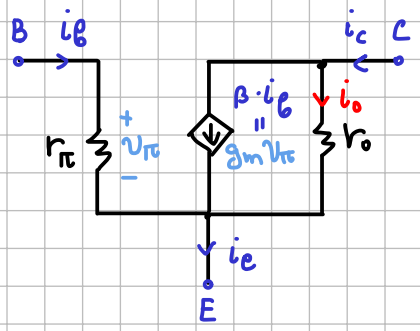
Модел биполарног транзистора за мале сигнале:

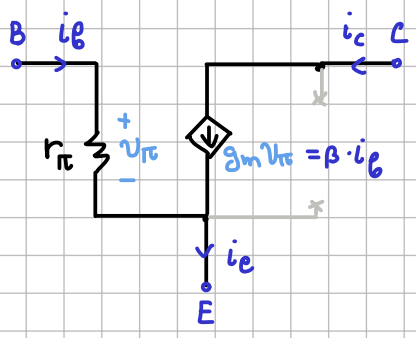


Са Ерлијевим ефектом

$r_o < \infty \ (V_A < \infty)$

$i_c = \beta \cdot i_B + i_o = g_m v_\pi + i_o$

$i_e = i_B + i_c + i_o = (\beta+1) i_B + i_o$



Без Ерлијевог ефекта

$r_o \to \infty \ (V_A \to \infty)$

$i_c = \beta \cdot i_B = g_m v_\pi$

$i_e = i_B + i_c = (\beta+1) i_B$ $\quad (i_o = 0)$

Параметри модела: (добијају се DC анализом)

$g_m = \frac{I_C}{V_T}$ - транскондуктанса

$r_\pi = \frac{V_T}{I_B}$ - (динамичка) отпорност споја база-емитер

$r_o = \frac{V_A + V_{CE}}{I_C} \approx \frac{V_A}{I_C}$ - (динамичка) отпорност споја колектор-емитер $\quad (V_A \gg V_{CE})$

I_B, I_C, I_E - DC струје транзистора

V_{CE} - DC напон споја колектор-емитер

$V_T = \frac{kT}{q}$ - термални напон
(око 25mV - 26mV на T=300K)

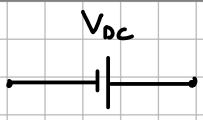
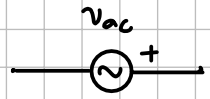
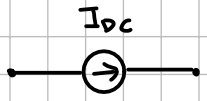
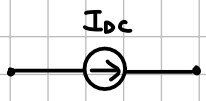
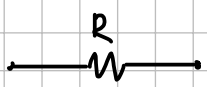
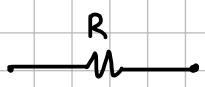
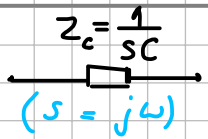
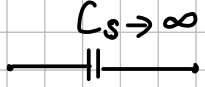
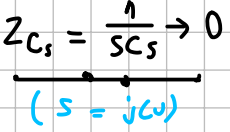
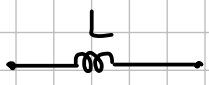
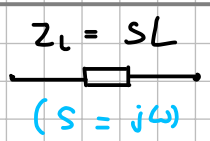
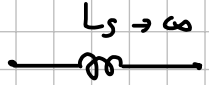
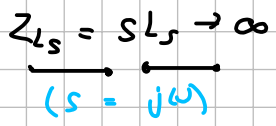
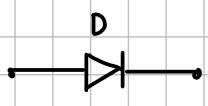
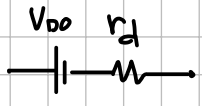
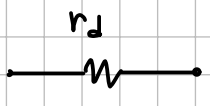
V_A - Ерлијев напон (реда 50-100V,
често се узима да је бесконачан)

Везе између параметара:

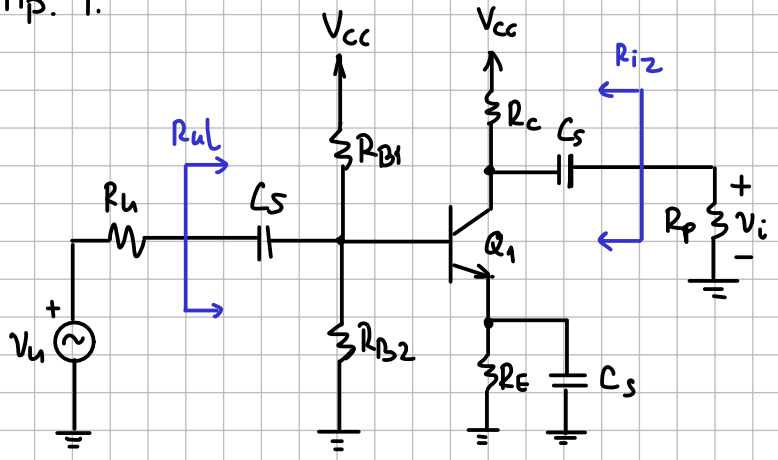
$\left.\begin{aligned} g_m \cdot r_\pi &= \beta \\ r_\pi \cdot i_B &= v_\pi \end{aligned}\right\} \Rightarrow g_m \cdot v_\pi = \beta \cdot i_B$

$\mu = g_m \cdot r_o$

Понашање различитих елемената при DC и AC анализи:

елемент	симбол	DC анализа	AC анализа
идеални генератор једносмерног напона			
идеални генератор наизменичног напона мале амплитуде			
идеални генератор једносмерне струје			
отпорник			
кондензатор			
спрежни кондензатор			
калем			
калем високе индуктивности (пригушница)			
проводна диода			

Пр. 1.



Познато је:

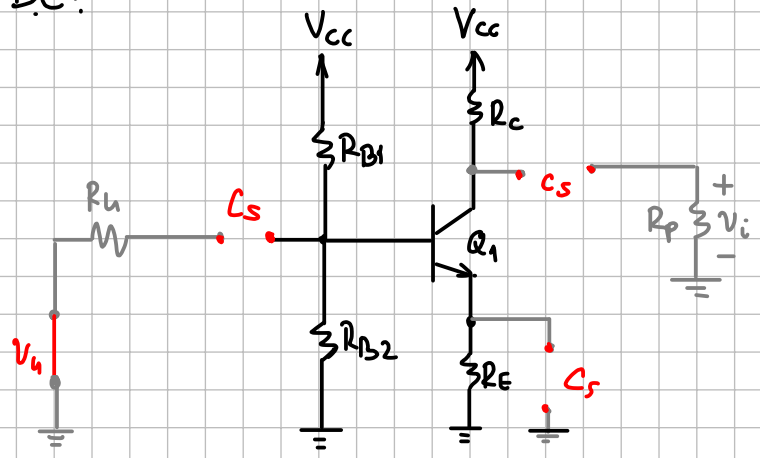
$R_{B1}, R_{B2}, R_C, R_E, R_P, R_u, V_{CC}$
$C_S \to \infty$
β, V_{BE}, V_A

а) $g_m, r_\pi, r_o = ?$

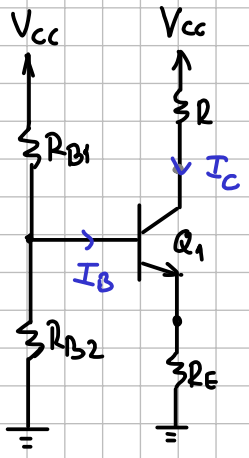
б) $A_n = \frac{v_i}{v_u} = ?$

в) $R_{uL}, R_{iz} = ?$

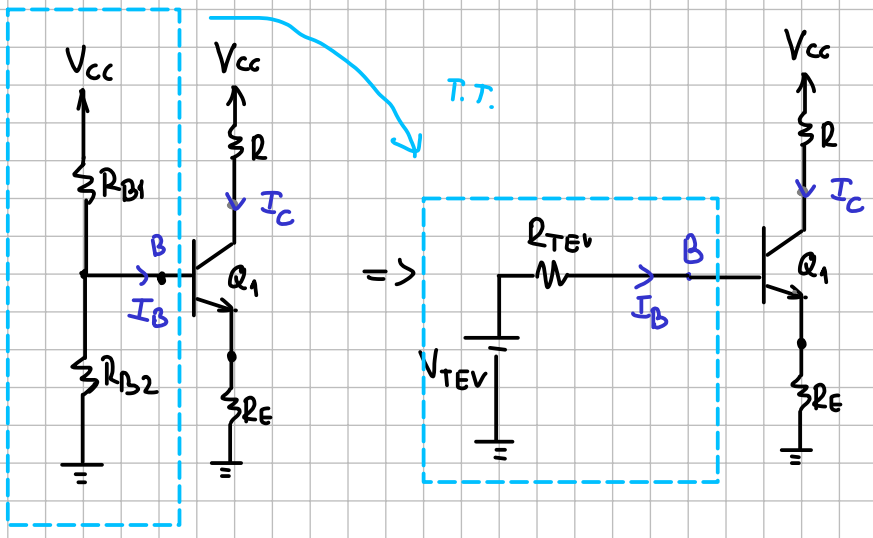
а) DC:



$\Rightarrow$

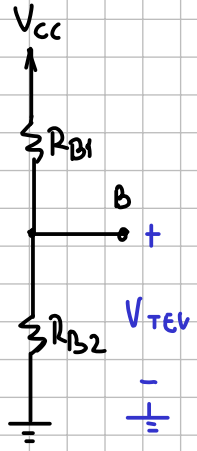


$I_B = ?$

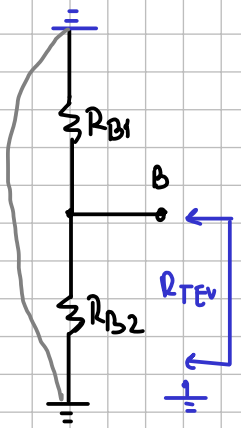


$V_{TEV} = ?$

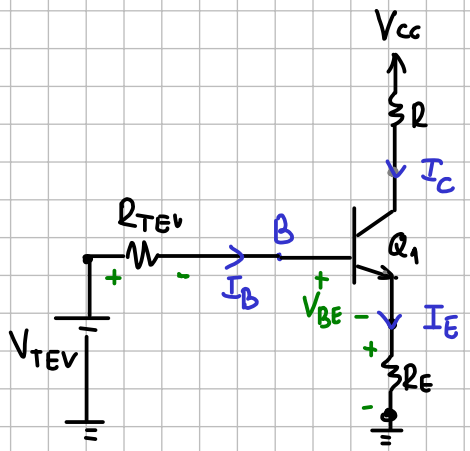
$R_{TEV} = ?$



$$V_{TEV} = \frac{R_{B2}}{R_{B1} + R_{B2}} \cdot V_{CC}$$



$$R_{TEV} = R_{B1} \parallel R_{B2} = \frac{R_{B1} \cdot R_{B2}}{R_{B1} + R_{B2}}$$



$$I_E = (\beta + 1) \cdot I_B$$

$$V_{TEV} = R_{TEV} \cdot I_B + V_{BE} + R_E \cdot I_E$$

$$= R_{TEV} \cdot I_B + V_{BE} + (\beta + 1) \cdot I_B \cdot R_E$$

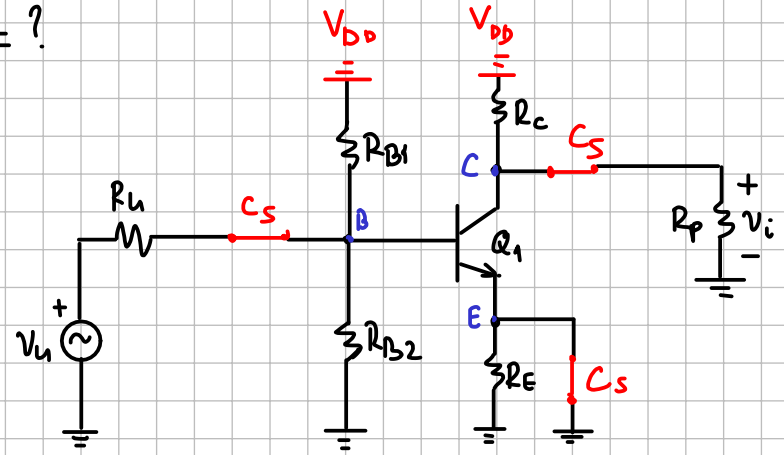
$$= \left[R_{TEV} + (\beta + 1) \cdot R_E \right] \cdot I_B + V_{BE}$$

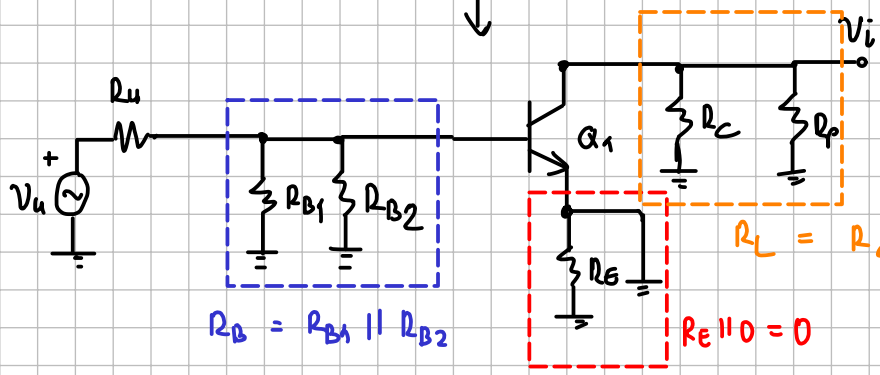
$$\Rightarrow I_B = \frac{V_{TEV} - V_{BE}}{R_{TEV} + (\beta + 1) \cdot R_E}$$

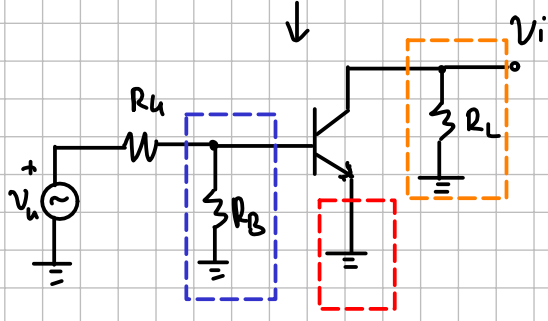
$I_C \rightarrow g_m$, r_o; r_π

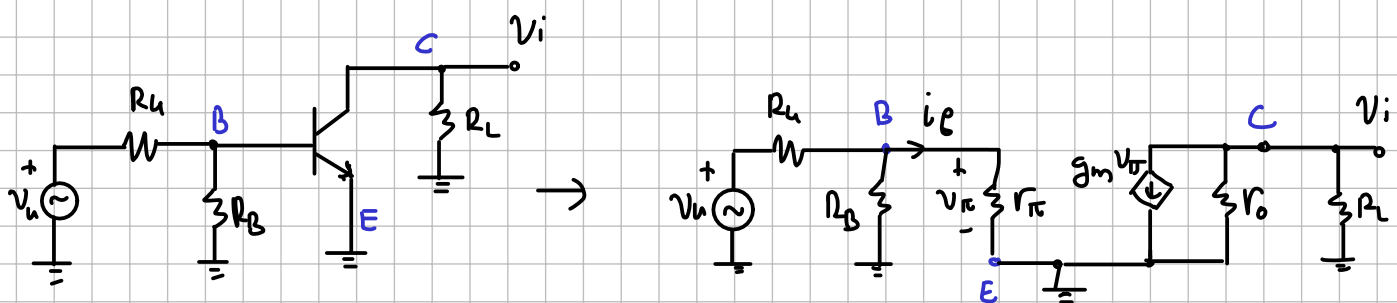
δ) $A_h = \frac{v_i}{v_h} = ?$

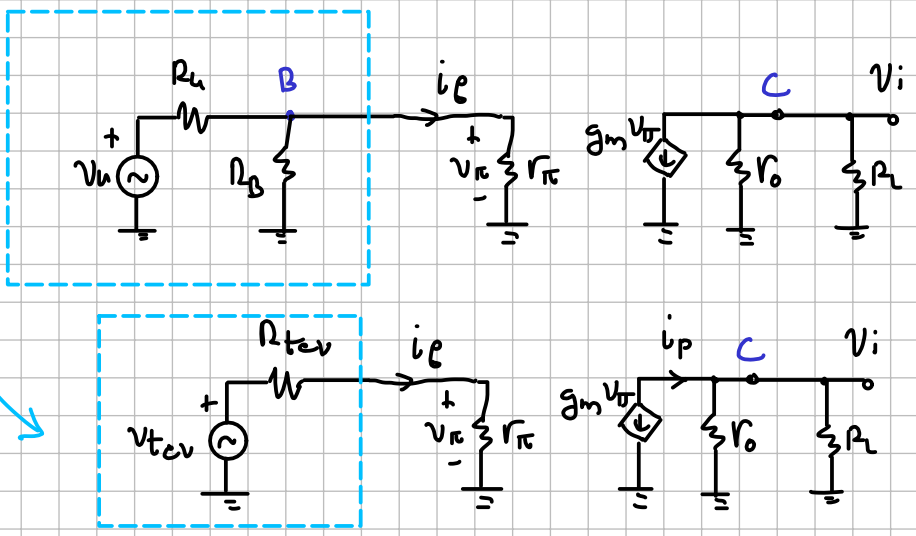
Ac:











$$v_{tev} = \frac{R_B}{R_u + R_B} \cdot v_u$$

$$R_{tev} = R_u \parallel R_B$$

T. +

$$A_n = \frac{v_i}{v_u}$$

$$i_p = \frac{v_i}{r_o \parallel R_L}$$

$$g_m v_\pi = -i_p$$

$$v_\pi = \frac{r_\pi}{R_{tev} + r_\pi} \cdot v_{tev}$$

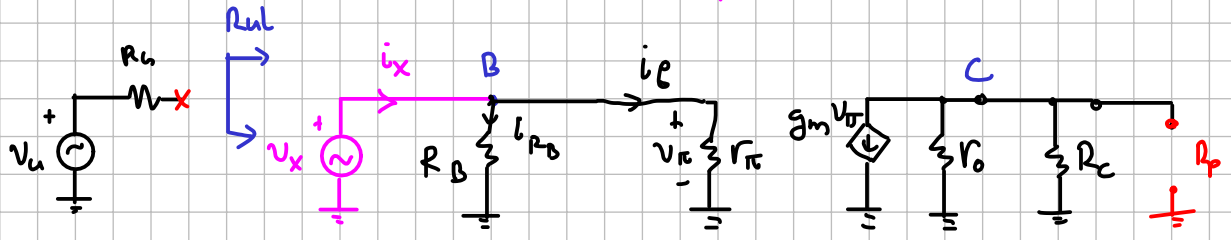
$$v_{tev} = \frac{R_B}{R_u + R_B} \cdot v_u$$

$$A_n = \frac{v_i}{i_p} \cdot \frac{i_p}{v_\pi} \cdot \frac{v_\pi}{v_{tev}} \cdot \frac{v_{tev}}{v_u}$$

$$\boxed{A_n = (r_o \parallel R_L) \cdot (-g_m) \cdot \frac{r_\pi}{R_{tev} + r_\pi} \cdot \frac{R_B}{R_u + R_B}}$$

b) $R_{uL} = ?$ $i_{i2} = ?$

$R_{uL} \rightarrow R_p \Rightarrow$ — • — $R_{uL} = \frac{v_x}{i_x}$



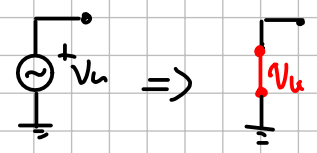
$$v_B = v_x$$

$$i_x = i_{RB} + i_\ell = \frac{v_x}{R_B} + \frac{v_x}{r_\pi} = v_x \left(\frac{1}{R_B} + \frac{1}{r_\pi}\right) \quad / : i_x$$

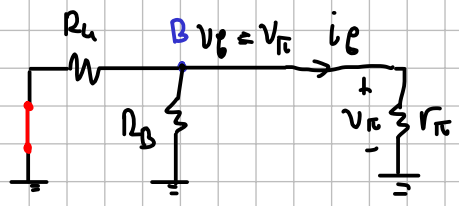
$$1 = \frac{v_x}{i_x} \cdot \left(\frac{1}{R_B} + \frac{1}{r_\pi}\right)$$

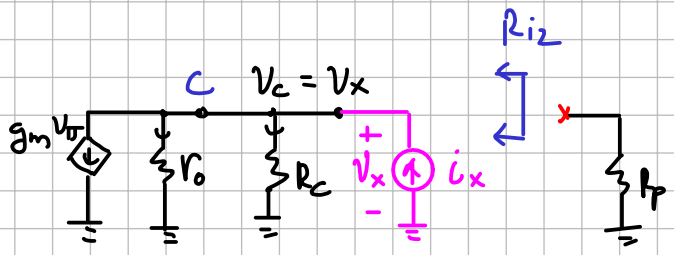
$$\frac{v_x}{i_x} = \frac{1}{\frac{1}{R_B} + \frac{1}{r_\pi}} = \frac{R_B \cdot r_\pi}{R_B + r_\pi} = R_B \parallel r_\pi \Rightarrow \boxed{R_{uL} = R_B \parallel r_\pi}$$

$R_{i2} = ?$ →



$R_{i2} = \frac{v_x}{i_x}$

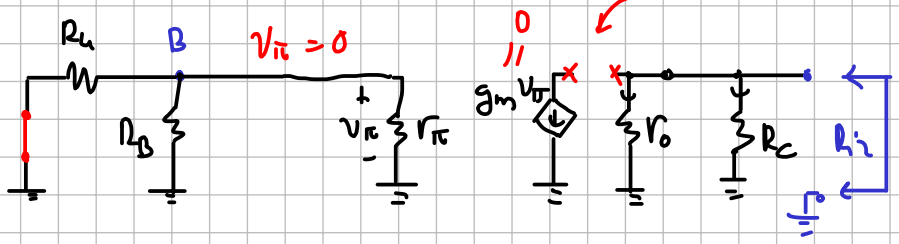




$$i_x = \frac{v_x}{R_C} + \frac{v_x}{r_o} + g_m \cdot v_\pi$$

$$\frac{v_B}{R_u} + \frac{v_B}{R_B} + \frac{v_B}{r_\pi} = 0 \Rightarrow v_B = v_\pi = 0 \Rightarrow i_x = \frac{v_x}{R_C} + \frac{v_x}{r_o} = \frac{v_x}{R_C \| r_o}$$

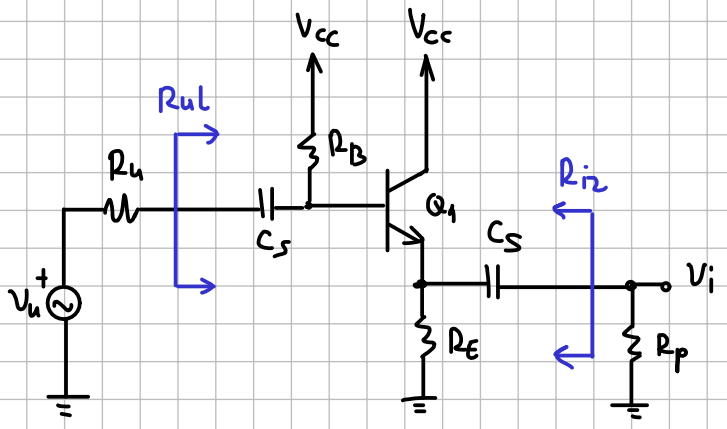
$$\Rightarrow \boxed{R_{i2} = \frac{v_x}{i_x} = R_C \| r_o}$$



$\Rightarrow R_{i2} = r_o \| R_C$

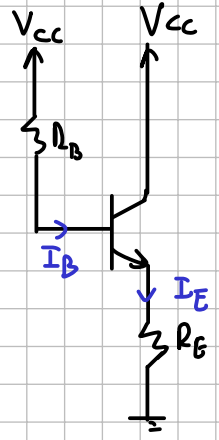
Пр. 2.

$(V_A \to \infty)$



a) $g_m,\ r_o,\ r_\pi = ?$

DC:

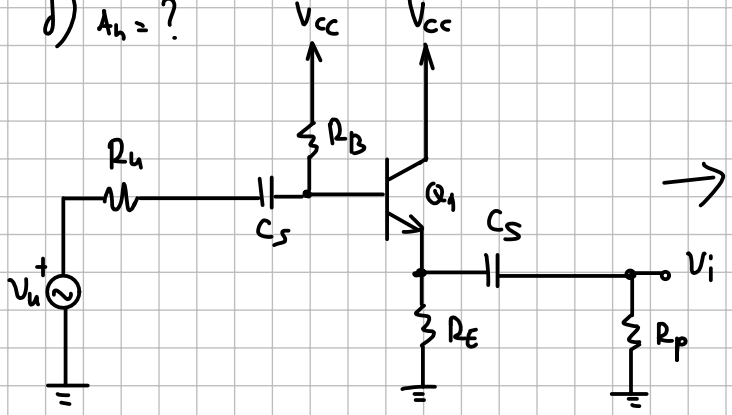


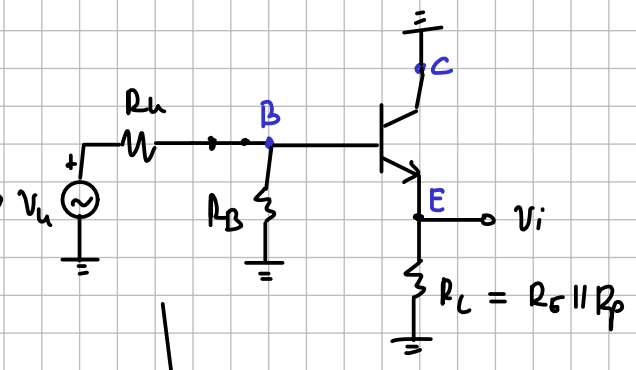
$$V_{CC} = R_B \cdot I_B + V_{BE} + R_E \cdot I_E$$

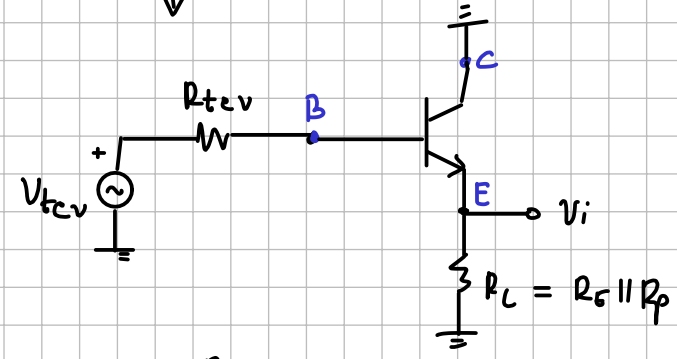
$$I_E = (\beta + 1) \cdot I_B$$

$$\Rightarrow \quad I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta+1)\cdot R_E} \longrightarrow I_C,\ g_m,\ r_\pi,\ r_o$$

б) $A_u = ?$

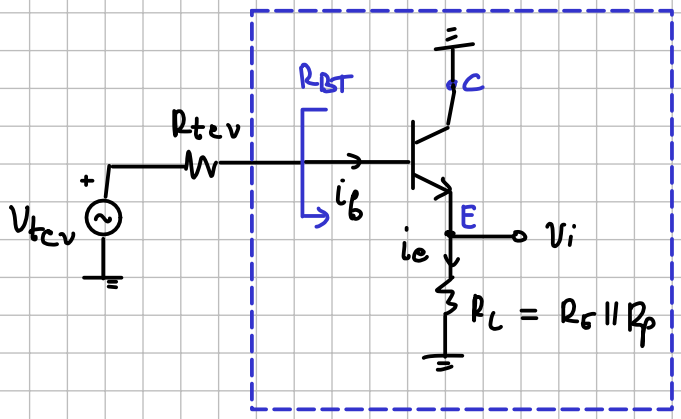






$$v_{tev} = \frac{R_B}{R_s + R_B} \cdot v_s$$

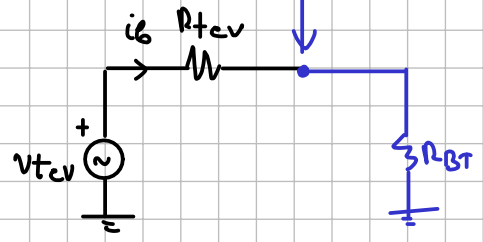
$$R_{tev} = R_B \parallel R_s$$



$$i_e = \frac{V_i}{R_L}$$

$$i_B = \frac{i_e}{\beta + 1}$$

$$\frac{V_{tev}}{i_b} = ?$$

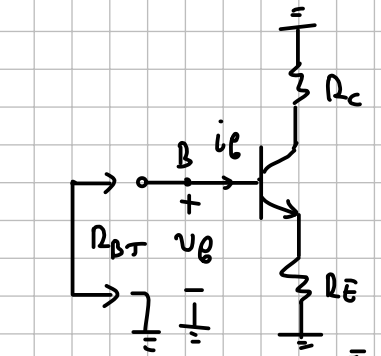


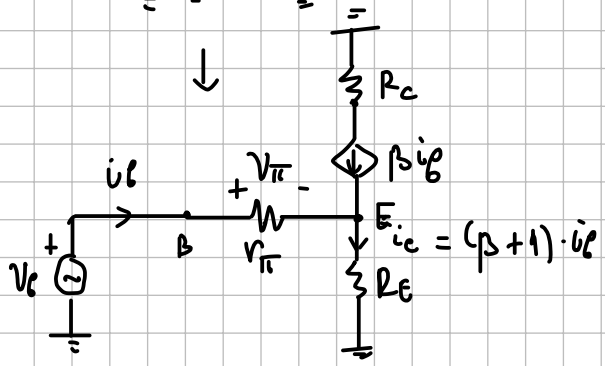
$R_{BT} = ?$

$$\frac{V_{tev}}{i_b} = R_{tev} + R_{BT}$$

$r_o \to \infty$

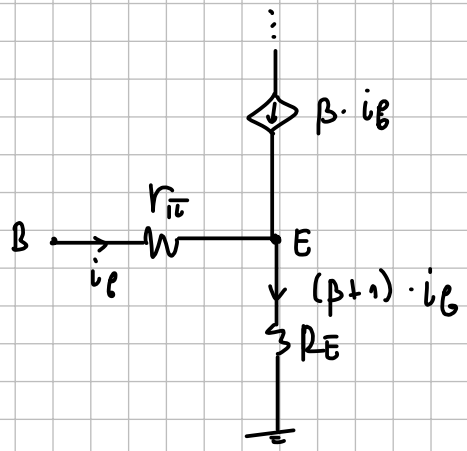
$$R_{BT} = \frac{V_b}{i_b}$$



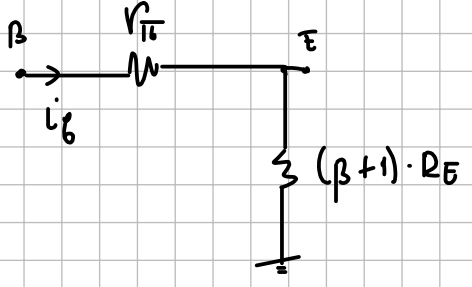


$$V_b = r_\pi \cdot i_b + R_E \cdot (\beta + 1)\, i_b \quad / : i_b$$

$$\boxed{\frac{V_b}{i_b} = R_{BT} = r_\pi + (\beta + 1)\, R_E}$$

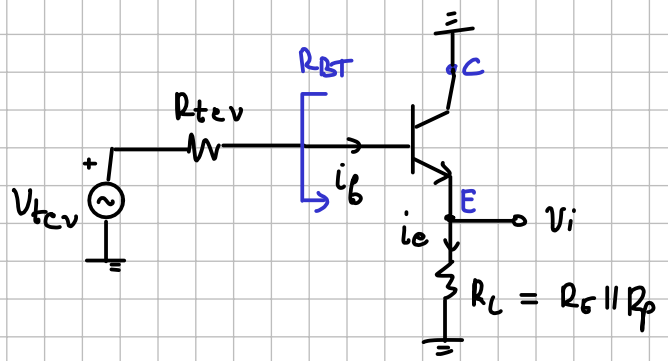


$\Longleftrightarrow$



$$V_e = R_E \cdot (\beta + 1) \cdot i_b$$

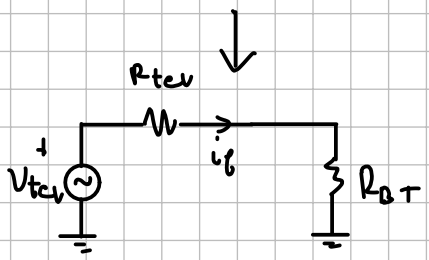
$$V_c = i_b \cdot (\beta + 1) \cdot R_E$$



$$i_e = \frac{V_i}{R_L}$$

$$i_B = \frac{i_e}{\beta + 1}$$

$$\frac{V_{tev}}{i_b} = ?$$



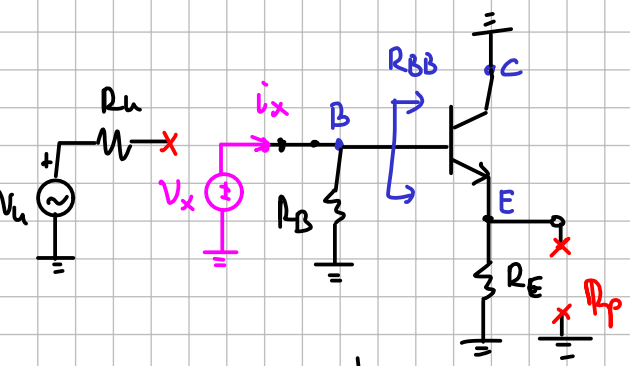
$$R_{BT} = r_\pi + (\beta + 1) \cdot R_L$$

$$\frac{V_{tev}}{i_b} = R_{tev} + R_{BT}$$

$$\frac{V_{tev}}{V_u} = \frac{R_B}{R_B + R_u}$$

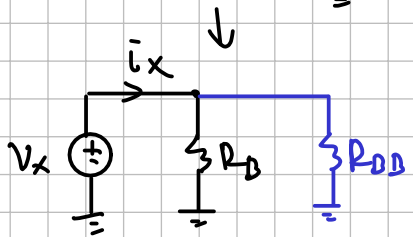
$$A_n = \frac{V_i}{V_u} = \frac{V_i}{i_e} \cdot \frac{i_e}{i_b} \cdot \frac{i_b}{V_{tev}} \cdot \frac{V_{tev}}{V_u} = R_L \cdot (\beta + 1) \cdot \frac{1}{R_{tev} + R_{BT}} \cdot \frac{R_B}{R_B + R_u}$$

b) $R_{uL} = ?$ $R_{i2} = ?$

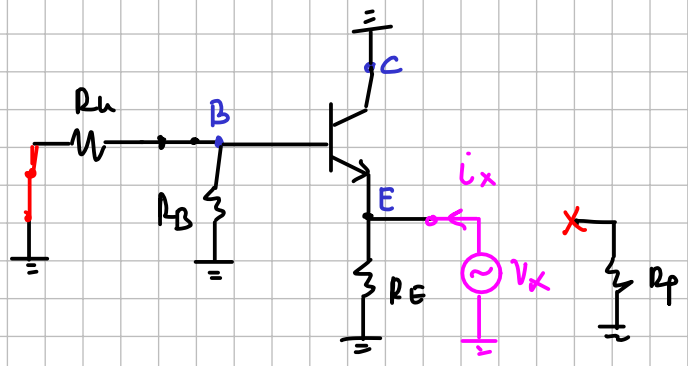


$$R_{BB} = r_\pi + (\beta + 1) \cdot R_E$$

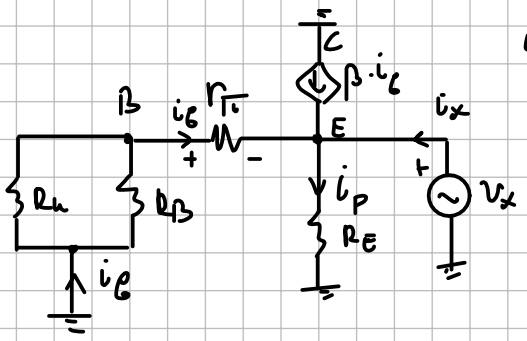
$$R_{uL} = R_{BB} \parallel R_B = \left[r_\pi + (\beta + 1) R_E \right] \parallel R_B$$



R_{i2}:



$$R_{i2} = \frac{v_x}{i_x}$$



E: $i_x + \beta \cdot i_b + i_b = i_p$

$$i_x + (\beta + 1) \cdot i_b = \frac{v_x}{R_E}$$

$$v_x = -r_\pi \cdot i_b - (R_u \parallel R_B) \cdot i_b$$
$$= -(r_\pi + R_u \parallel R_B) \cdot i_b$$

$$i_x + (\beta+1) \cdot \frac{v_x}{-(r_\pi + R_u \parallel R_B)} = \frac{v_x}{R_E}$$

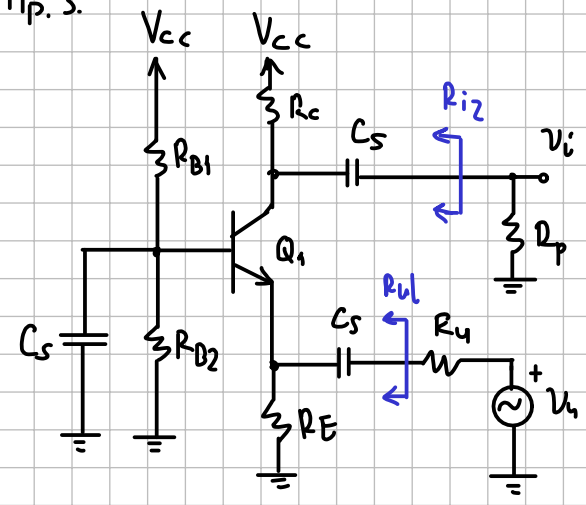
$$v_x \left(\frac{1}{R_E} + \frac{\beta+1}{r_\pi + R_u \parallel R_B} \right) = i_x \Rightarrow$$

$$\frac{v_x}{i_x} = R_{i2} = \frac{1}{\frac{1}{R_E} + \frac{\beta+1}{r_\pi + R_u \parallel R_B}}$$

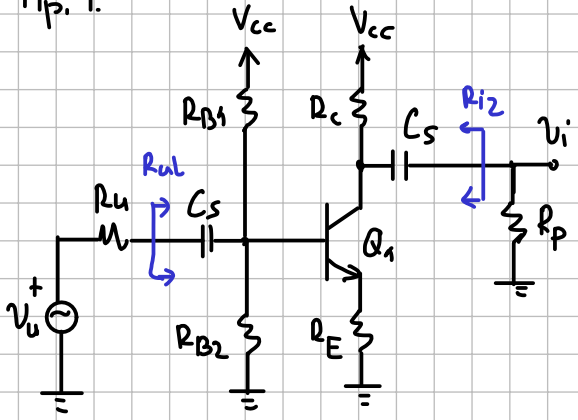
$$R_{i2} = R_E \parallel \left(\frac{r_\pi + R_u \parallel R_p}{\beta + 1} \right)$$

За вежбу (са и без Ерлијевог ефекта):

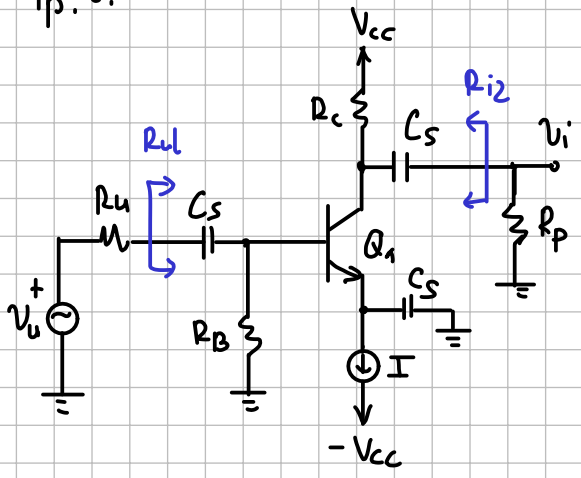
Пр. 3.



Пр. 4.



Пр. 5.



Пр. 6.