$

(E) $\quad -i_b - h_{21E} \cdot i_b + \frac{v_o}{R_{EC}} = 0$

$i_b = \frac{v_b - v_o}{h_{11e}} = \frac{v_b}{R_{int}}$

$v_o = (1 + h_{21e}) \cdot R_{EC} \cdot \frac{v_b}{R_{in}}$

$\frac{v_o}{v_b} = \frac{(1 + h_{21e}) \cdot R_{EC}}{R_{int}}$

$\frac{v_b}{v_g} = \frac{R_B \parallel R_{int}}{R_g + R_B \parallel R_{int}} = \frac{R_{in}}{R_g + R_{in}}$

$A_n = \frac{v_o}{v_g} = \frac{v_o}{v_b} \cdot \frac{v_b}{v_g} = \frac{(1 + h_{21e}) \cdot R_{EC}}{R_{int}} \cdot \frac{R_{in}}{R_g + R_{in}}$

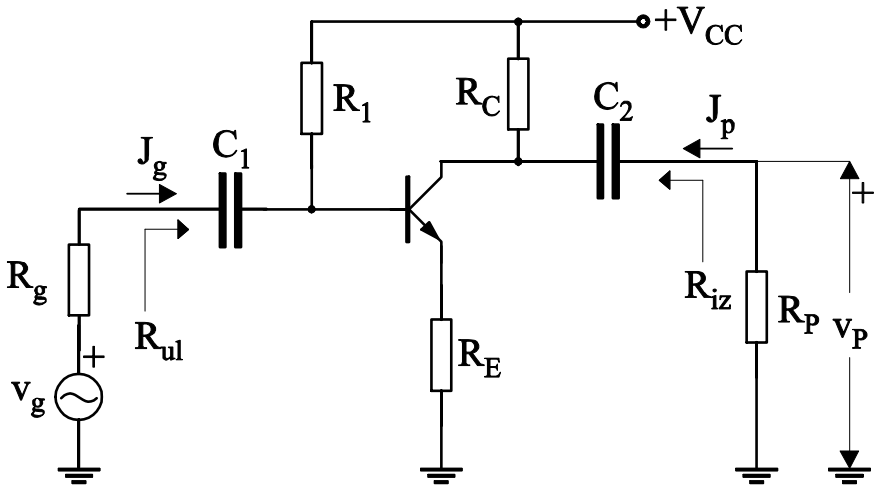
2. ZADATAK

Kolo na slici predstavlja jednostepeni pojačavač sa bipolarnim tranzistorom. Parametri tranzistora su: V_{BE}=0,6 V; $h_{12E} = 0$; $h_{21E} = \beta = 50$; $h_{22E} = 0$ S. Elementi kola su: $R_p = R_C = 5$ kΩ; $R_g = 1$ kΩ; $R_1 = 500$ kΩ; $R_E = 200$ Ω; V_{CC}=12 V; $C_1 \to \infty$; $C_2 \to \infty$.

Odrediti:

a) ulaznu otpornost pojačvača R_{in};

b) naponsko pojačanje $A = \frac{v_p}{v_g}$.



Rešenje:

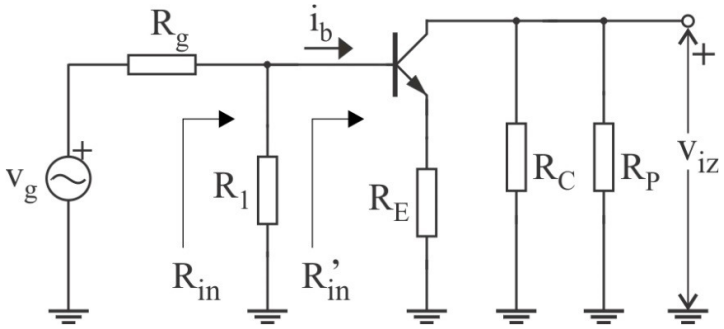
$$V_{CC} - R_1 \cdot I_B - V_{BE} - R_E \cdot (1 + \beta) \cdot I_B = 0$$

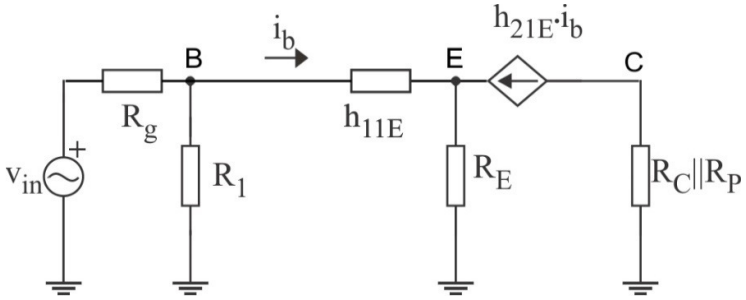
$$I_B = \frac{V_{CC} - V_{BE}}{R_1 + R_E \cdot (1 + \beta)} = 20\ \mu A$$

$$h_{11E} = r_\pi = \frac{V_T}{I_B} = \frac{26\ mV}{20 \mu A} = 1{,}3\ k\Omega$$

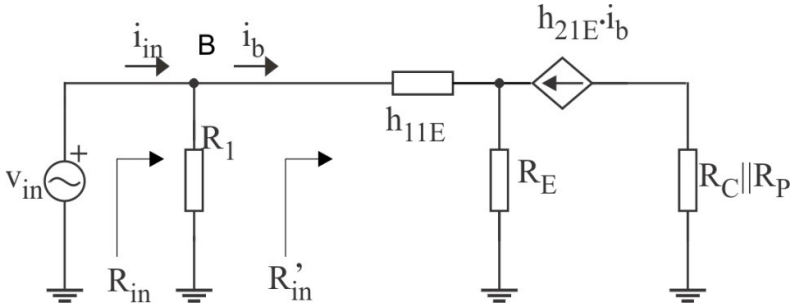
$$h_{21E} = \beta$$

$$g_m = \frac{h_{21E}}{r_\pi} = \frac{I_C}{V_T} = 38{,}5\ mS$$





a)



(E) $\frac{v_e}{R_E} - i_b - h_{21e} \cdot i_b = 0$

$i_b = \frac{v_{in} - v_e}{h_{11E}}$

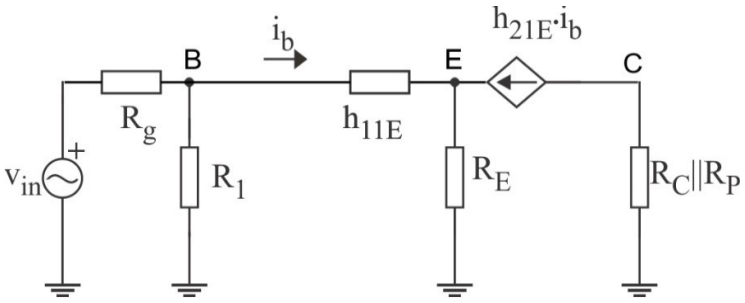
(E) $v_e = R_E \cdot i_b \cdot (1 + h_{21E})$

$i_b = \frac{v_{in}}{h_{11E} + R_E \cdot (1 + h_{21E})}$

$R'_{in} = \frac{v_{in}}{i_b} = h_{11E} + R_E \cdot (1 + h_{21E}) = 11{,}5\ k\Omega$

$R_{in} = R'_{in} \parallel R_1 = 11{,}24\ k\Omega$

b)



(E) $\frac{v_e}{R_E} - i_b - h_{21e} \cdot i_b = 0$

(B) $\frac{v_b}{R_1} + \frac{v_b - v_g}{R_g} + i_b = 0$

(C) $\frac{v_c}{R_C \| R_P} - h_{21E} \cdot i_b = 0$

$$i_b = \frac{v_b - v_e}{h_{11E}}$$

(E) $v_e = R_E \cdot i_b \cdot (1 + h_{21E})$

(B) $v_b = v_g \cdot \frac{R_1}{R_1 + R_g} - i_b \cdot \frac{R_1 \cdot R_g}{R_1 + R_g}$

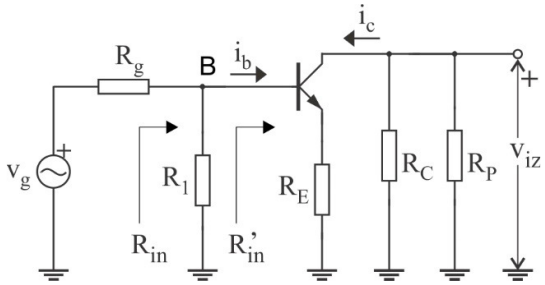
$$i_b = \frac{v_g \cdot \frac{R_1}{R_1 + R_g}}{R_E \cdot (1 + h_{21E}) + \frac{R_1 \cdot R_g}{R_1 + R_g} + h_{11E}}$$

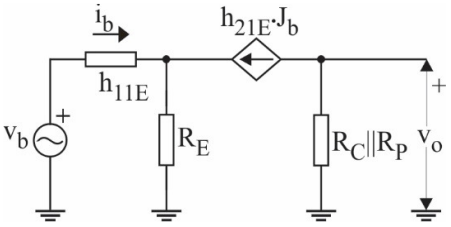
$$v_p = v_c = -h_{21E} \cdot i_b \cdot R_C \parallel R_P$$

$$A_n = \frac{v_c}{v_p} = -\frac{h_{21E} \cdot R_C \parallel R_P \cdot \frac{R_1}{R_1 + R_g}}{R_E \cdot (1 + h_{21E}) + \frac{R_1 \cdot R_g}{R_1 + R_g} + h_{11E}} = 10$$

II način za određivanje naponskog pojačanja

Primenom teoreme o kompenzaciji i korišćenjem ulazne otpornosti

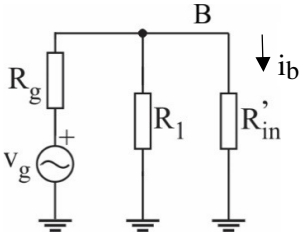




$$i_b = \frac{v_b}{R'_{in}}$$

$$v_o = -h_{21E} \cdot i_b \cdot R_C \parallel R_P = -h_{21E} \cdot \frac{v_b}{R'_{in}} \cdot R_C \parallel R_P$$

$$\frac{v_o}{v_b} = -h_{21E} \cdot \frac{R_C \parallel R_P}{R'_{in}}$$



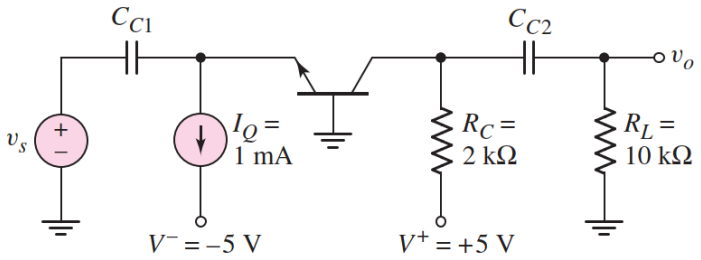
$$\frac{v_b}{v_g} = \frac{R_{in}}{R_g + R_{in}}$$

$$A_n = \frac{v_o}{v_g} = \frac{v_o}{v_b} \cdot \frac{v_b}{v_g} = -h_{21E} \cdot (R_C \parallel R_P) \cdot \frac{R_{in}}{R_{in} + R_g} \cdot \frac{1}{R'_{in}}$$

3. ZADATAK

Na slici je prikazan pojačavač u sprezi sa zajedničkom bazom. Ukolik je: β=80, V_{BE}=0,7 V, $V_A = 100\ V$ odrediti:

a) Radnu tačku tranzistora;
b) Parametre naizmeničnom režima rada;
c) Naponsko pojačanje $A = \frac{v_O}{v_s}$
d) Iznaznu otpornost R_o



Rešenje:

a)

$V_E = -V_{BE} = -0{,}7\ V$

$I_B = \frac{I_C}{\beta} = \frac{I_E}{1+\beta}$

$I_E = I_Q = 1\ mA$

$I_C + \frac{V_C - V_{CC}}{R_C} = 0$

$I_C = I_Q \frac{\beta}{\beta + 1} = 0{,}98\ V$

$V_C = V_{CC} - R_C \cdot I_C = 3{,}02\ V$

$V_{CE} = V_C + V_{BE} = 3{,}72\ V$

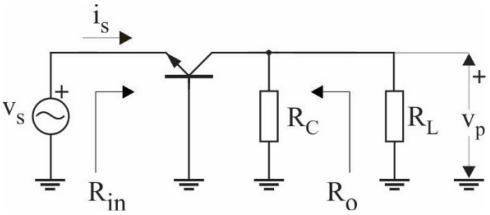
b)

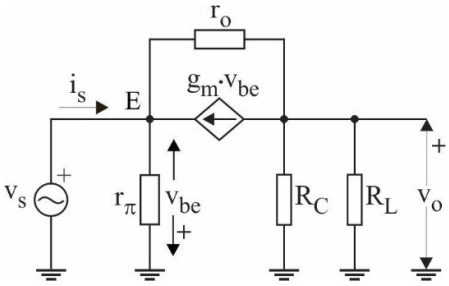
$r_\pi = h_{11E} = \frac{V_T}{I_B} = \frac{26\ mV}{12{,}3\ \mu V} = 2{,}1\ k\Omega$

$g_m = \frac{I_C}{V_T} = \frac{0{,}98\ mA}{26\ mV} = 37{,}7\ mS$

$r_o = \frac{V_A}{I_C} = \frac{100\ V}{0{,}98\ mA} = 102\ k\Omega$

c)





$$R_{CB} = R_C \parallel R_L = 1{,}66\ k\Omega$$

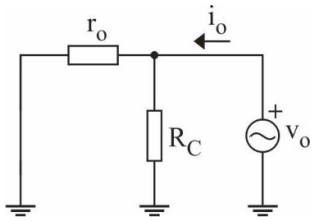
$$\frac{v_o}{R_{CB}} + \frac{v_o - v_s}{r_o} + g_m \cdot v_{be} = 0$$

$$v_{be} = -v_s$$

$$v_o = \frac{g_m + \frac{1}{r_o}}{\frac{1}{R_{CB}} + \frac{1}{r_o}} \cdot v_s$$

$$A_n = \frac{v_o}{v_s} = \frac{g_m \cdot R_{CB} \cdot r_o + R_{CB}}{R_{CB} + r_o} = 61{,}6$$

d)

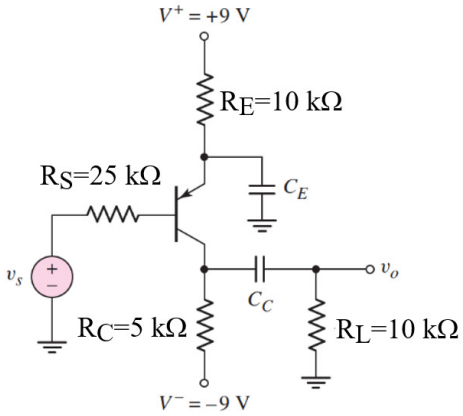


$$\frac{v_o}{r_o} + \frac{v_o}{R_C} - i_o = 0$$

$$R_o = \frac{v_o}{i_o} = \frac{R_c \cdot r_o}{R_C + r_o} \approx R_C = 2\ k\Omega$$

4. ZADATAK

Tranzistor u kolu sa slike ima koeficijent strujnog pojačanja β=80, $V_{BE} = -0{,}65\ V$, $V_A \nearrow \infty$. Odrediti naponsko pojačanje pojačavača $A = \frac{v_o}{v_s}$.



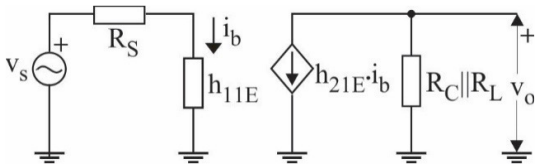
Rešenje:

$$-I_B \cdot R_S + V_{BE} - R_E \cdot I_E + V_{CC} = 0$$

$$I_B = \frac{V_{CC} + V_{BE}}{R_S + (1+\beta) \cdot R_E} = \frac{8{,}35\ V}{835\ k\Omega} = 10\ \mu A$$

$$r_\pi = h_{11E} = \frac{V_T}{I_B} = \frac{26\ mV}{10\ \mu A} = 2{,}6\ k\Omega$$

$$h_{21E} = \beta = 80$$



$$R_{CE} = R_C \parallel R_L = 3{,}3\ k\Omega$$

$$v_b = h_{11E} \cdot i_b$$

$$\frac{v_b}{h_{11E}} + \frac{v_b - v_s}{R_S} = 0$$

$$\frac{v_o}{R_{CE}} + h_{21E} \cdot i_b = 0$$

$$A_n = \frac{v_o}{v_s} = -\frac{h_{21E} \cdot R_{CE}}{R_S + h_{11E}} = 9{,}5$$

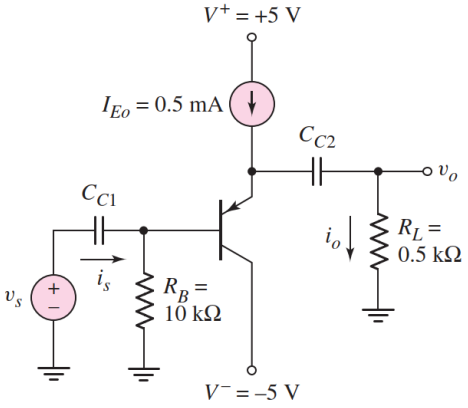
5. ZADATAK

Na slici je prikazan pojačavač u sprezi sa zajedničkom bazom. Ukoliko je: β=80, V_{BE}=0,7 V, $V_A = 100\ V$ odrediti:

a) Ulaznu otpornost $R_{in} = \frac{v_s}{i_s}$

b) Naponsko pojačanje $A = \frac{v_O}{v_s}$

c) Iznaznu otpornost R_o

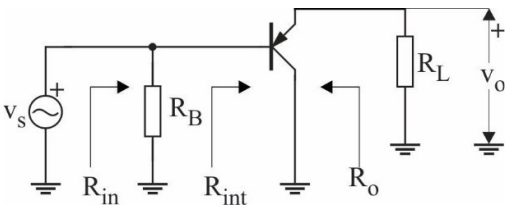


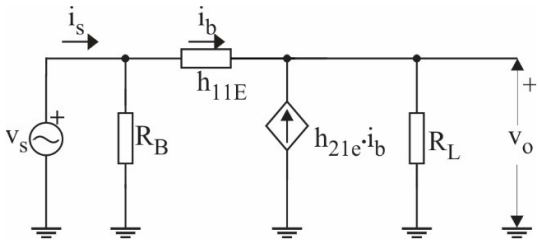
Rešenje:

a)

$$I_B = \frac{I_{Eo}}{1+\beta} = 6{,}17\ \mu A$$

$$h_{11E} = \frac{V_T}{I_B} = \frac{26\ mV}{6{,}17\ \mu V} = 4{,}2\ k\Omega$$





$$-i_b - h_{21E} \cdot i_b + \frac{v_0}{R_L} = 0$$

$$i_b = \frac{v_s - v_o}{h_{11E}}$$

$$v_o = i_b \cdot R_L + h_{21E} \cdot i_b \cdot R_L$$

$$v_s = h_{11} \cdot i_b + v_o$$

$$v_s = h_{11} \cdot i_b + i_b \cdot R_L + h_{21E} \cdot i_b \cdot R_L$$

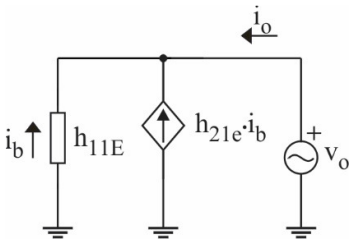
$$R_{int} = \frac{v_s}{i_b} = h_{11} + R_L + h_{21E} \cdot R_L = 44{,}7\ k\Omega$$

$$R_{in} = R_{int} \parallel R_B = 8{,}17\ k\Omega$$

b)

$$A_n = \frac{v_o}{v_s} = \frac{i_b}{v_s} \cdot \frac{v_o}{i_b} = \frac{1}{R_{int}} \cdot (1 + h_{21E}) \cdot R_L = \frac{(1 + h_{21E}) \cdot R_L}{h_{11} + R_L + h_{21E} \cdot R_L} = 0{,}9$$

c)



$$i_b = -\frac{v_o}{h_{11E}}$$

$$-i_o - i_b - h_{21E} \cdot i_b = 0$$

$$i_o = v_o \cdot \left(\frac{1 + h_{21E}}{h_{11E}}\right)$$

$$R_o = \frac{v_o}{i_o} = \frac{h_{11E}}{(1 + h_{21E})} = 52\ \Omega$$