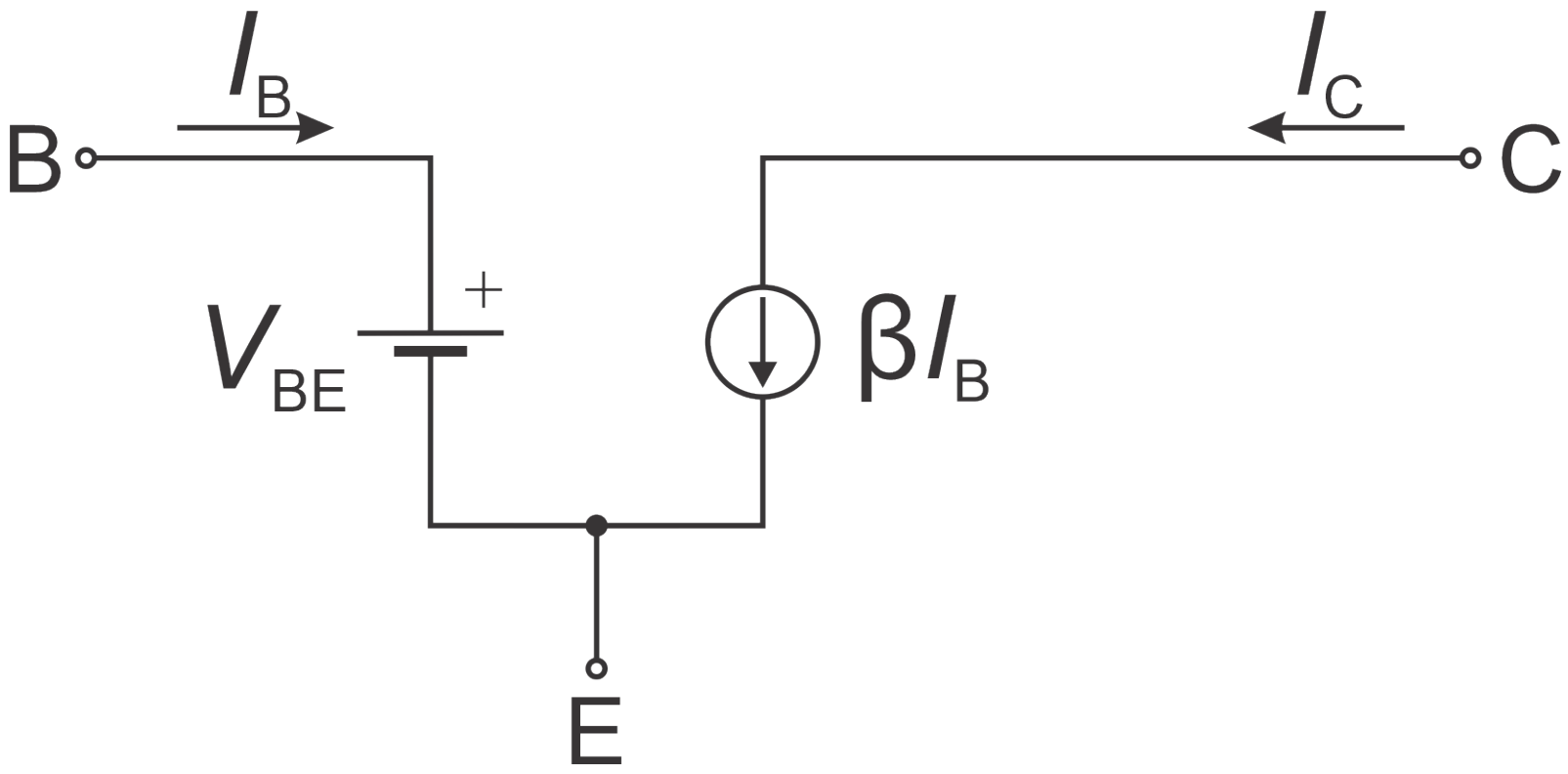
Pojačavači sa bipolarnim tranzistorima

Marko Dimitrijević

Model za jednosmerni signal (linearizovani)

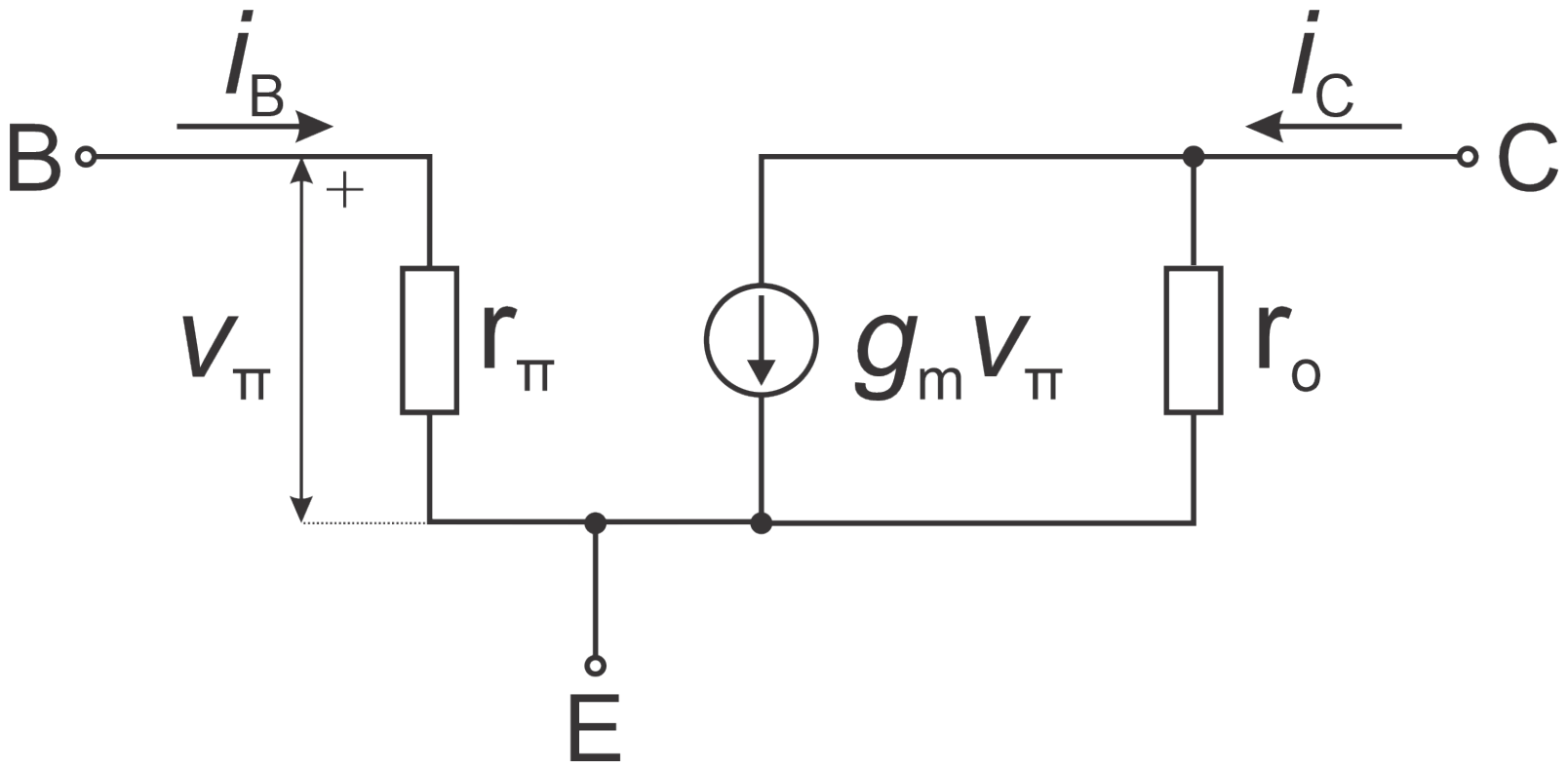
Parametri: β, V_{BE}



Model za male signale

Parametri: g_m, r_π, r_o

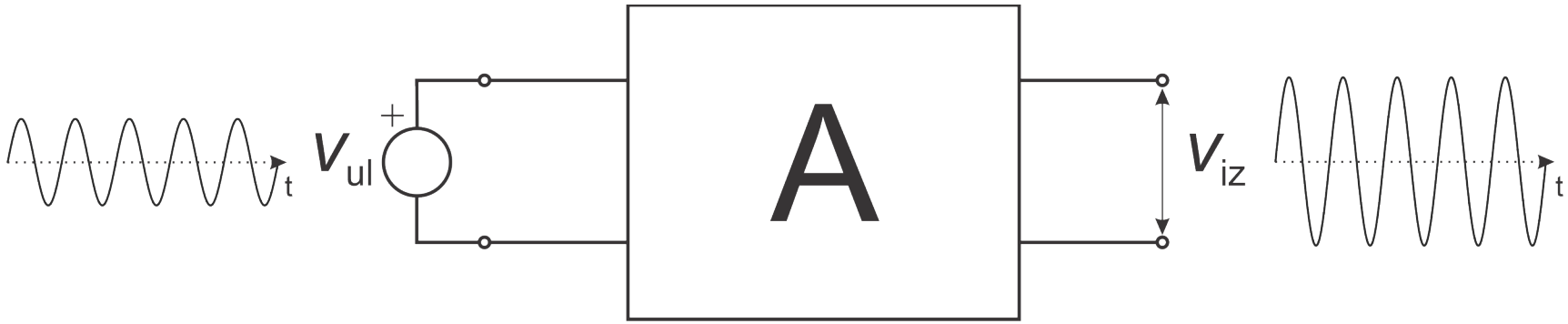
$$g_m = \frac{I_C}{V_T}, \quad r_\pi = \frac{\beta \cdot V_T}{I_C}, \quad r_o = \frac{V_A}{I_C}$$



Pojačavač – analiza i sinteza

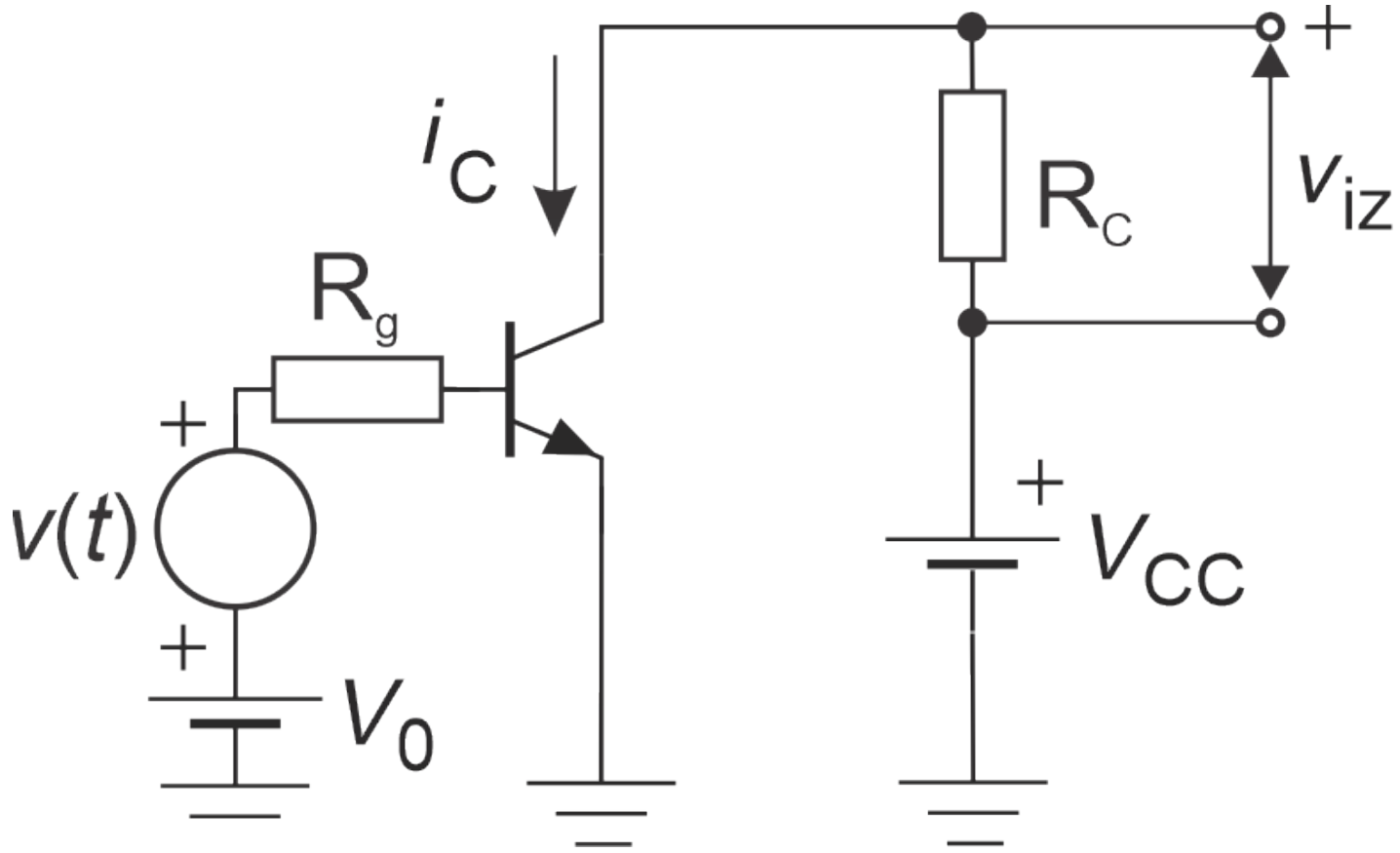
- Izbor topologije
- Obezbeđenje odgovarajućih polarizacija svih tranzistora u kolu (određivanje radnih tačaka svih tranzistora).
- Analiza ponašanja realizovanog kola za **jednosmerni režim.**
- Analiza ponašanja realizovanog kola za **male signale** (pojačanje, amplitudska karakteristika, ulazna i izlazna impedansa, snaga, itd.).

Karakteristike pojačavača

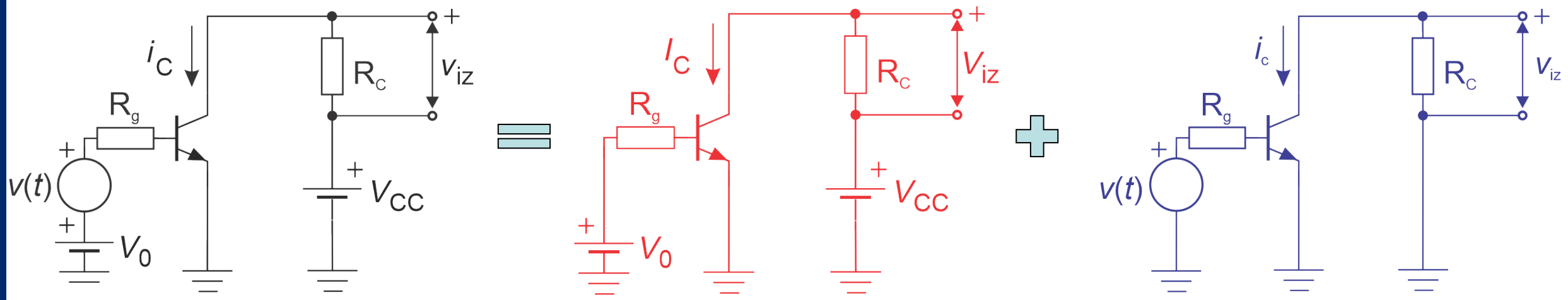


- Pojačanje A=v_{iz}/v_{ul}
- Potrošnja – polarizacija tranzistora zahteva energiju
- Ulazna i izlazna impedansa
- Zavisnost od temperature
- …

Pojačavač sa zajedničkim emitorom



Superpozicija – kola za velike i male signale

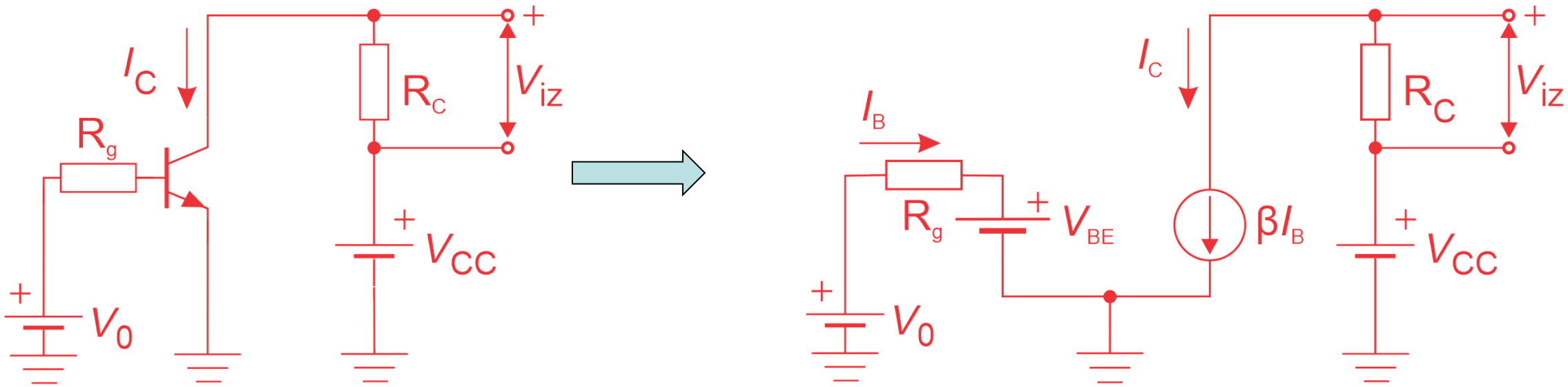


Veliki signali (polarizacija)

Signali malih amplituda

Jednosmerni režim (veliki signali)

- Pronalazi se se I_C, izračunava g_m, r_π, r_o.

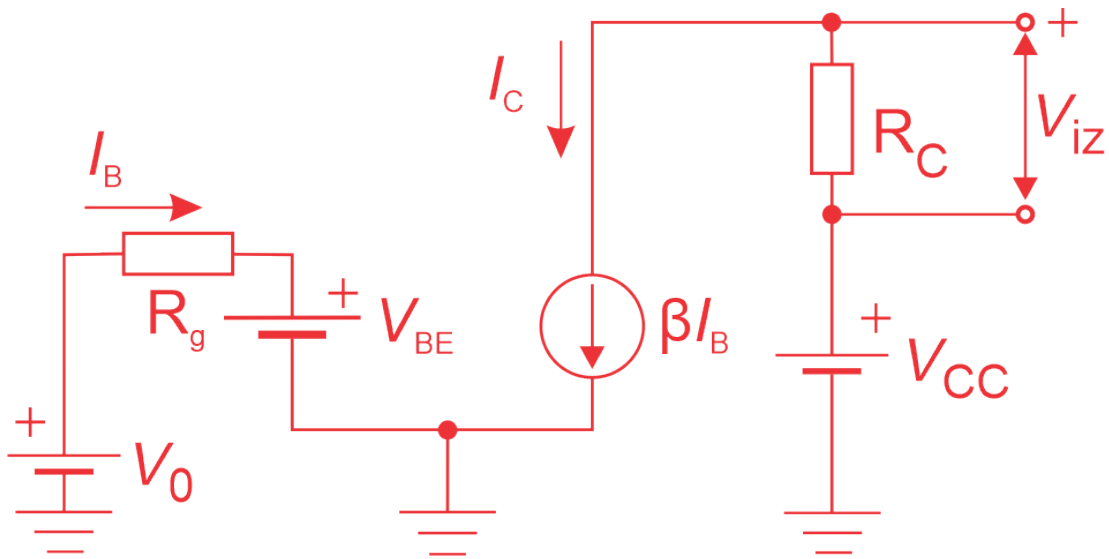


Jednosmerni režim (veliki signali)

- V_{BE}, β, V_A=∞

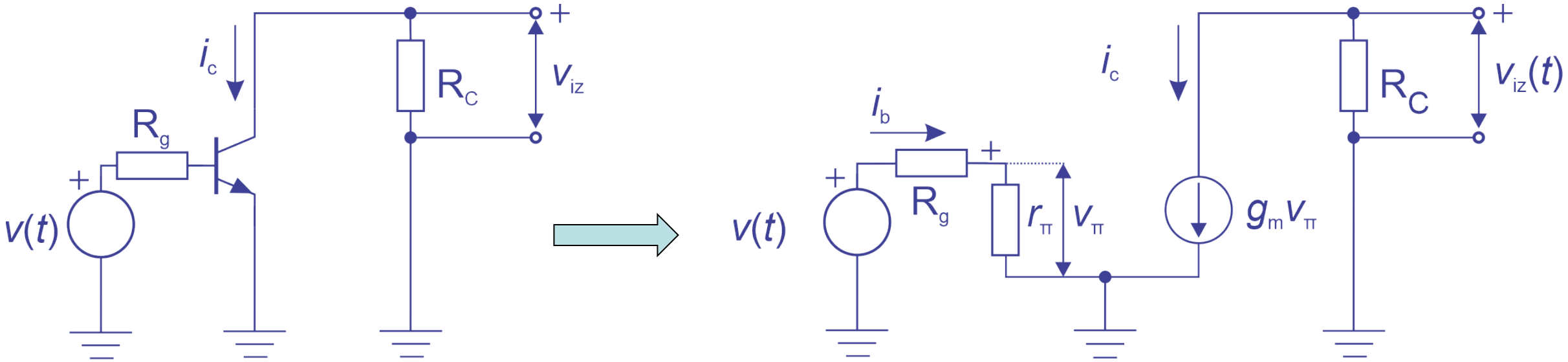
$$I_B = \frac{V_0 - V_{BE}}{R_g}$$

$$I_C = \beta \cdot I_B = \beta \cdot \frac{V_0 - V_{BE}}{R_g}$$



Naizmenični režim (mali signali)

- g_m, r_π, $r_o=\infty$



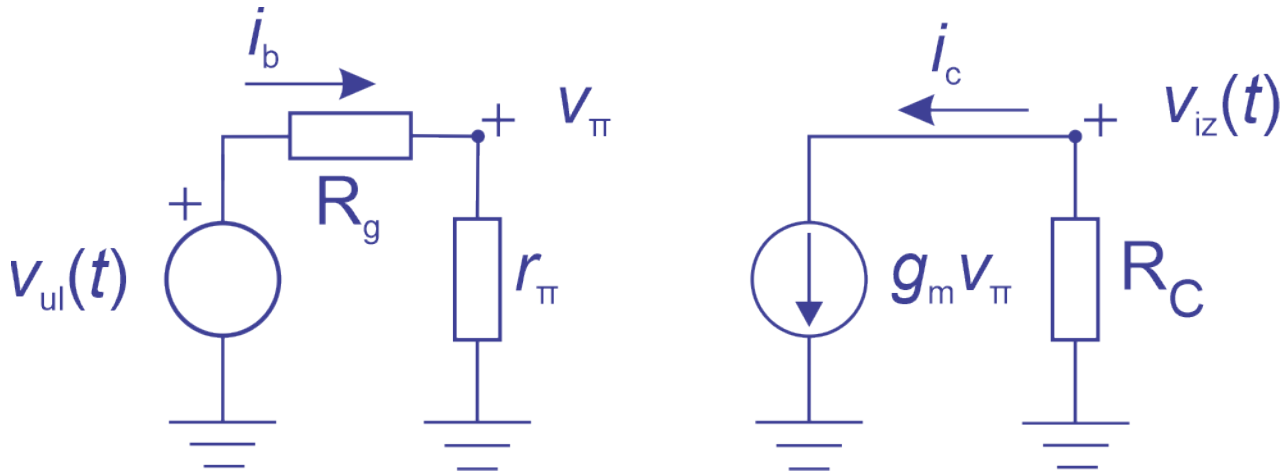
Naizmenični režim (mali signali)

$$v_\pi = \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$

$$v_{iz} = -i_c \cdot R_C$$

$$v_{iz} = -g_m \cdot R_C \cdot v_\pi$$

$$v_{iz} = -g_m \cdot R_C \cdot \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$



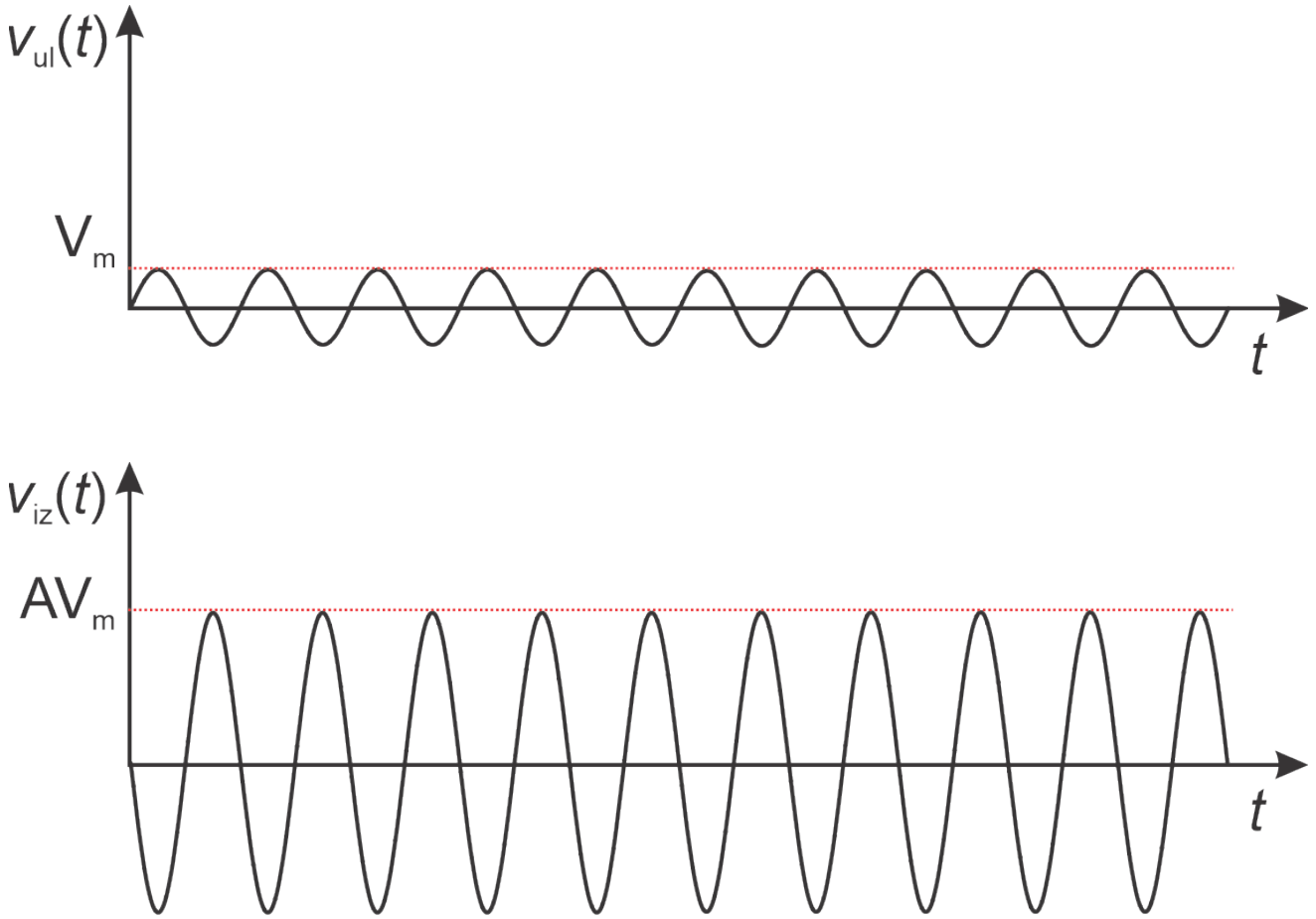
Pojačanje pojačavača

$$A = \frac{v_{iz}}{v_{ul}}$$

$$A = -g_m \cdot R_C \cdot \frac{r_\pi}{r_\pi + R_g}$$

za $r_\pi \gg R_g$

$$A = -g_m \cdot R_C$$

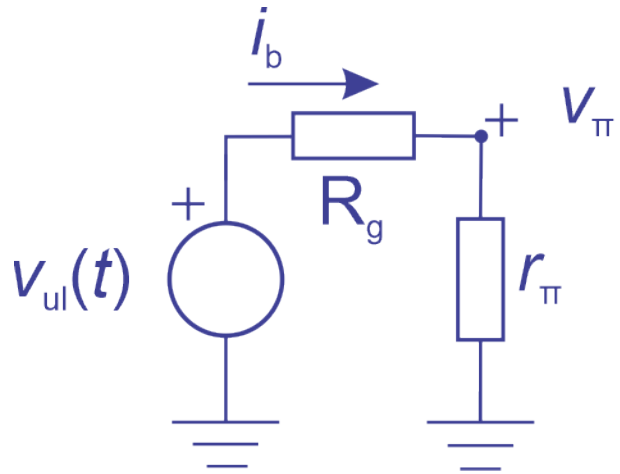


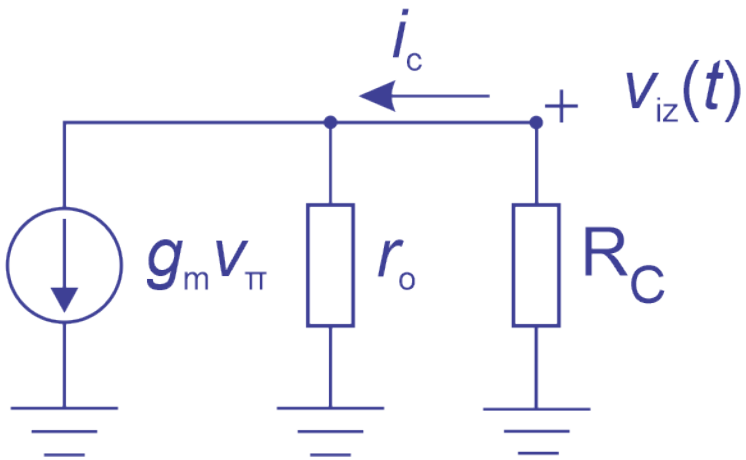
Uticaj Erlijevog efekta na pojačanje

$$v_\pi = \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$

$$v_{iz} = -g_m \cdot \left(R_C \parallel r_o\right) \cdot v_\pi$$

$$v_{iz} = -g_m \cdot \left(R_C \parallel r_o\right) \cdot \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$





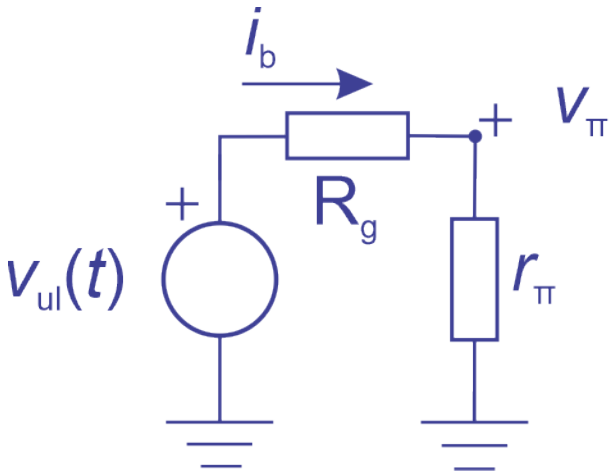
Uticaj Erlijevog efekta na pojačanje

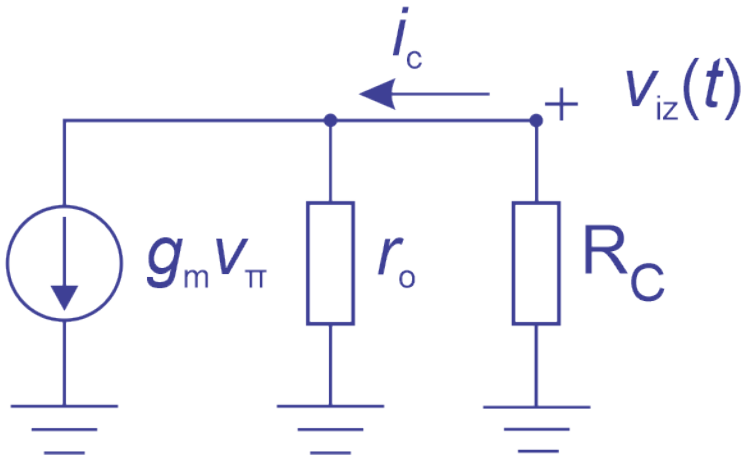
$$A = \frac{v_{iz}}{v_{ul}}$$

$$A = -g_m \cdot \left(R_C \parallel r_o\right) \cdot \frac{r_\pi}{r_\pi + R_g}$$

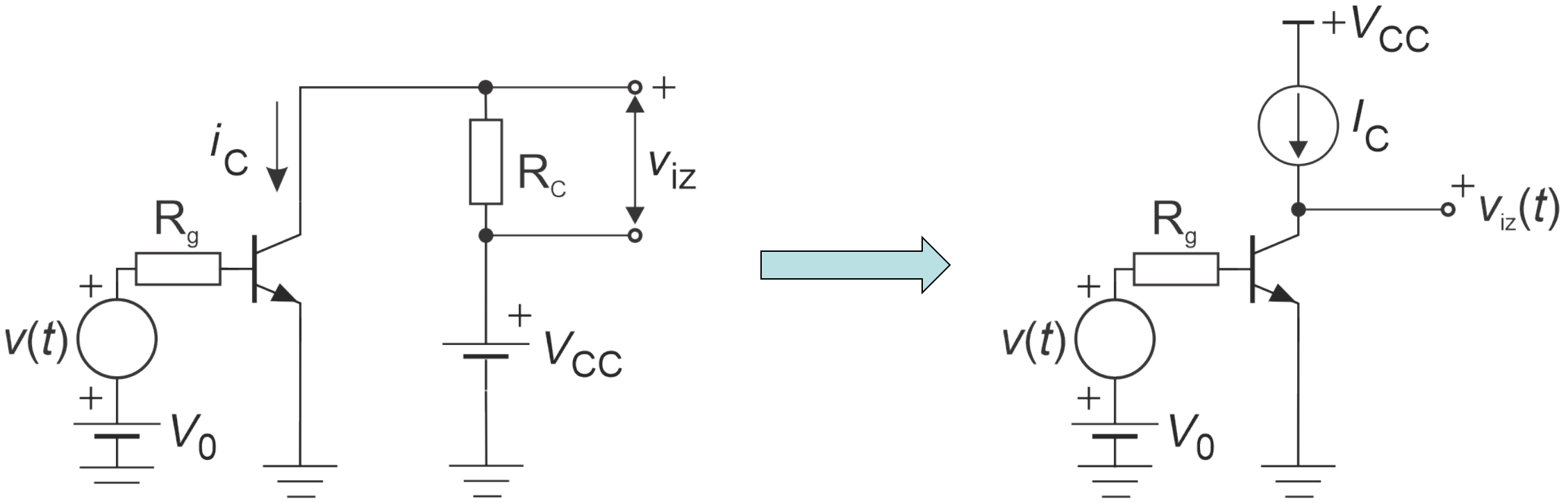
za $r_\pi \gg R_g$

$$A = -g_m \cdot \left(R_C \parallel r_o\right)$$





Intrinsično (maksimalno) pojačanje

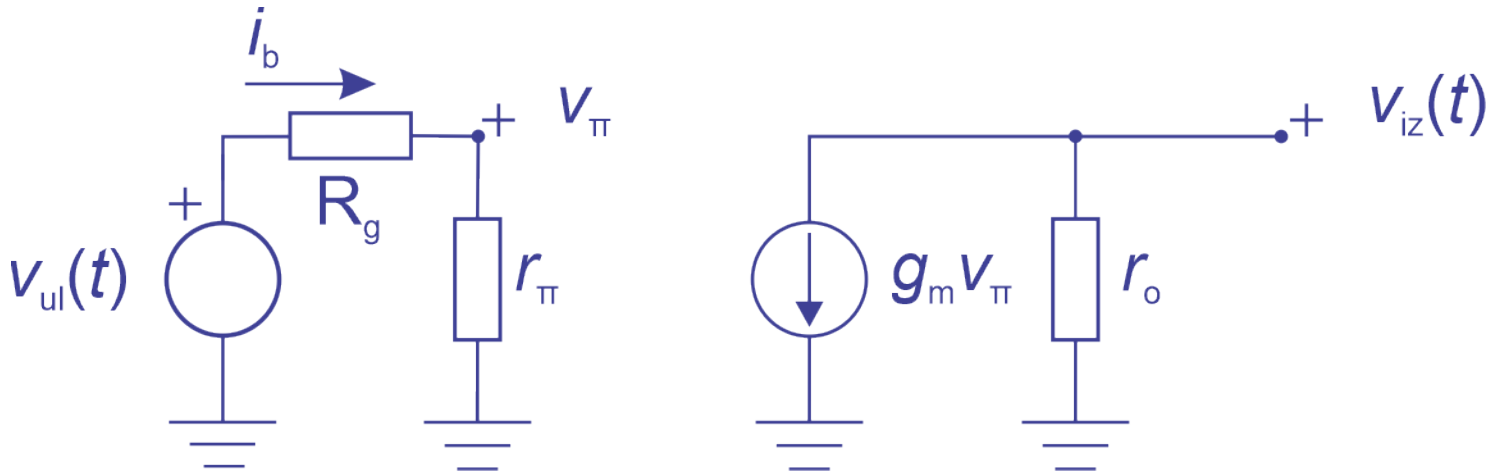


Intrinsično (maksimalno) pojačanje

$$v_\pi = \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$

$$v_{iz} = -g_m \cdot r_o \cdot v_\pi$$

$$v_{iz} = -g_m \cdot r_o \cdot \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$



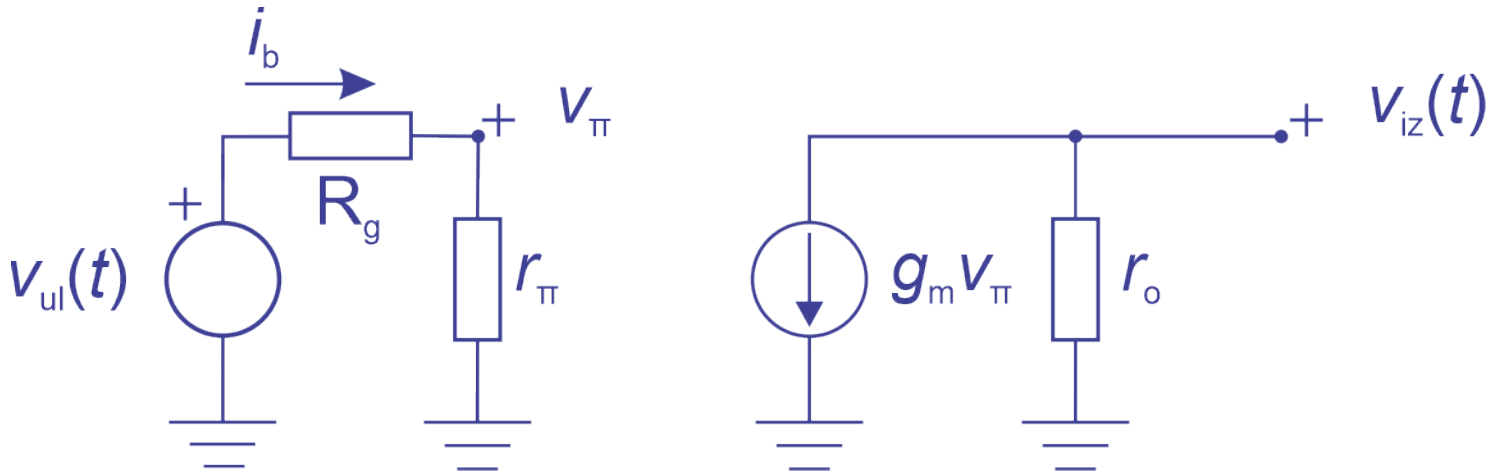
Intrinsično (maksimalno) pojačanje

$$A = \frac{v_{iz}}{v_{ul}}$$

$$A = -g_m \cdot r_o \cdot \frac{r_\pi}{r_\pi + R_g}$$

za $r_\pi \gg R_g$

$$A = -g_m \cdot r_o$$

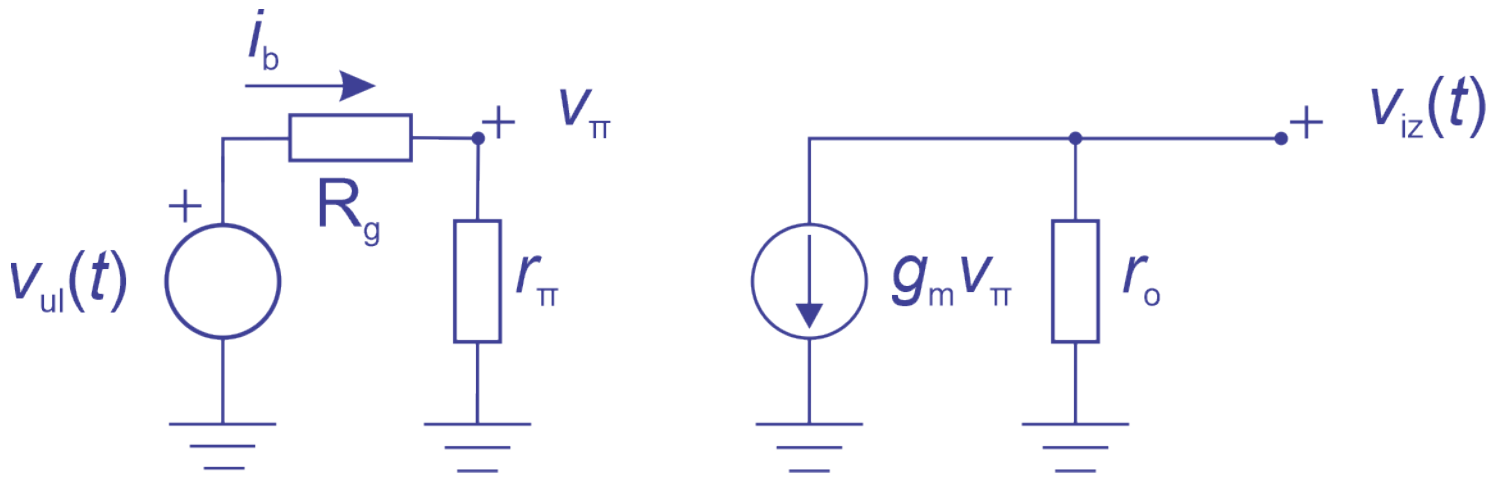


Intrisično (maksimalno) pojačanje

$$A = -g_m \cdot r_o$$

$$A = -\frac{I_C}{V_T} \cdot \frac{V_A}{I_C}$$

$$A = -\frac{V_A}{V_T}$$

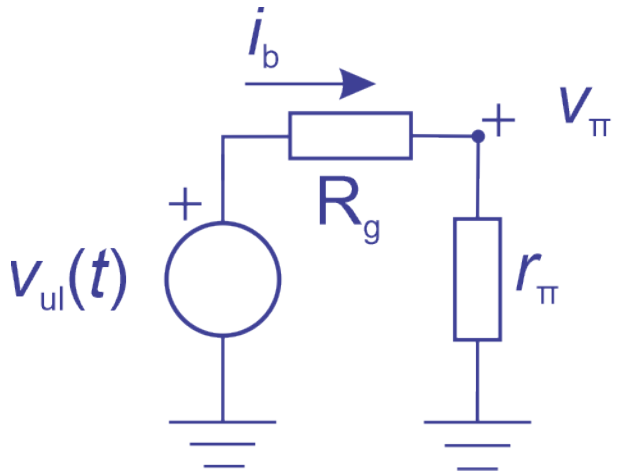


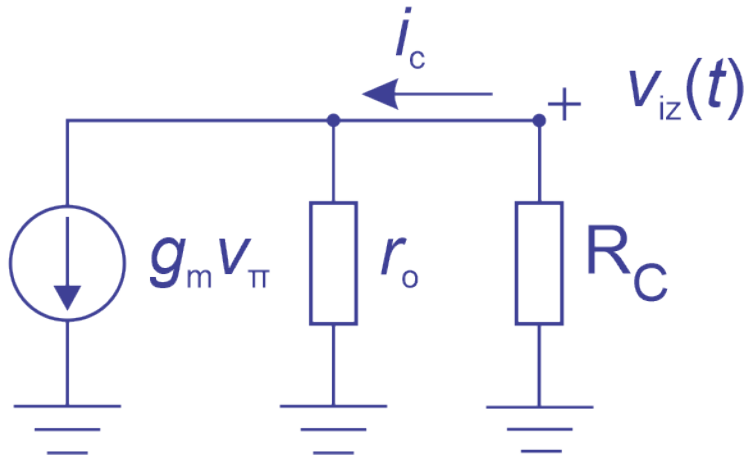
Analiza pojačavača – pojačanje *A*

$$v_\pi = \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$

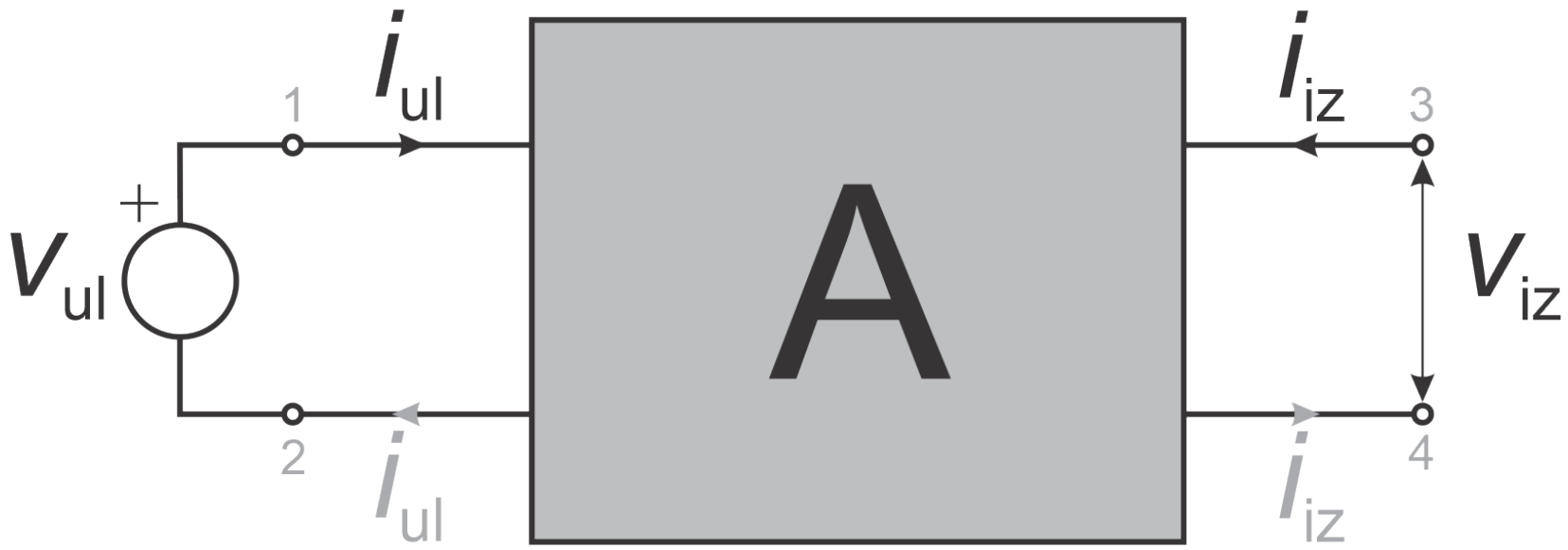
$$v_{iz} = -g_m \cdot \left(R_C \parallel r_o\right) \cdot \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$

$$A = -g_m \cdot \left(R_C \parallel r_o\right) \cdot \frac{r_\pi}{r_\pi + R_g}$$



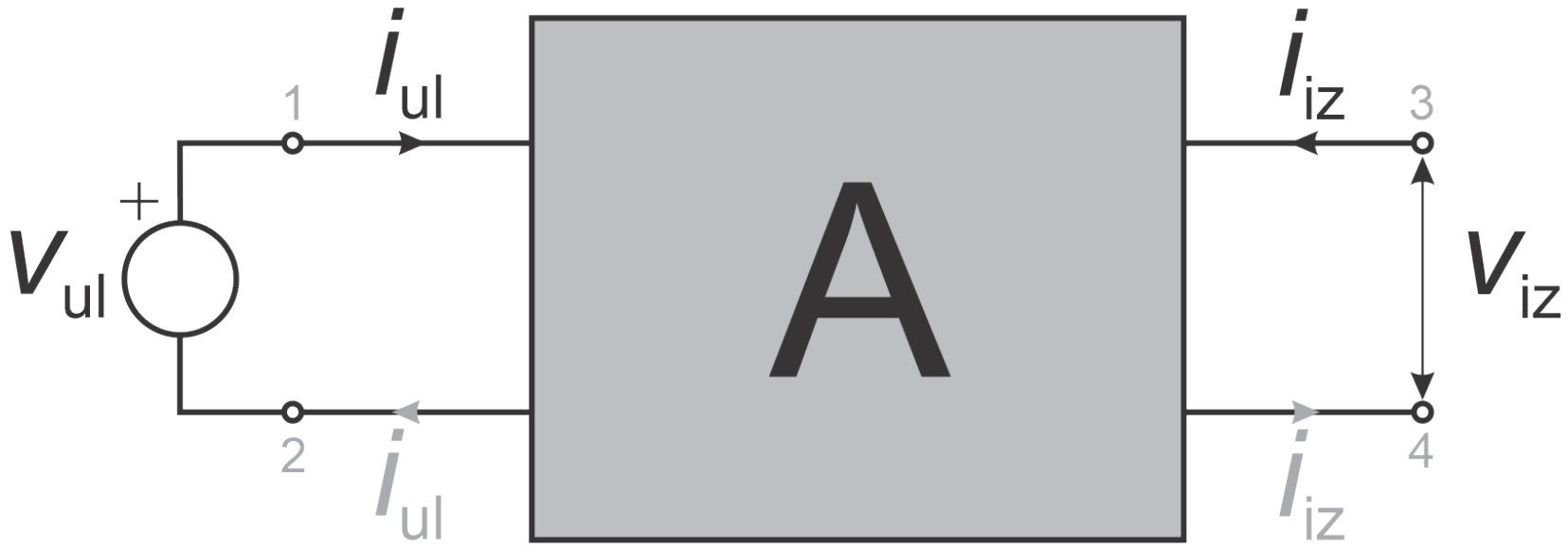


Analiza pojačavača – impedanse



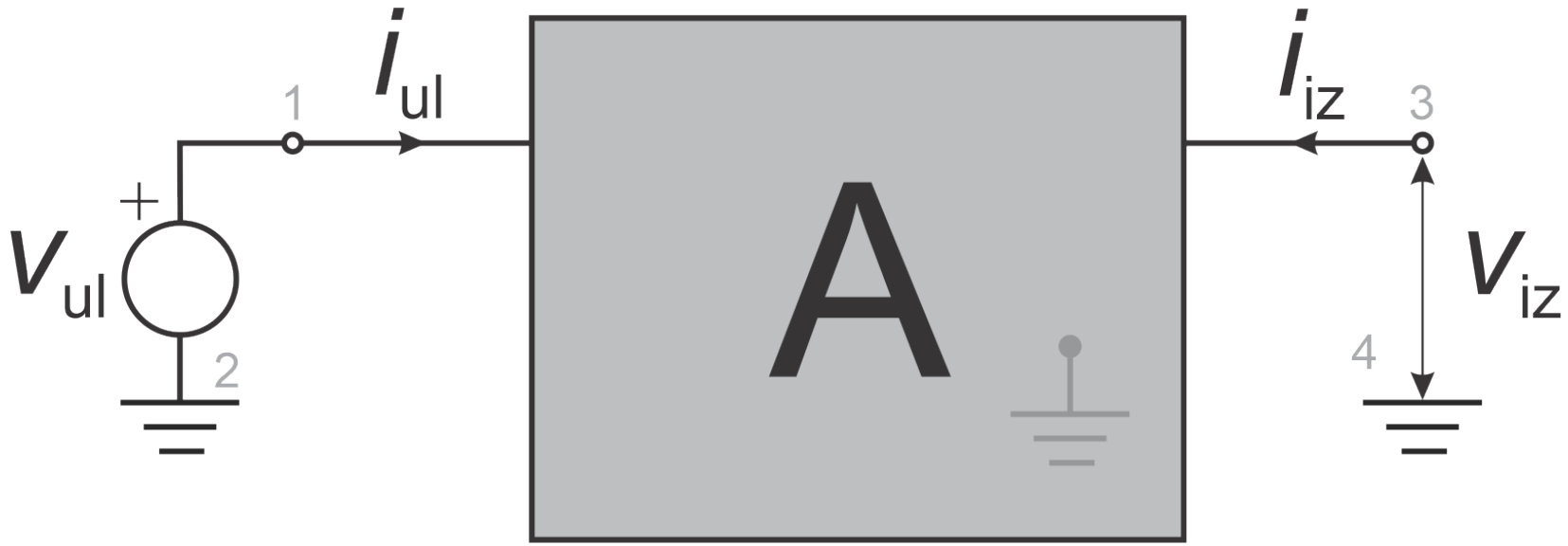
- Pojačavači su **četvoropoli**. Četvoropoli imaju dva para priključaka: **ulazne** (1 i 2) i **izlazne** (3 i 4) priključke.
- Ponašanje pojačavača se može opisati pomoću četiri nezavisna parametra koji definišu zavisnosti između v_{ul}, i_{ul}, v_{iz} i i_{iz}.

Analiza pojačavača – impedanse



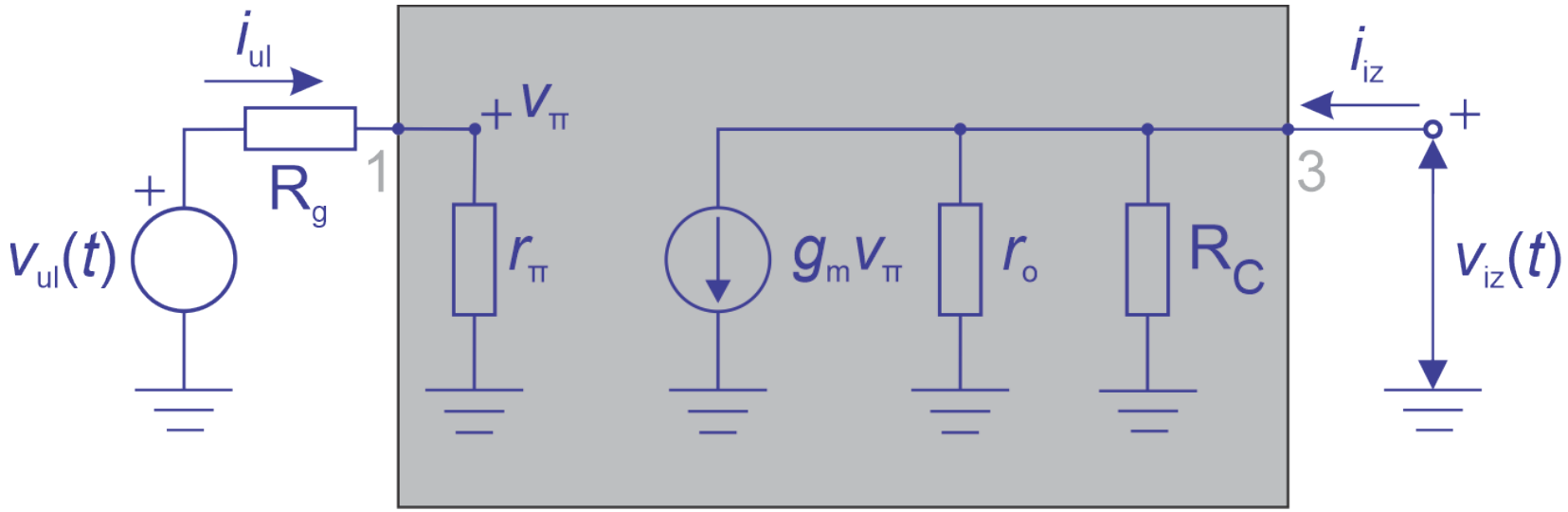
- Za pojačavač se, pod određenim uslovima, mogu definisati **ulazna impedansa** i **izlazna impedansa**. Ove impedanse predstavljaju odnos ulaznog napona i ulazne struje, odnosno izlaznog napona i izlazne struje.

Analiza pojačavača – impedanse



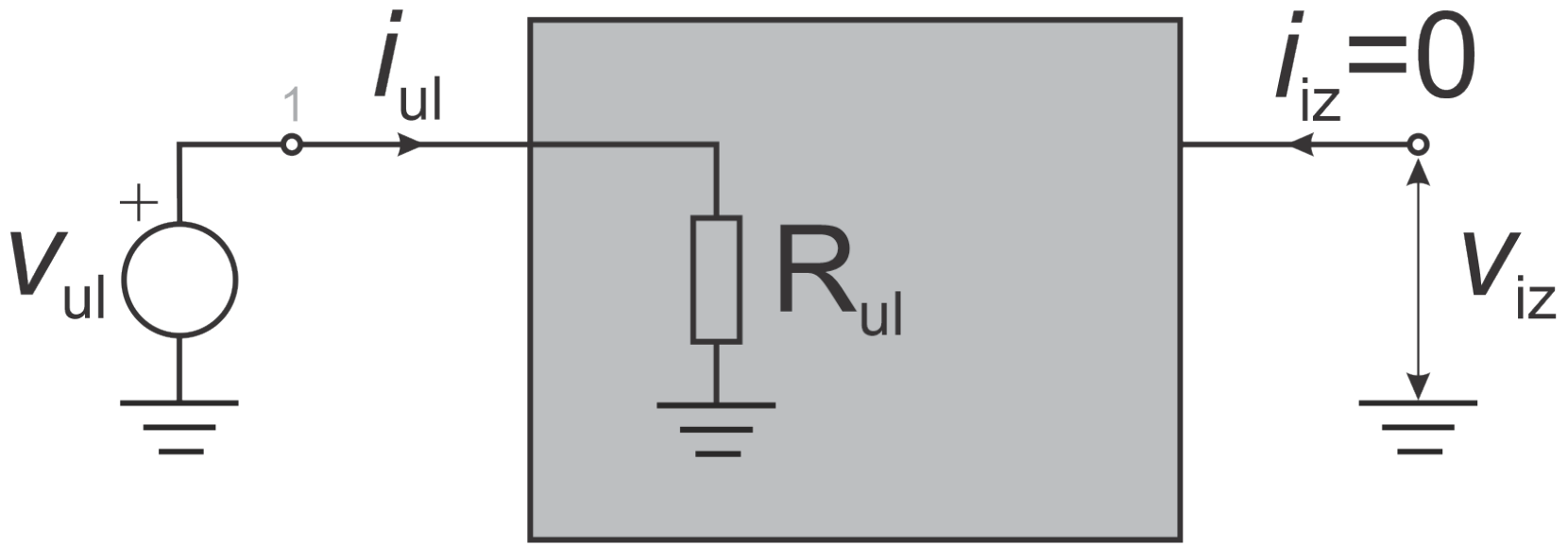
- U elektronskim kolima se obično jedan čvor koristi kao referentni – **čvor mase**, ili **masa**. Naponi svih čvorova se određuju u odnosu na potencijal mase.
- **Masa** je obično zajednički čvor ulaza i izlaza pojačavača (čvorovi 2 i 4 su kratkospojeni sa masom).

Analiza pojačavača – impedanse



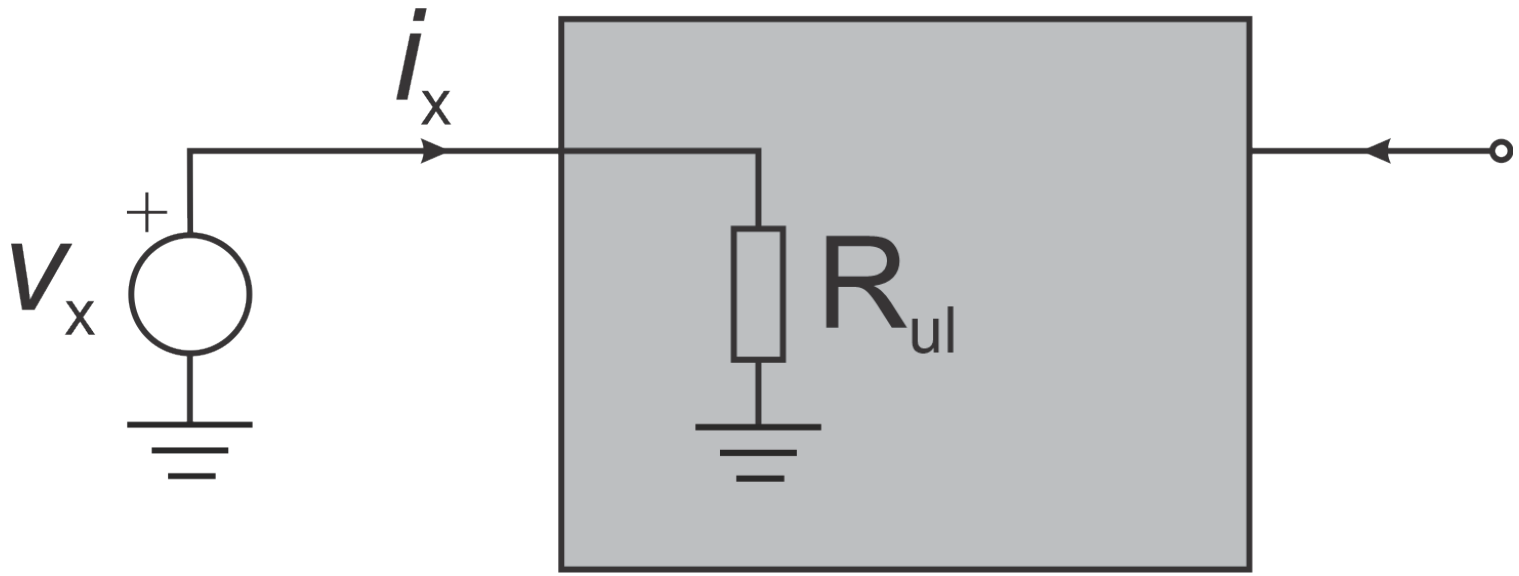
- **Ulazni priključci** pojačavača su čvor 1 i masa, izlazni priključci čvor 3 i masa. Masa ima referentni potencijal, u odnosu na koji se određuju svi naponi u kolu.

Ulazna impedansa – R_{ul}



- **Ulazna impedansa** je impedansa pojačavača između ulaznog čvora (čvor 1 na slici) i mase, kada je izlaz pojačavača rasterećen, tj. Izlazna struja jednaka nuli ($i_{iz} = 0$).

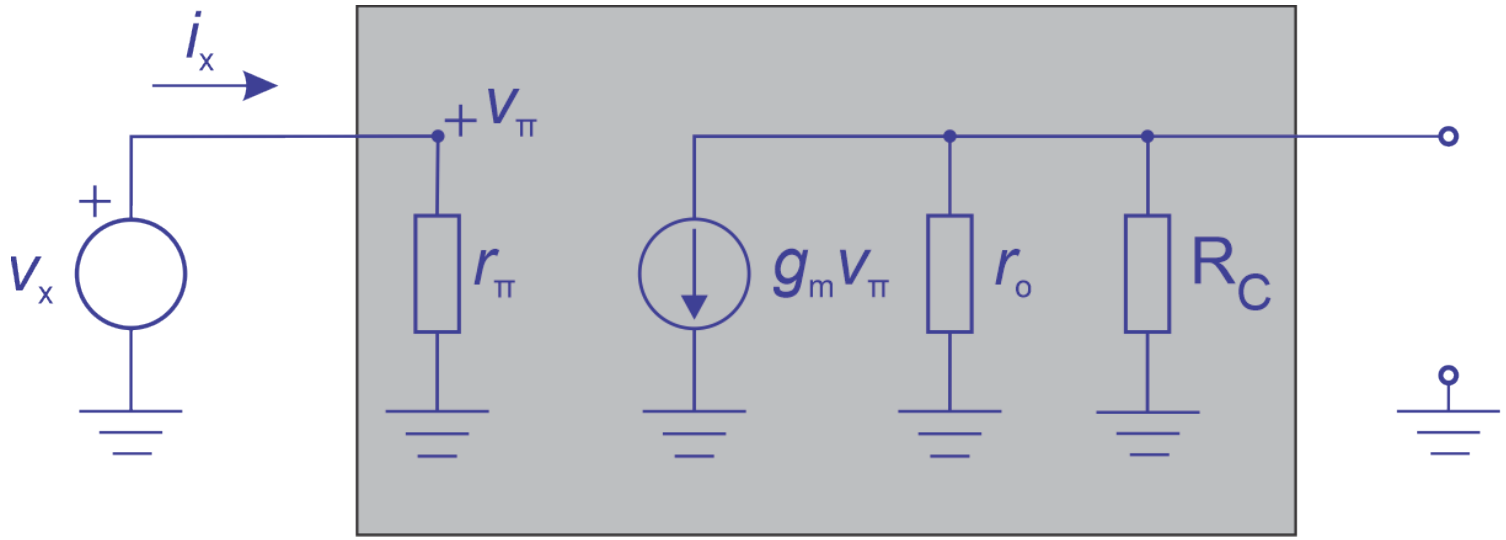
Ulazna impedansa – R_{ul}



- **Kratkospojiti sve nezavisne naponske generatore u kolu,**
- **odvezati sve nezavisne strujne generatore u kolu,**
- **postaviti izvor malog signala na ulaz kola v_X,**
- **izračunati struju koju proizvodi izvor i_X.**

$$R_{ul} = \frac{v_X}{i_X}$$

Ulazna impedansa – R_{ul}



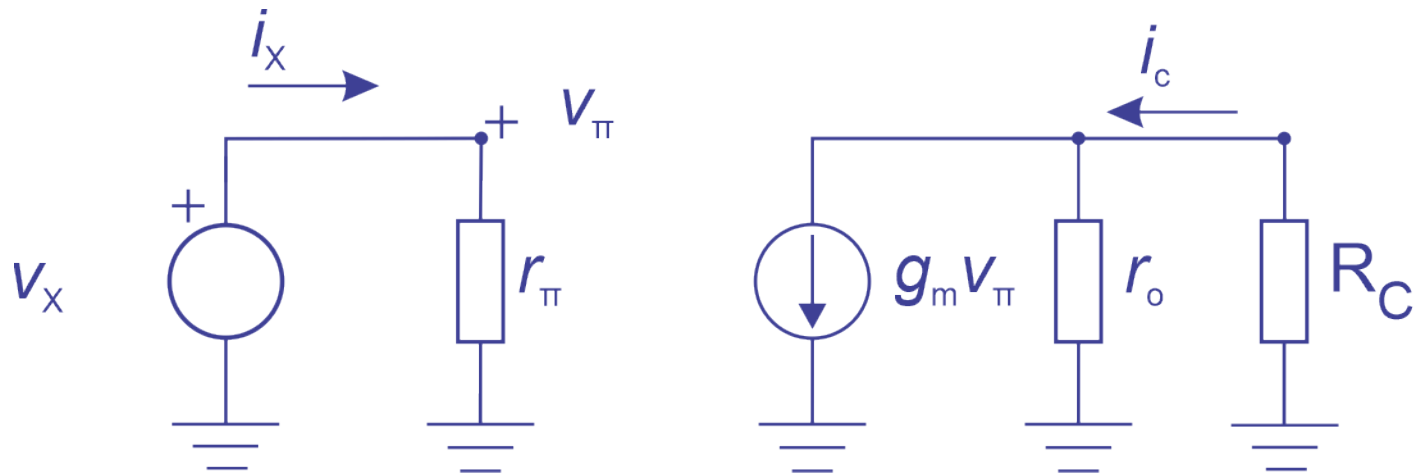
- U kolu pojačavača nema nezavisnih naponskih i strujnih generatora.
- Za određivanje ulazne impedanse potrebno je odrediti samo struju jedne konture, i_x.

Ulazna impedansa – R_{ul}

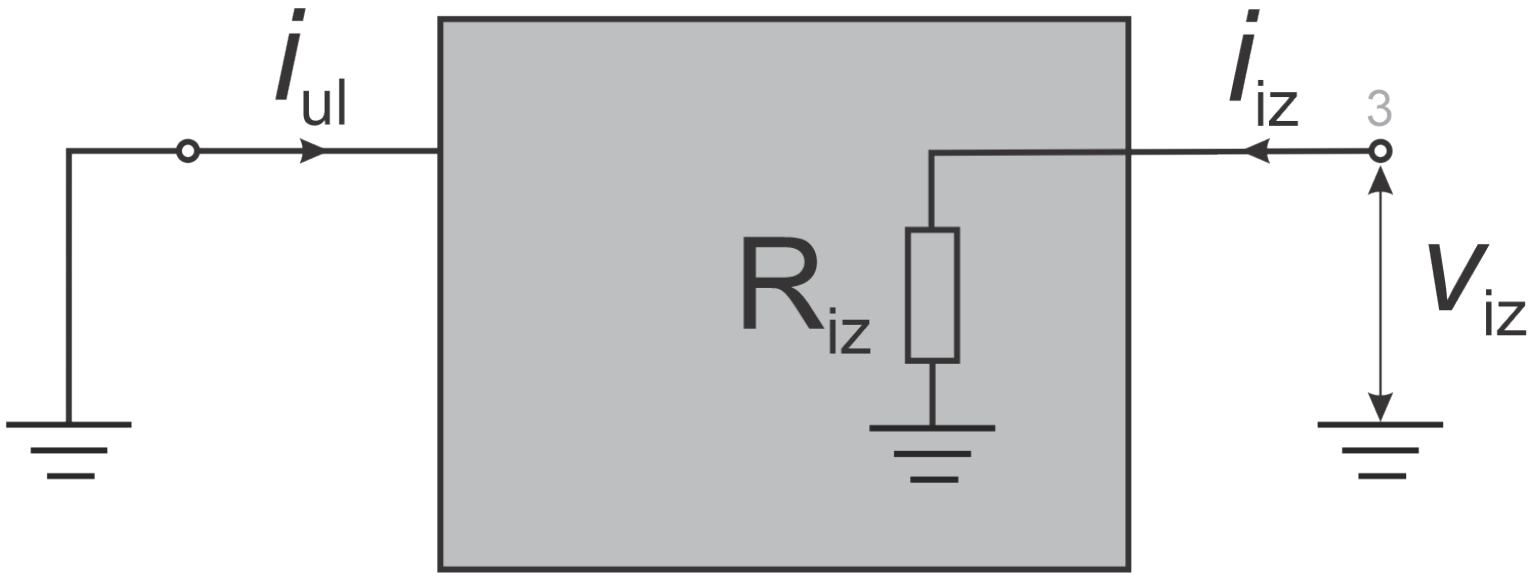
$$i_X = \frac{v_X}{r_\pi}$$

$$R_{ul} = \frac{v_X}{i_X}$$

$$\boxed{R_{ul} = r_\pi}$$

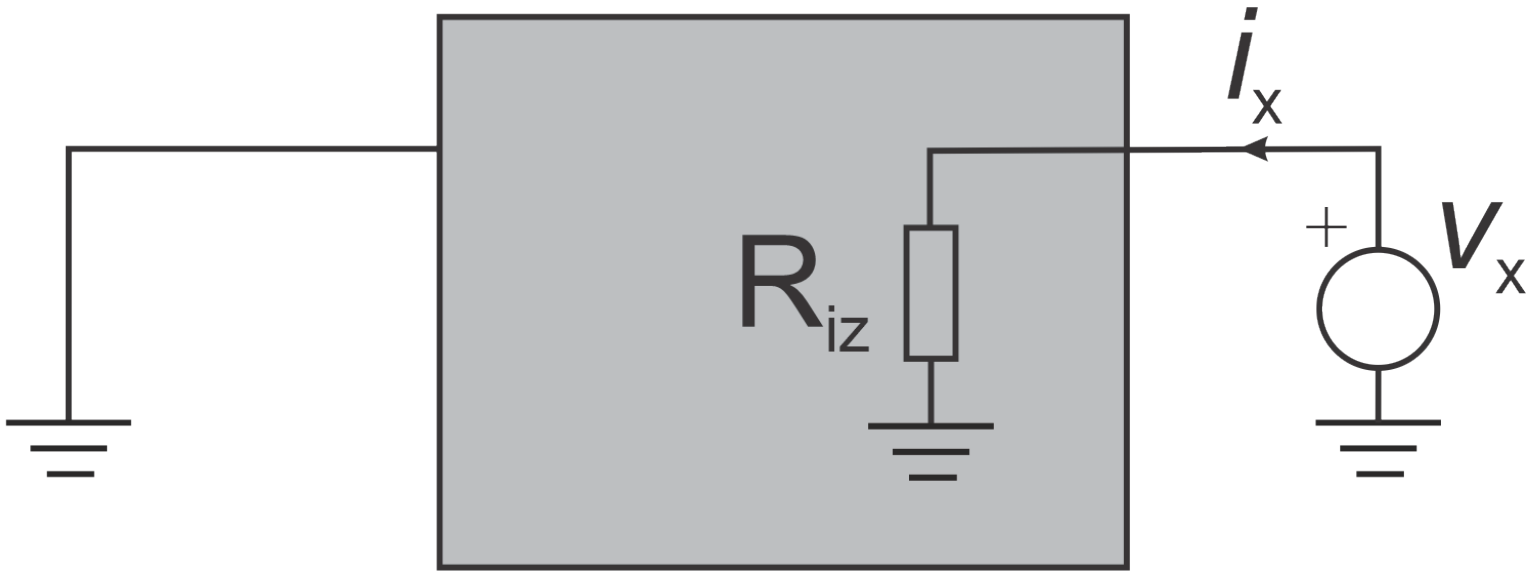


Izlazna impedansa – R_{iz}



- **Izlazna impedansa** je impedansa pojačavača između izlaznog čvora (čvor 3 na slici) i mase, kada je ulaz pojačavača kratkospojen, tj. ulazni napon jednak nuli ($v_{ul} = 0$).

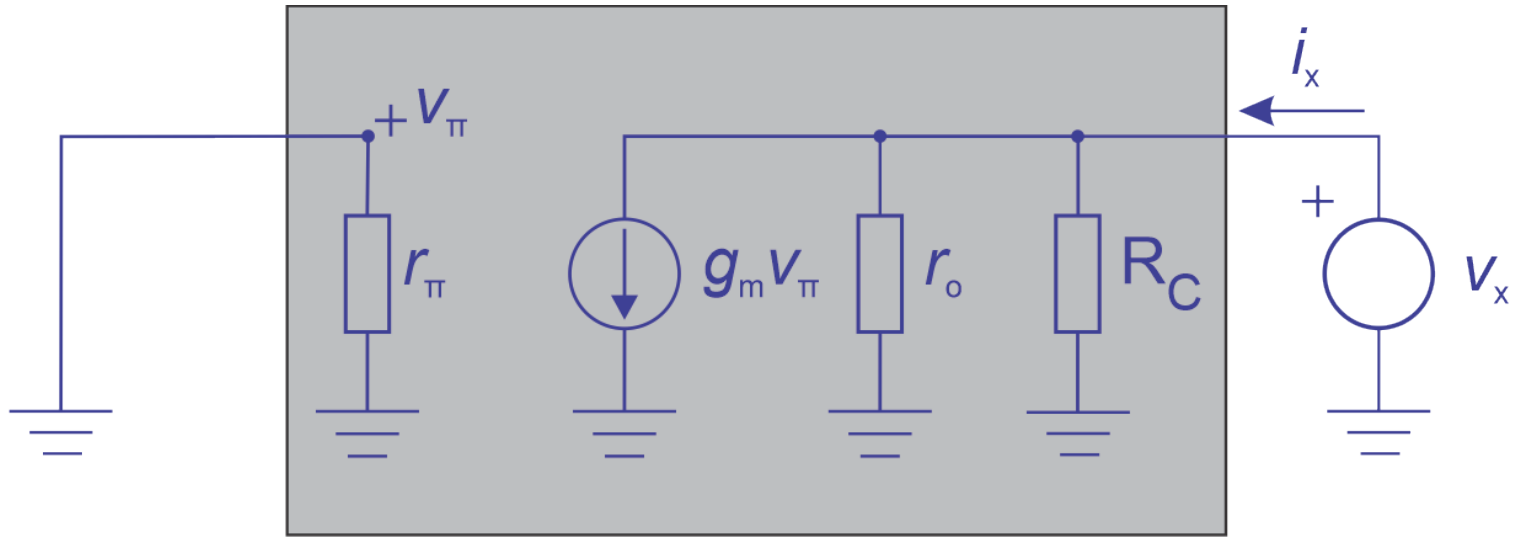
Izlazna impedansa – R_{iz}



- **Kratkospojiti sve nezavisne naponske generatore,**
- **odvezati sve nezavisne strujne generatore,**
- **postaviti izvor malog signala na ulaz kola v_x,**
- **izračunati struju koju proizvodi izvor i_x.**

$$R_{iz} = \frac{v_X}{i_X}$$

Izlazna impedansa – R_{iz}



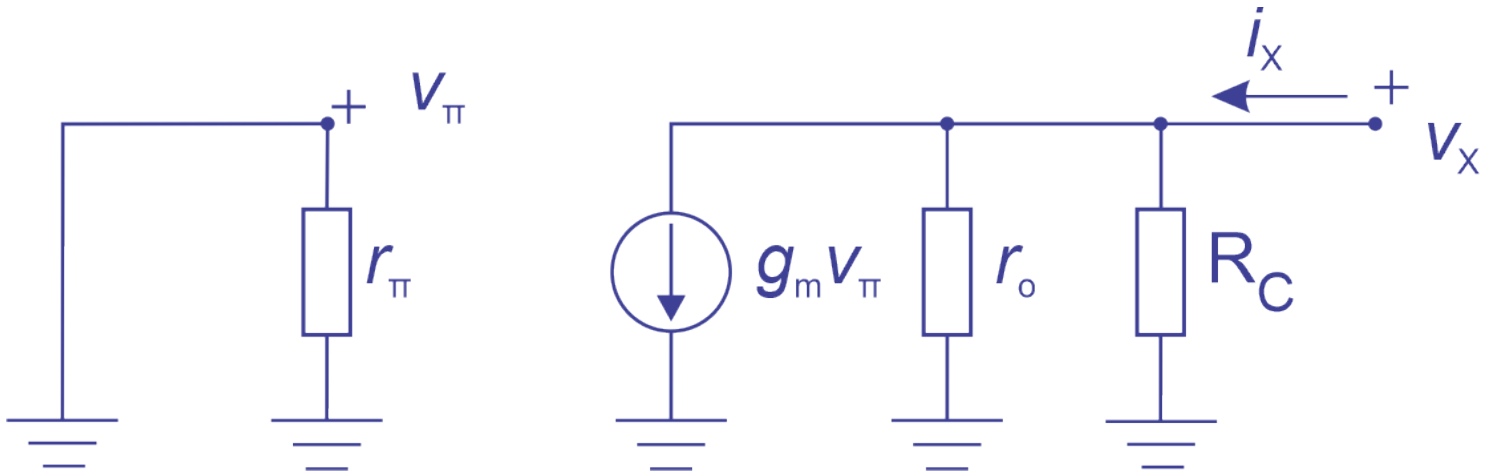
- U kolu pojačavača nema nezavisnih naponskih i strujnih generatora.
- Napon na ulazu je jednak nuli, tako da je struja strujnog generatora kontrolisanog naponom jednaka nuli.

Izlazna impedansa – R_{iz}

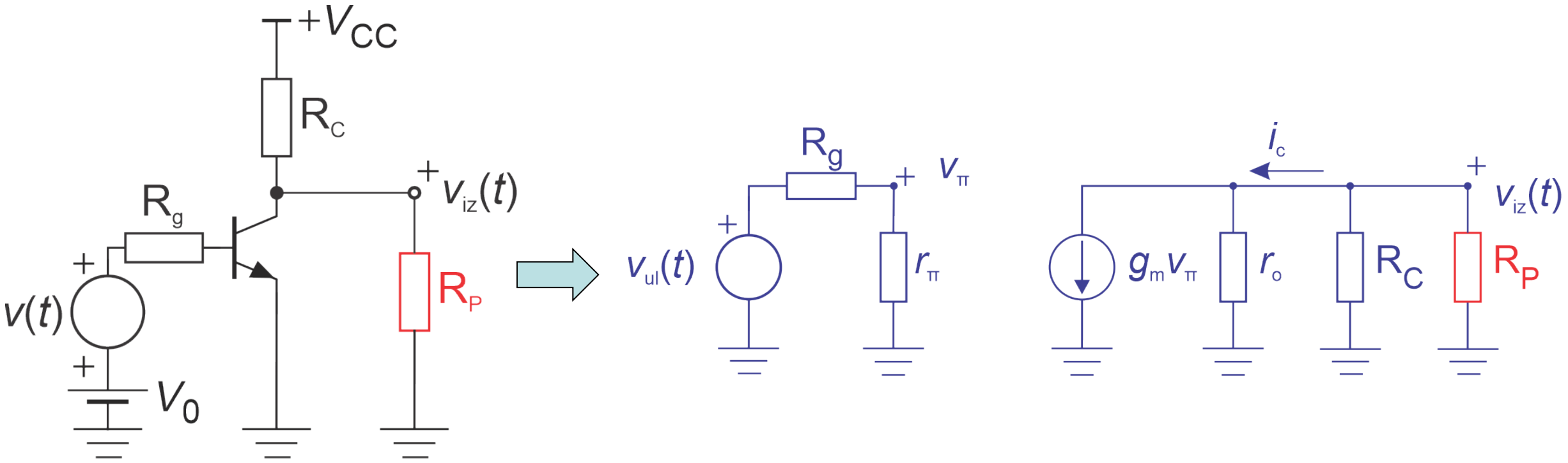
$$v_\pi = 0$$

$$v_X = i_X \cdot r_o \parallel R_C$$

$$\boxed{R_{iz} = r_o \parallel R_C}$$



Uticaj otpornosti potrošača R_P na pojačanje



Uticaj otpornosti potrošača R_P na pojačanje

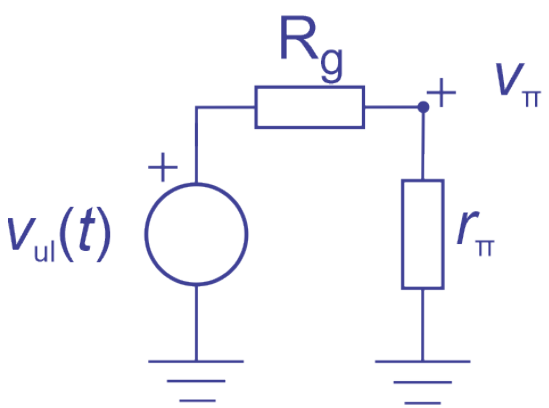
$$v_\pi = \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$

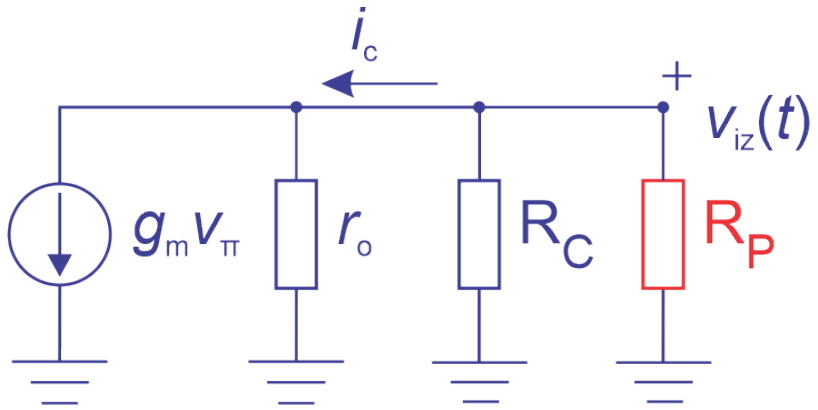
$$v_{iz} = -g_m \cdot \left(R_C \parallel r_o \parallel R_P\right) \cdot \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$

$$A = -g_m \cdot \left(R_C \parallel r_o \parallel R_P\right) \cdot \frac{r_\pi}{r_\pi + R_g}$$

za $r_\pi \gg R_g$

$$A = -g_m \cdot \left(R_C \parallel r_o \parallel R_P\right)$$





Uticaj otpornosti potrošača R_P na pojačanje

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

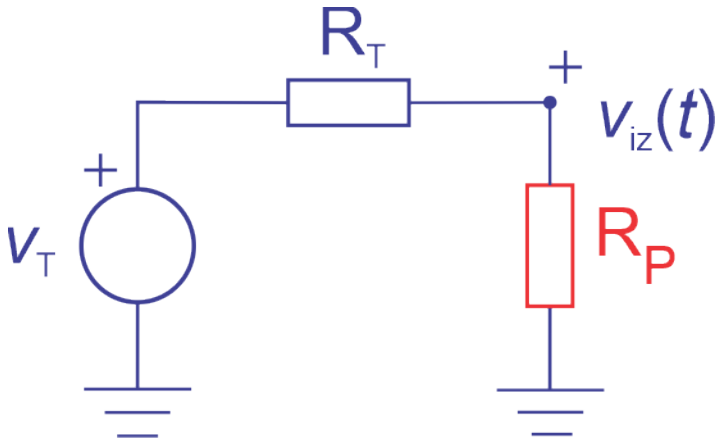
$$R_T = R_C \parallel r_o$$

$$v_{iz} = \frac{R_P}{R_T + R_P} \cdot v_T$$

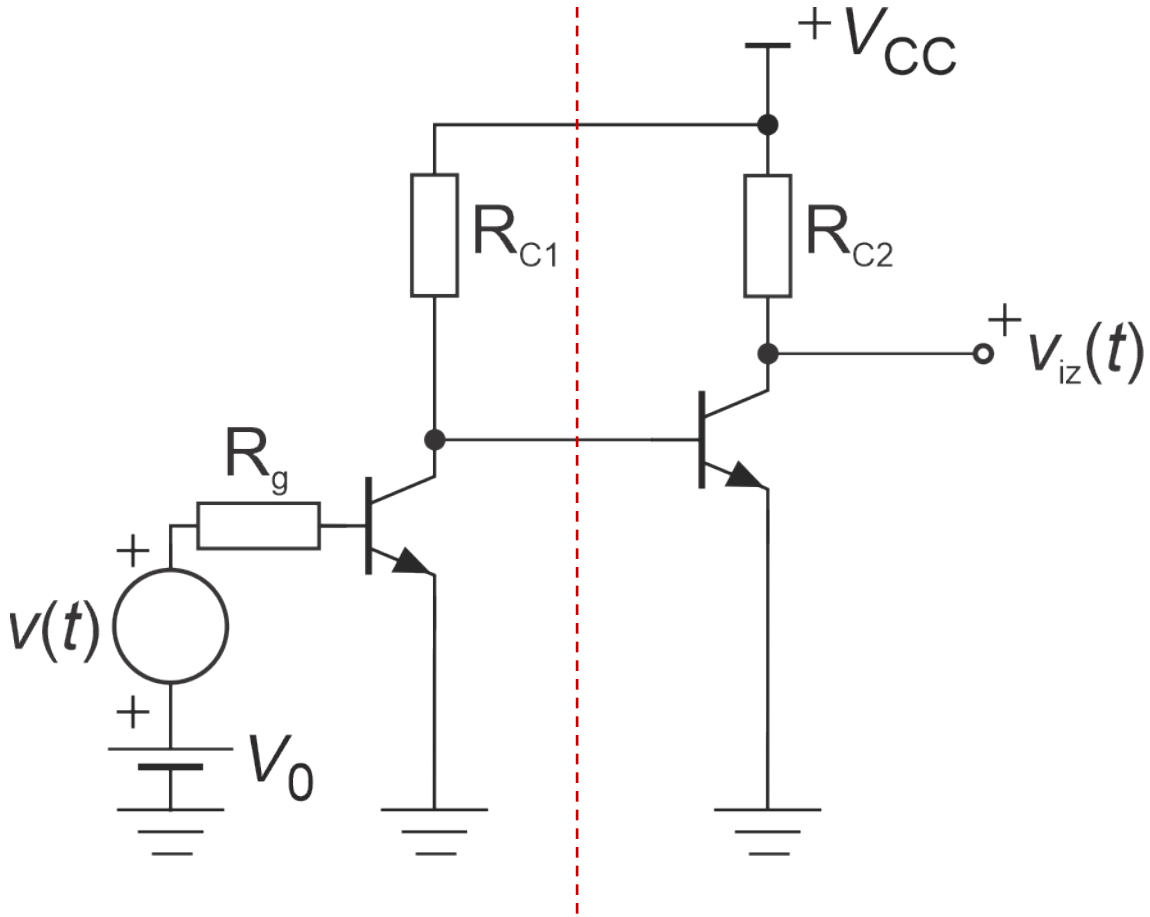
$$v_{iz} = -g_m \cdot v_\pi \cdot \frac{R_P R_C r_o}{R_C r_o + R_C R_P + r_o R_P}$$

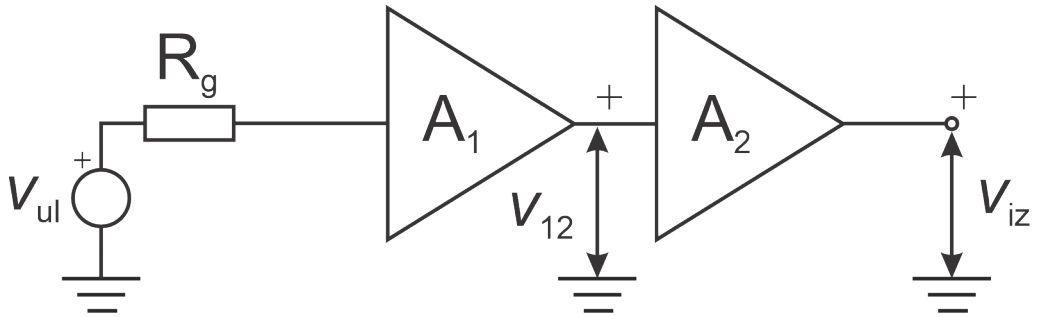
$$v_{iz} = -g_m \cdot (R_C \parallel r_o \parallel R_P) \cdot \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$

- Pojačavač možemo da predstavimo ekvivalentnim Tevenenovim generatorom čiji napon je jednak izlaznom naponu pojačavača (bez potrošača R_P), a unutrašnja otpornost izlaznoj otpornosti pojačavača.



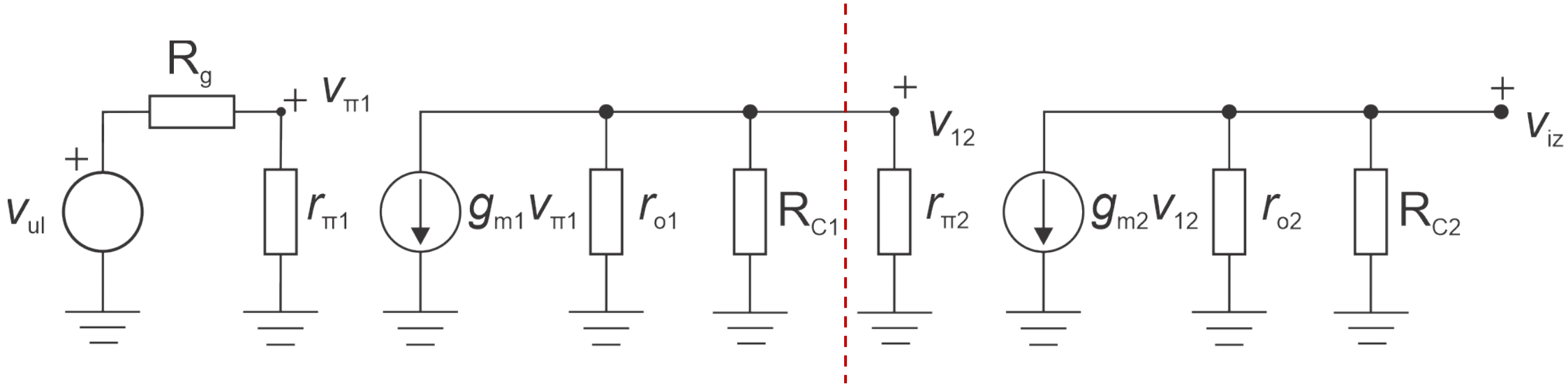
Kaskadna veza pojačavača





$A=A_1A_2$?

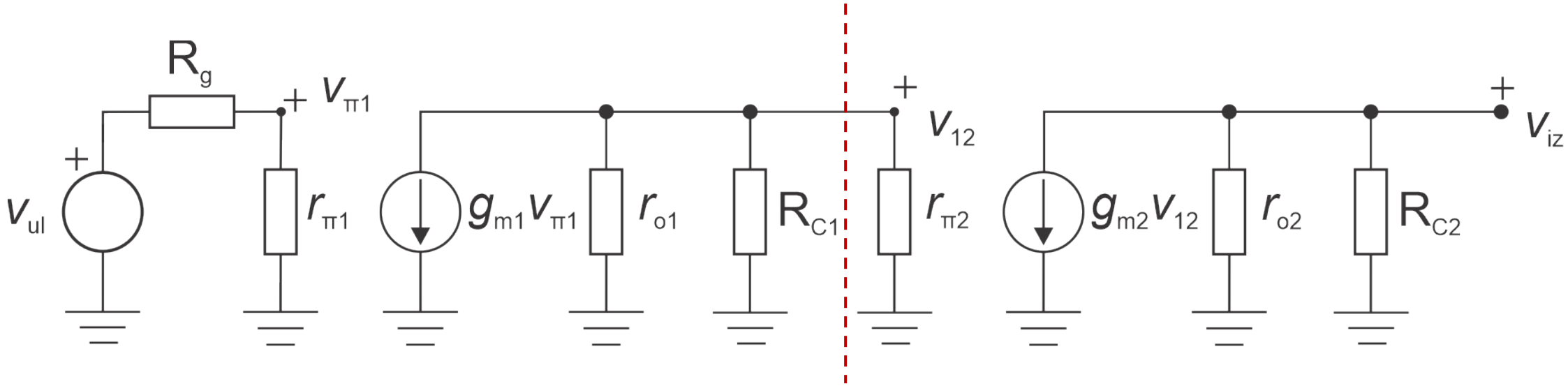
Kaskadna veza pojačavača



$$v_{12} = -g_{m1} \cdot \left(r_{o1} \parallel R_{C1} \parallel r_{\pi 2} \right) \cdot \frac{r_{\pi 1}}{r_{\pi 1} + R_g} \cdot v_{ul}$$

$$v_{iz} = -g_{m2} \cdot \left(r_{o2} \parallel R_{C2} \right) \cdot v_{12}$$

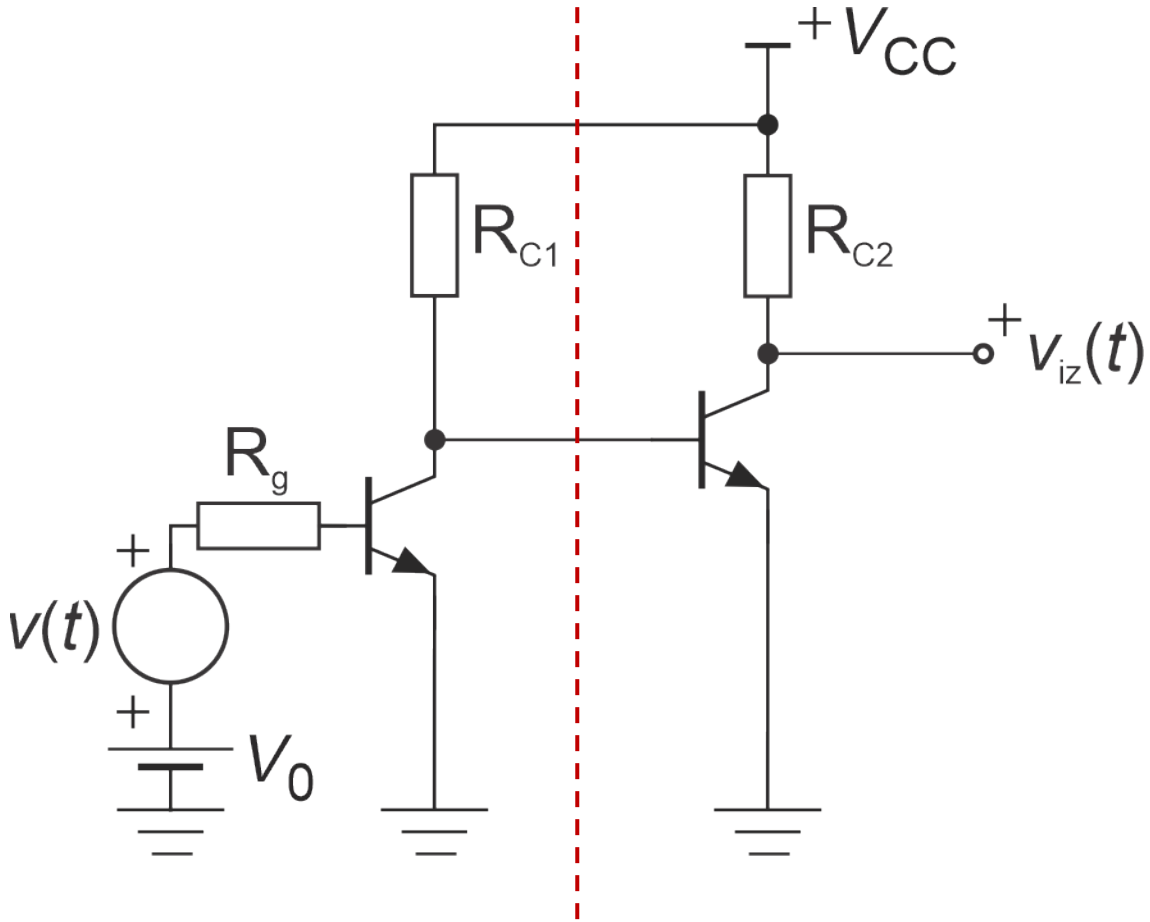
Kaskadna veza pojačavača

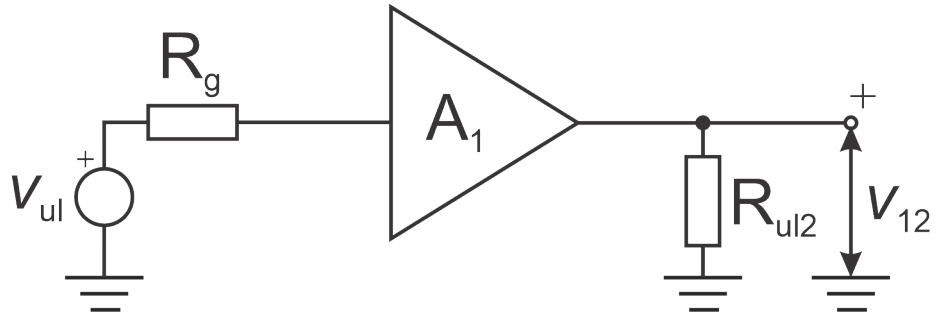


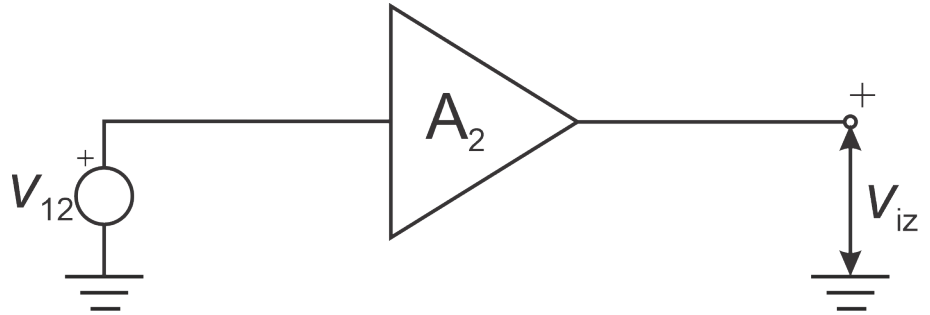
$$A_1 = -g_{m1} \cdot \left(r_{o1} \parallel R_{C1} \parallel r_{\pi 2} \right) \cdot \frac{r_{\pi 1}}{r_{\pi 1} + R_g}$$

$$A_2 = -g_{m2} \cdot \left(r_{o2} \parallel R_{C2} \right)$$

Kaskadna veza pojačavača







Temperaturna zavisnost pojačavača

- Varijacija pojačanja usled promene temperature.
- Kolektorska struja i termalni napon zavise od temperature, samim tim i transkonduktansa i pojačanje pojačavača:

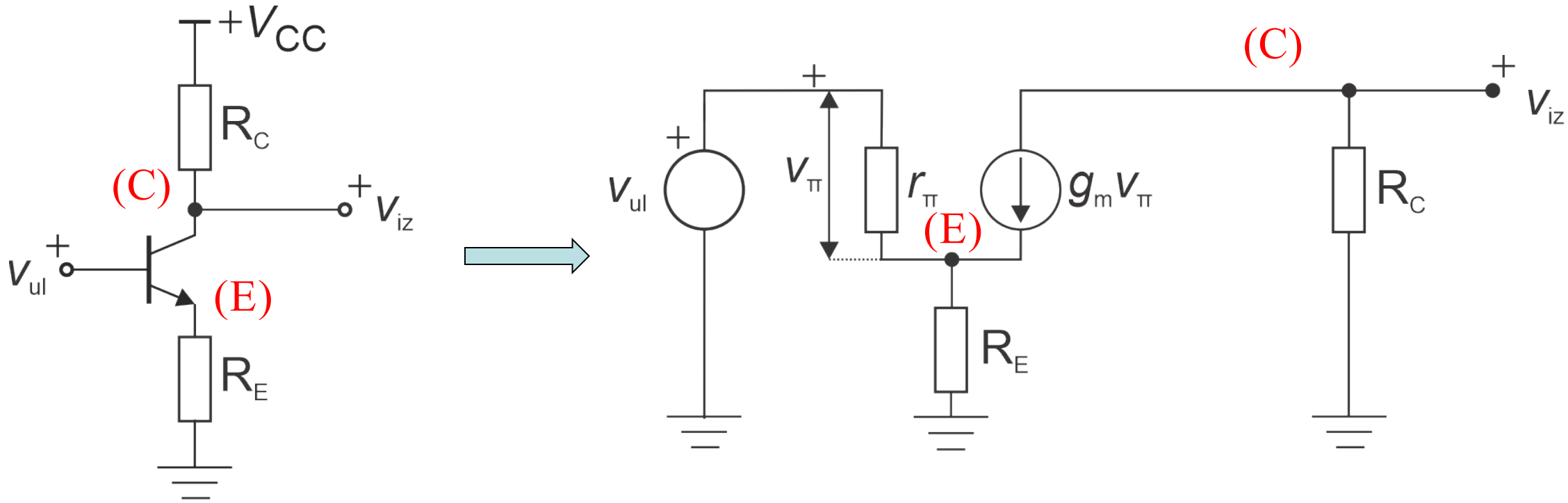
$$A = -g_{\mathrm{m}} \cdot \left(r_{\mathrm{o}} \parallel R_{\mathrm{C}} \right)$$

$$g_{\mathrm{m}} = \frac{I_{\mathrm{C}}}{V_{\mathrm{T}}}, \quad I_{\mathrm{C}} = I_{\mathrm{S}} \exp\left(\frac{V_{\mathrm{BE}}}{V_{\mathrm{T}}} \right), \quad V_{\mathrm{T}} = \frac{\mathrm{k}T}{\mathrm{q_e}}$$

$$I_{\mathrm{S}} \sim n_i^2 \sim T^3 \exp\left(-\frac{\varepsilon_{\mathrm{g}}}{\mathrm{k}T} \right) \qquad g_{\mathrm{m}} \sim T^2 \exp\left(\frac{\mathrm{q_e} V_{\mathrm{BE}} - \varepsilon_{\mathrm{g}}}{\mathrm{k}T} \right)$$

Degenerisani emitor

- Otpornik u grani emitora (zanemaren Erlijev efekat, $r_o=\infty$)



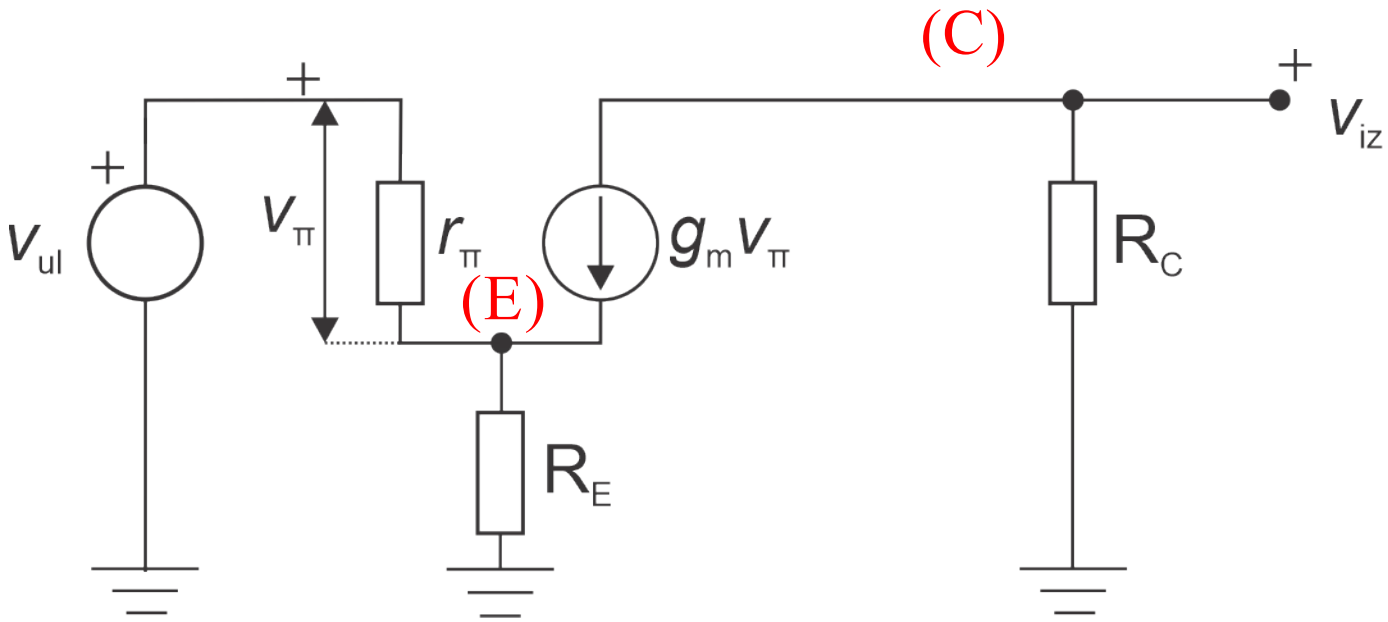
Degenerisani emitor – pojačanje

$$\frac{v_{\text{iz}}}{R_{\text{C}}} + g_{\text{m}} \cdot v_{\pi} = 0 \quad \text{(C)}$$

$$v_{\text{iz}} = -g_{\text{m}} R_{\text{C}} \cdot v_{\pi}$$

$$\frac{v_{\text{ul}} - v_{\pi}}{R_{\text{E}}} - \frac{v_{\pi}}{r_{\pi}} = g_{\text{m}} \cdot v_{\pi} \quad \text{(E)}$$

$$\frac{v_{\text{ul}}}{R_{\text{E}}} = v_{\pi}\left(\frac{1}{R_{\text{E}}} + \frac{1}{r_{\pi}} + g_{\text{m}}\right)$$

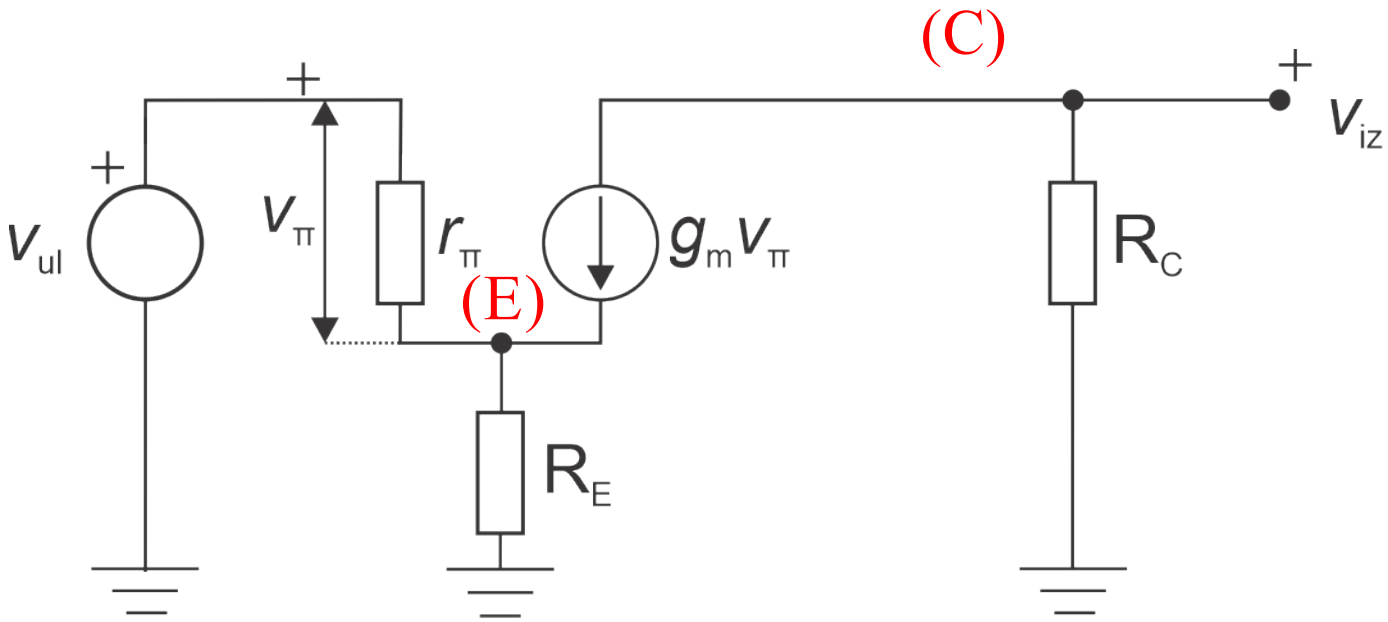


Degenerisani emitor – pojačanje

$$v_\pi = \frac{v_{ul}}{1 + \frac{R_E}{r_\pi} + g_m R_E}$$

$$v_{iz} = -\frac{g_m R_C}{1 + \frac{R_E}{r_\pi} + g_m R_E} \cdot v_{ul}$$

$$v_{iz} = -\frac{g_m R_C}{1 + \left(\frac{1}{r_\pi} + g_m\right) R_E} \cdot v_{ul}$$



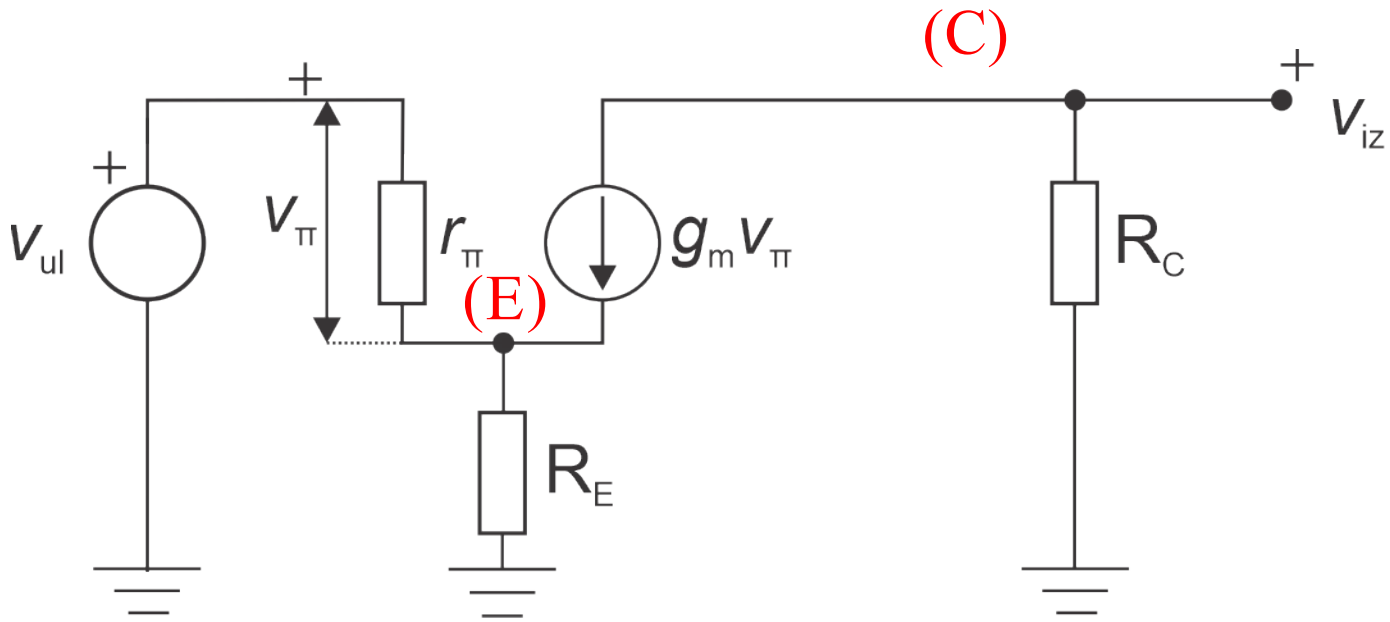
Degenerisani emitor – pojačanje

$$r_\pi = \frac{\beta}{g_m}, \frac{1}{r_\pi} = \frac{g_m}{\beta}$$

$$v_{iz} = -\frac{g_m R_C}{1 + \left(\frac{g_m}{\beta} + g_m\right) R_E} \cdot v_{ul}$$

$$v_{iz} = -\frac{g_m R_C}{1 + \left(\frac{1}{\beta} + 1\right) g_m R_E} \cdot v_{ul}$$

$$\boxed{A = \frac{v_{iz}}{v_{ul}} \approx -\frac{g_m R_C}{1 + g_m R_E}, \quad \frac{1}{\beta} \ll 1}$$



Temperaturna zavisnost pojačavača

- Varijacija pojačanja usled promene temperature.
- Kolektorska struja i termalni napon zavise od temperature, samim tim i transkonduktansa i pojačanje pojačavača:

$$g_{\mathrm{m}} = \frac{I_{\mathrm{C}}}{V_{\mathrm{T}}}, \quad I_{\mathrm{C}} = I_{\mathrm{S}} \exp\left(\frac{V_{\mathrm{BE}}}{V_{\mathrm{T}}}\right), \quad V_{\mathrm{T}} = \frac{\mathrm{k}T}{\mathrm{q_e}}$$

$$I_{\mathrm{S}} = \underbrace{\frac{A_{\mathrm{E}} \cdot q_{\mathrm{e}}}{W_{\mathrm{B}} \cdot N_{\mathrm{B}}}}_{const.} \cdot D_{\mathrm{n}} \cdot n_i^2 = \frac{A_{\mathrm{E}} \cdot q_{\mathrm{e}}}{W_{\mathrm{B}} \cdot N_{\mathrm{B}}} \cdot \frac{\mu_n \mathrm{k}T}{\mathrm{q_e}} \cdot 2.704 \cdot 10^{31} \cdot T^3 \cdot e^{-\frac{\varepsilon_g}{\mathrm{k}T}}$$

Temperaturna zavisnost pojačavača

$$I_S = \underbrace{2.704\cdot 10^{31}\cdot\frac{A_E\cdot\mu_n\cdot k}{W_B\cdot N_B}}_{const.}\cdot T^4\cdot e^{-\frac{\varepsilon_g}{kT}}$$

$$I_C = I_S\exp\left(\frac{V_{BE}}{V_T}\right) = \underbrace{2.704\cdot 10^{31}\cdot\frac{A_E\cdot\mu_n\cdot k}{W_B\cdot N_B}}_{const.}\cdot T^4\cdot\exp\left(-\frac{\varepsilon_g}{kT}\right)\cdot\exp\left(\frac{q_e V_{BE}}{kT}\right)$$

$$g_m = \frac{I_C}{V_T} = 2.704\cdot 10^{31}\cdot\frac{A_E\cdot\mu_n\cdot k}{W_B\cdot N_B}\cdot\frac{q_e}{kT}T^4\cdot\exp\left(-\frac{\varepsilon_g}{kT}\right)\cdot\exp\left(\frac{q_e V_{BE}}{kT}\right)$$

$$g_m = \underbrace{2.704\cdot 10^{31}\cdot\frac{A_E\cdot\mu_n\cdot k\cdot q_e}{W_B\cdot N_B}}_{=C,\text{ ne zavisi od temperature}}\cdot T^3\cdot\exp\left(\frac{q_e V_{BE}-\varepsilon_g}{kT}\right) = C\cdot T^3\cdot\exp\left(\frac{q_e V_{BE}-\varepsilon_g}{kT}\right)$$

Temperaturna zavisnost pojačavača

- Pojačanje pojačavača sa zajedničkim emitorom:

$$A = -g_{\mathrm{m}} \cdot R_{\mathrm{C}}$$

- Temperatirna zavisnost:

$$g_{\mathrm{m}} = \frac{I_{\mathrm{C}}}{V_{\mathrm{T}}}, \quad I_{\mathrm{C}} = I_{\mathrm{S}} \exp\left(\frac{V_{\mathrm{BE}}}{V_{\mathrm{T}}}\right), \quad V_{\mathrm{T}} = \frac{\mathrm{k}T}{\mathrm{q_e}}$$

$$I_{\mathrm{S}} \sim n_i^2 \sim T^3 \exp\left(-\frac{\varepsilon_{\mathrm{g}}}{\mathrm{k}T}\right) \qquad g_{\mathrm{m}} \sim T^2 \exp\left(\frac{\mathrm{q_e}V_{\mathrm{BE}} - \varepsilon_{\mathrm{g}}}{\mathrm{k}T}\right)$$

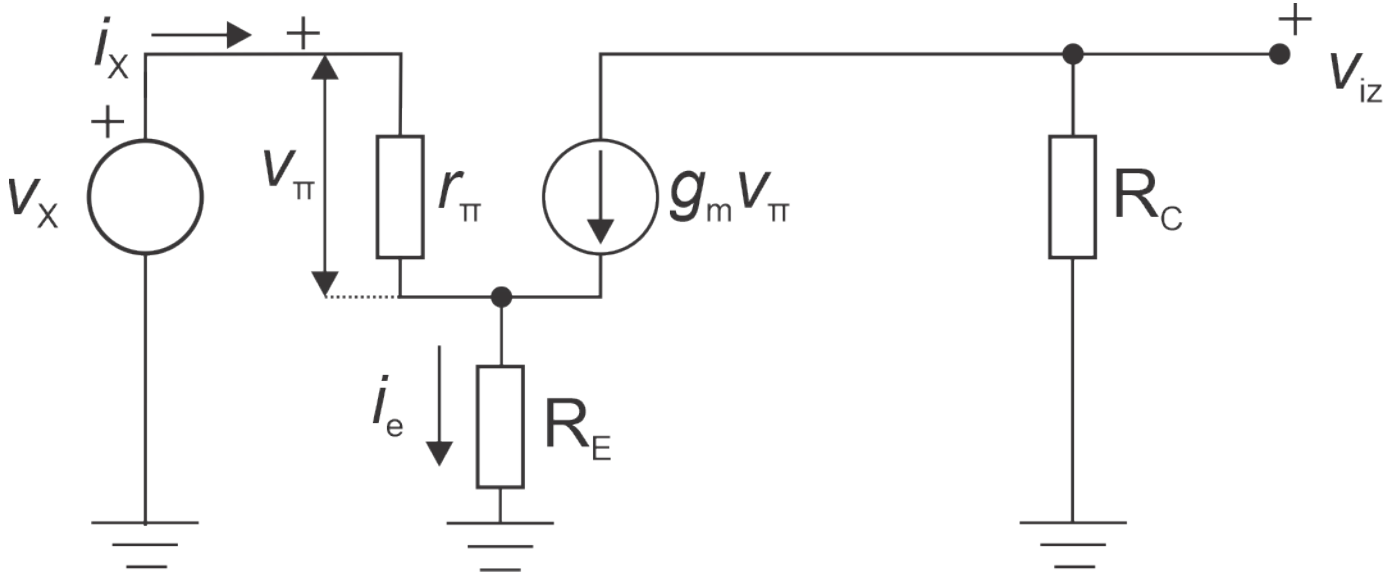
Degenerisani emitor – ulazna impedansa

$$i_e = (\beta + 1) i_X$$

$$v_X = R_E \cdot i_e + r_\pi \cdot i_X$$

$$v_X = R_E \cdot (\beta + 1) i_X + r_\pi i_X$$

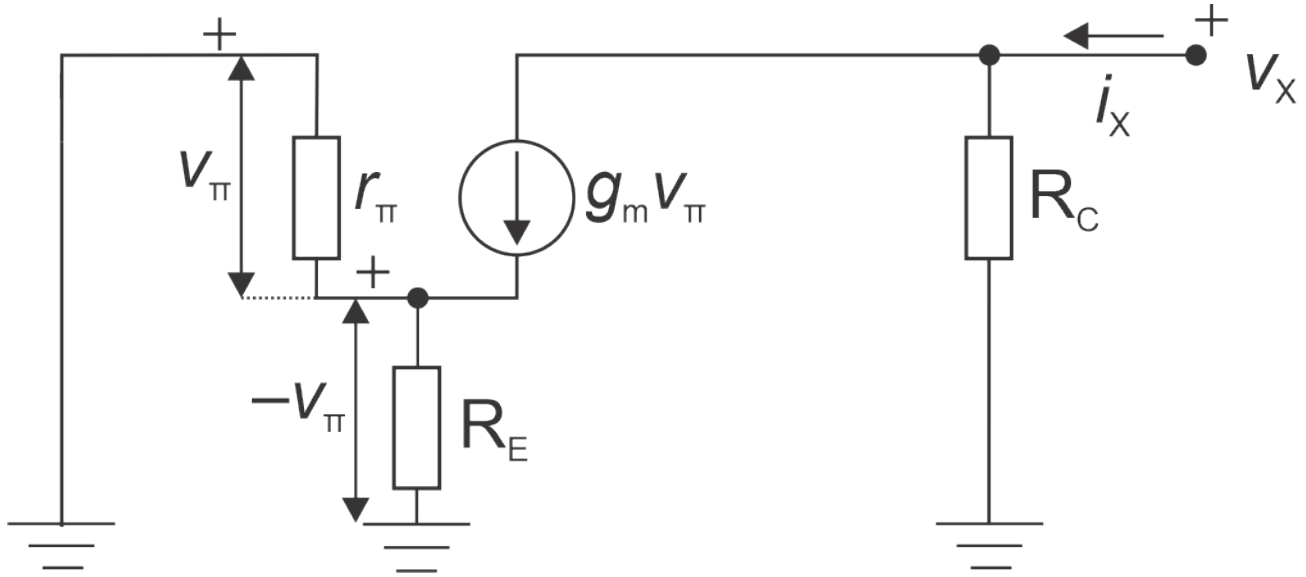
$$\boxed{R_{ul} = \frac{v_X}{i_X} = (\beta + 1) R_E + r_\pi}$$



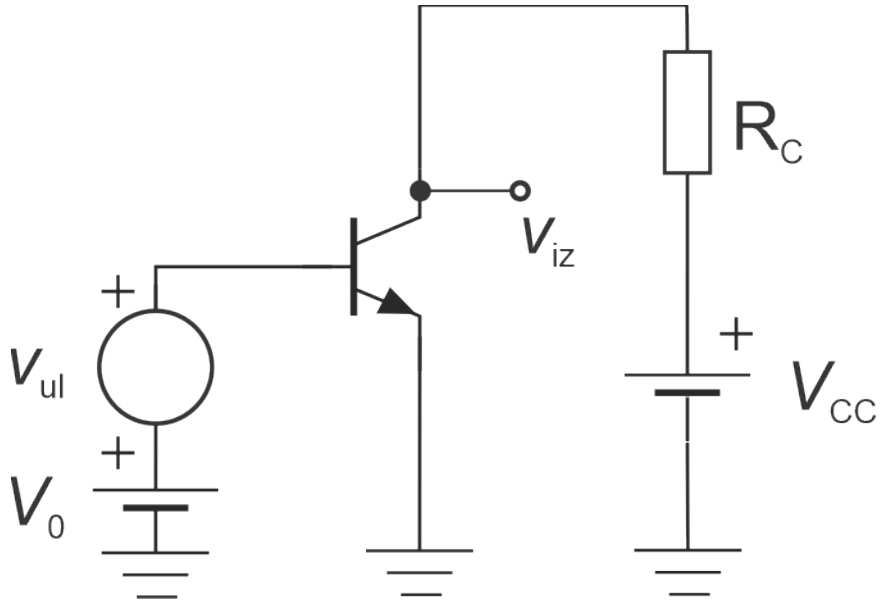
Degenerisani emitor – izlazna impedansa

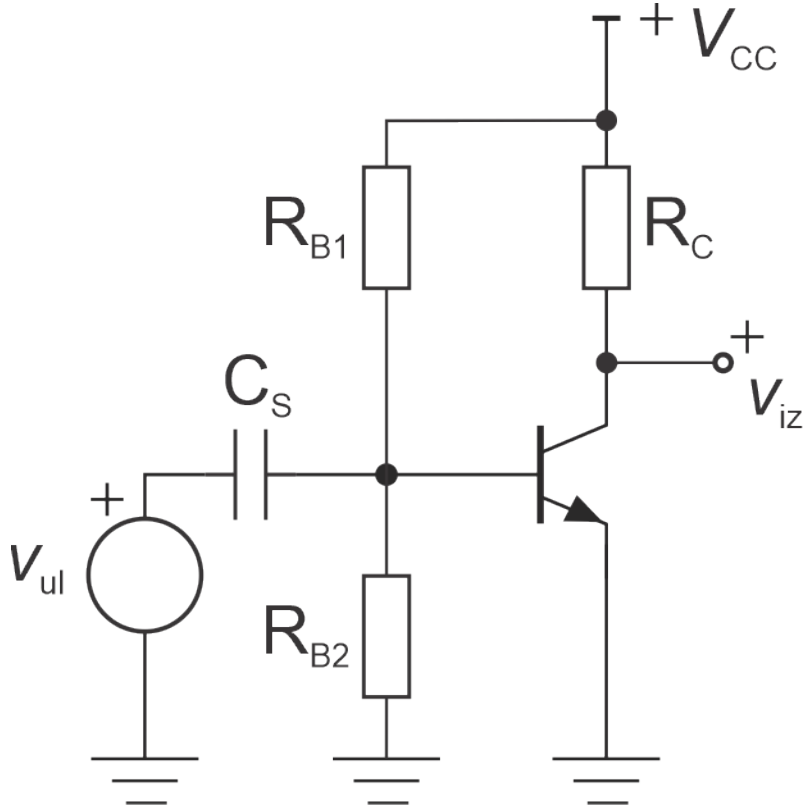
$$\frac{v_\pi}{r_\pi} + g_\mathrm{m} v_\pi = -R_\mathrm{E} v_\pi \Rightarrow v_\pi = 0$$

$$\boxed{R_\mathrm{iz} = \frac{v_\mathrm{X}}{i_\mathrm{X}} = R_\mathrm{C}}$$



Kola za polarizaciju tranzistora





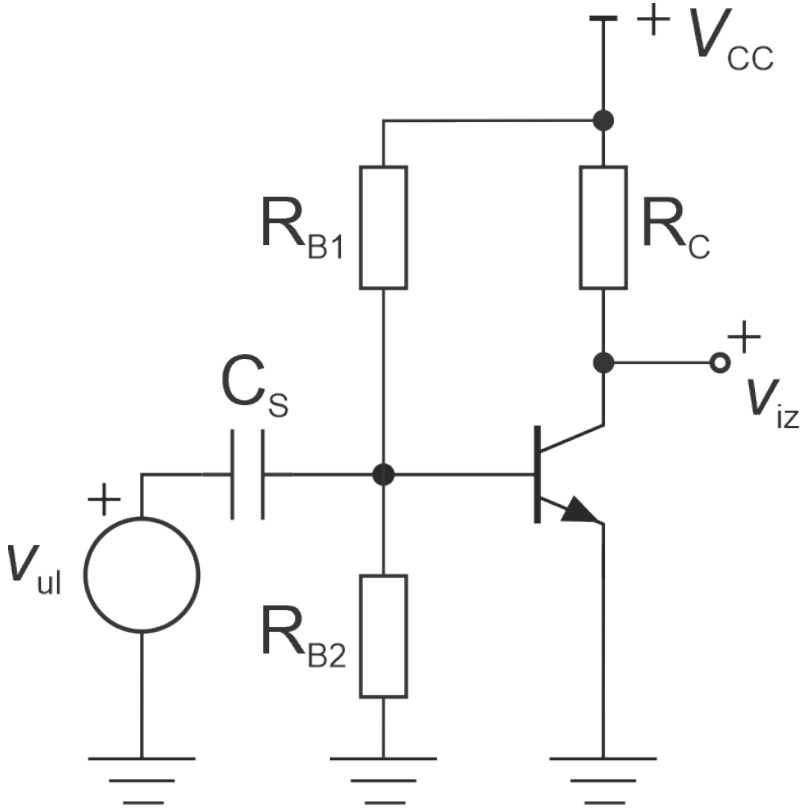
Kola za polarizaciju

$$I_{B1} = \frac{V_{CC} - V_{BE}}{R_{B1}}$$

$$I_{B2} = \frac{V_{BE}}{R_{B2}}$$

$$I_B = I_{B1} - I_{B2}$$

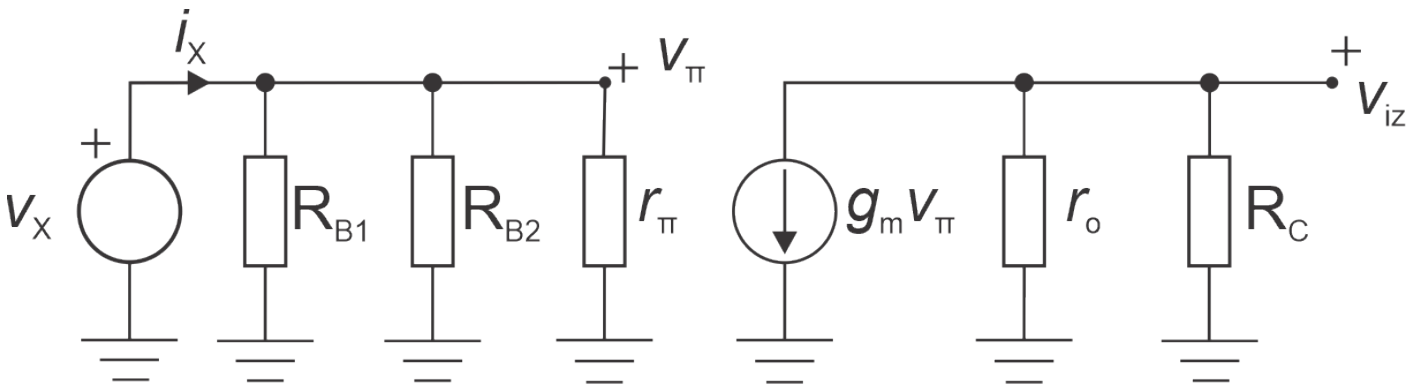
$$I_C = \beta \cdot I_B \quad \Rightarrow \quad g_m, r_\pi, r_o$$

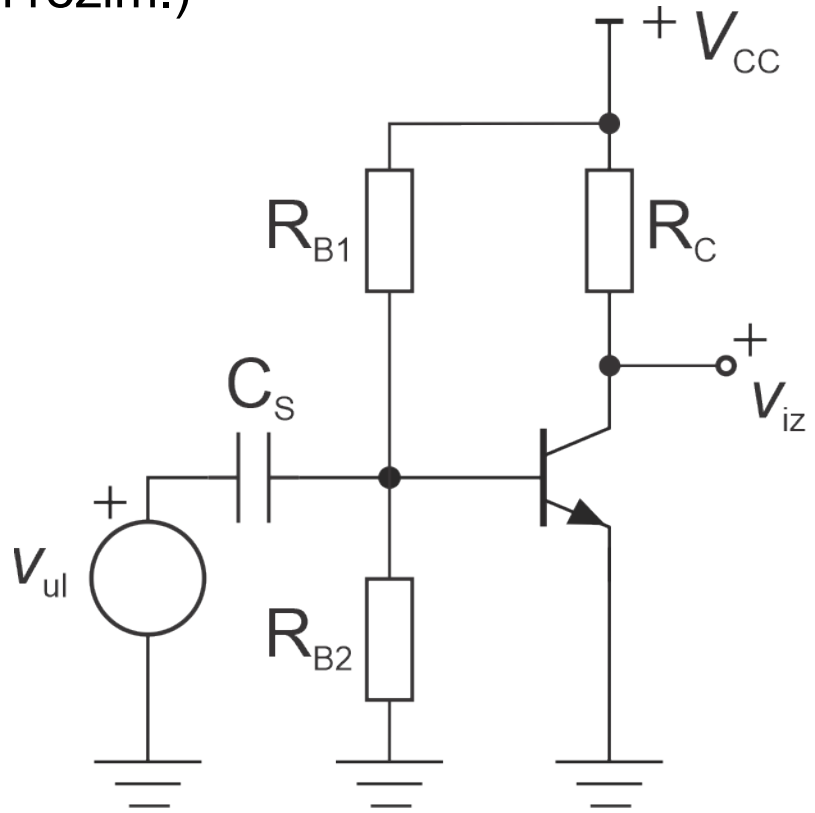


Kola za polarizaciju

$C_s = \infty$ (Kratak spoj za naizmenični, prekid za jednosmerni režim.)

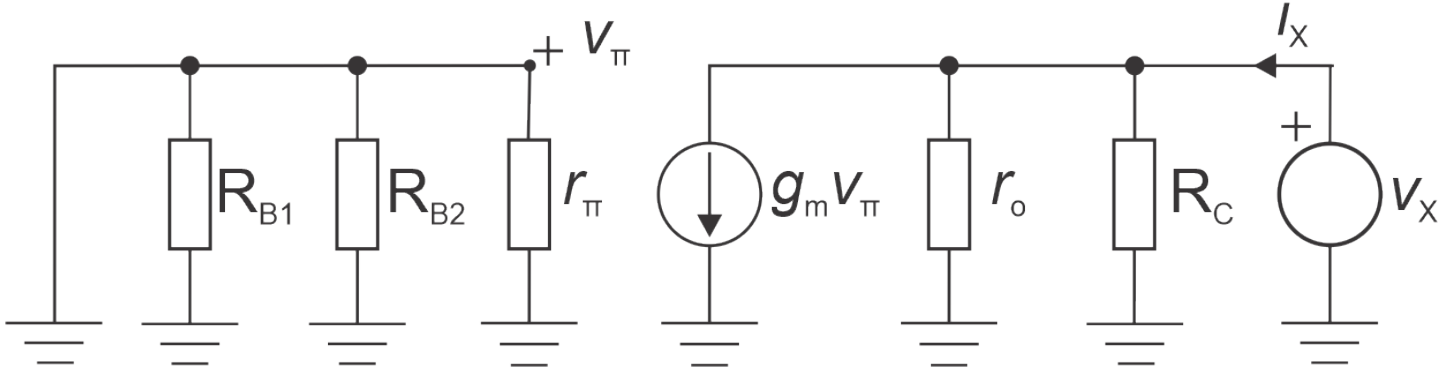
$R_{ul} = R_{B1} \parallel R_{B2} \parallel r_\pi$

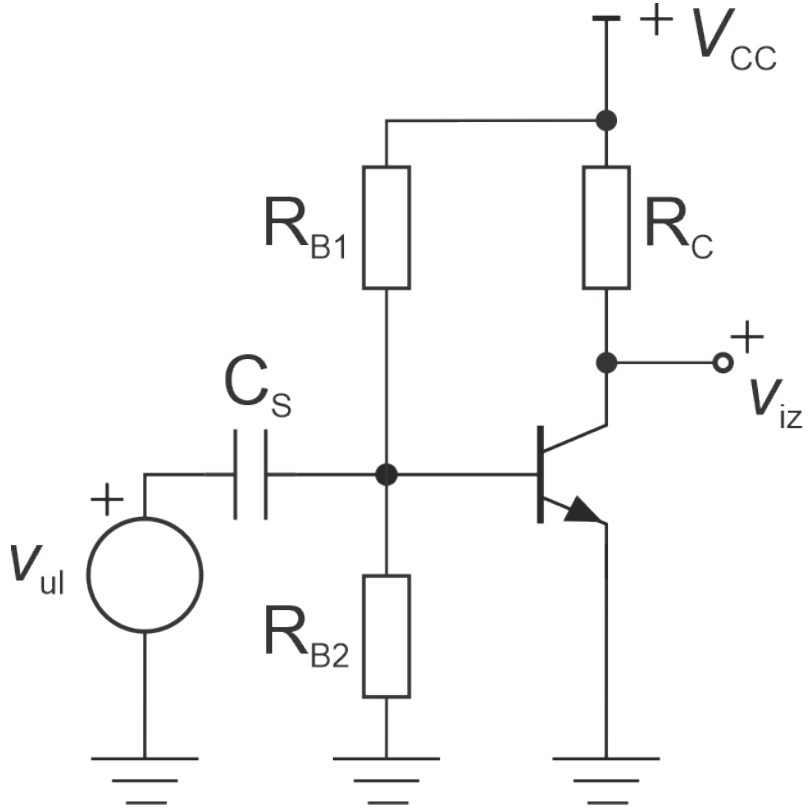




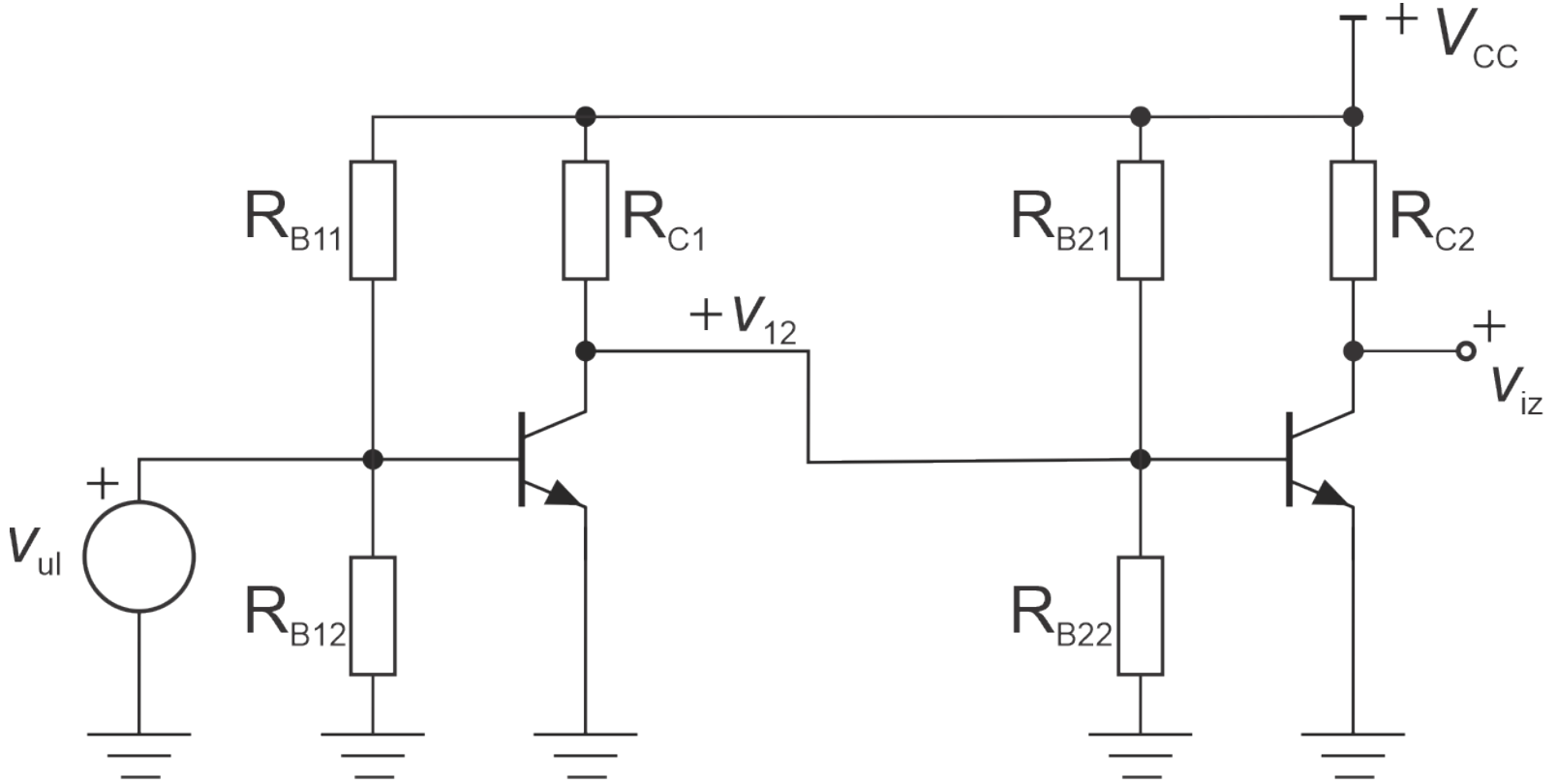
Kola za polarizaciju

$$R_{iz} = r_o \parallel R_C$$



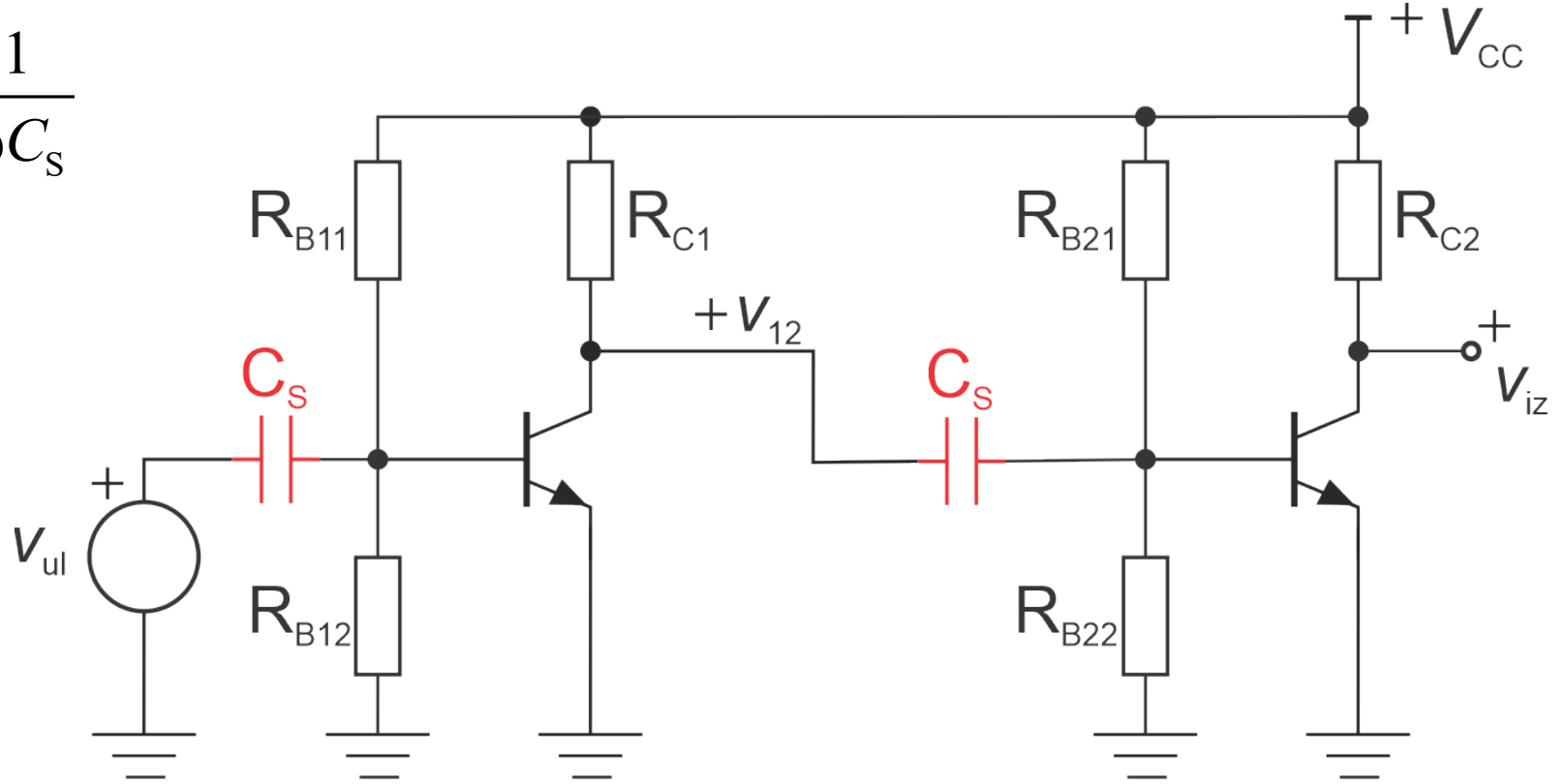


Kola za polarizaciju



Kola za polarizaciju

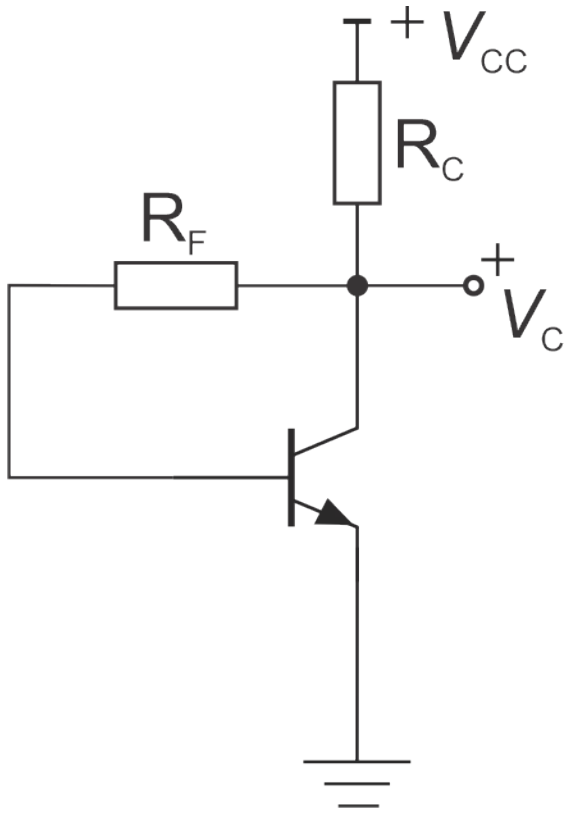
$$R_{ul2}, R_{ul2} \gg \frac{1}{\omega C_S}$$



Kola za polarizaciju

- Self-bias kolo
- Mala osetljivost na promene V_{CC}
- Tranzistor je uvek u aktivnom režimu:

$$V_{\mathrm{B}} = V_{\mathrm{C}} - I_{\mathrm{B}} R_{\mathrm{F}}$$



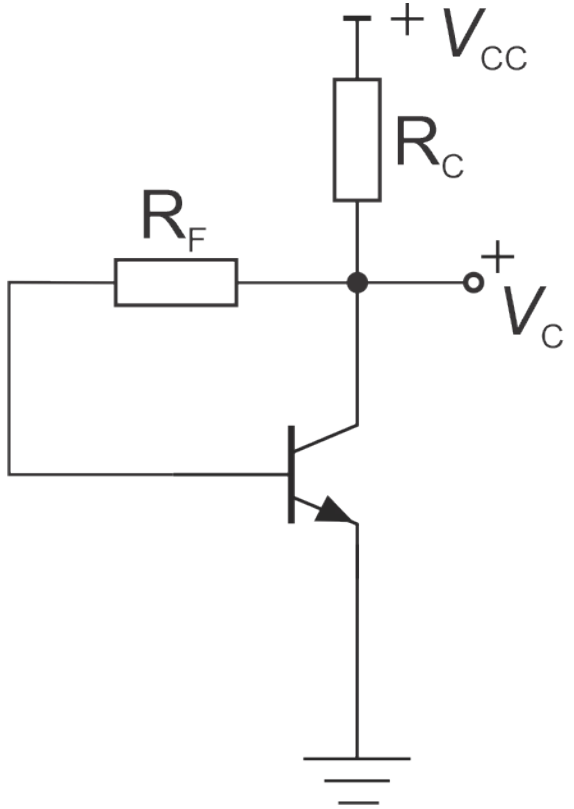
Kola za polarizaciju

$$\beta \gg 1 \quad \Rightarrow \quad I_C \gg I_B$$

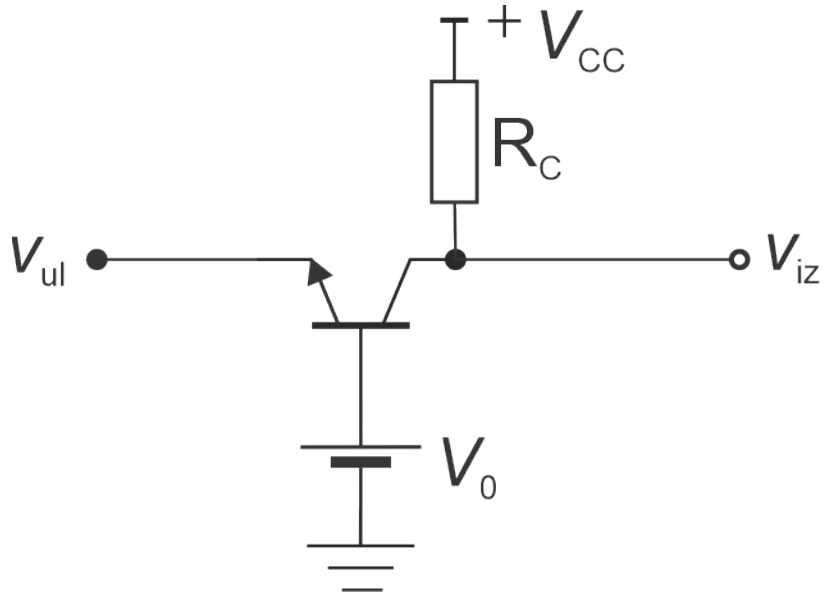
$$V_C = V_{CC} - I_C R_C$$

$$V_{BE} = V_{CC} - I_C R_C - I_B R_F$$

$$I_C = \frac{V_{CC} - V_{BE}}{R_C + R_F/\beta} \qquad R_C \gg R_F/\beta$$



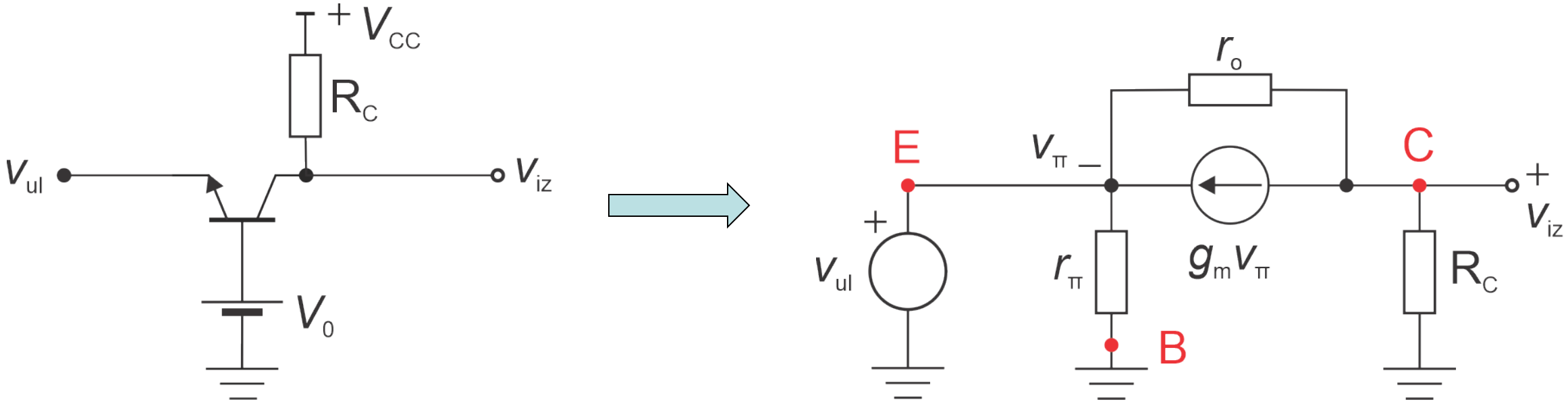
Pojačavač sa zajedničkom bazom



- **Pojačavač sa zajedničkom bazom** je konfiguracija pojačavača sa bipolarnim tranzistorom. Baza tranzistora je zajednički priključak ulaza i izlaza kola. **Ulazni priključak je emitor, izlazni priključak kolektor**.
- Značajni parametri su pojačanje, ulazna i izlazna impedansa.

Pojačavač sa zajedničkom bazom

- Ekvivalentno kolo za male signale (zanemaren Erlijev efekat, $r_o=\infty$):



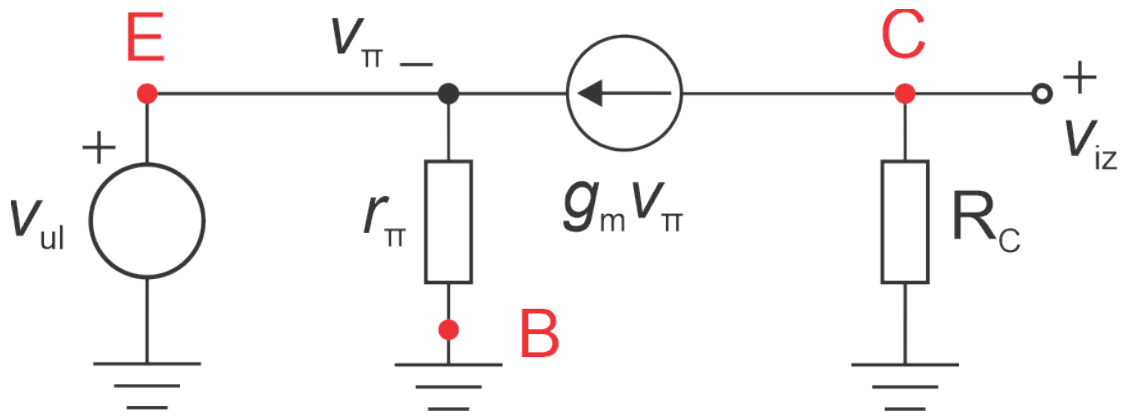
Pojačavač sa zajedničkom bazom – pojačanje A

$$v_\pi = -v_{ul}$$

$$v_{iz} = -g_m v_\pi R_C$$

$$v_{iz} = g_m R_C v_{ul}$$

$$\boxed{A = g_m R_C}$$



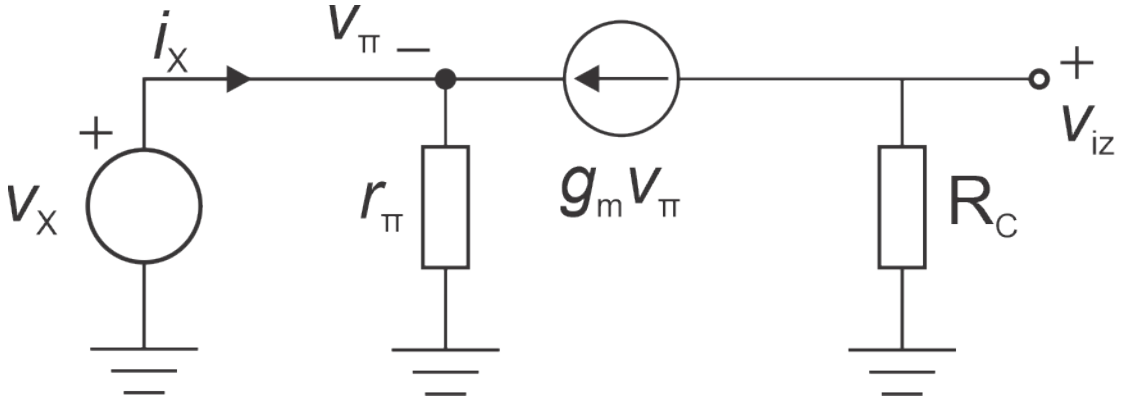
Pojačavač sa zajedničkom bazom – ul. Impedansa, R_{ul}

$$-v_\pi = g_m v_\pi r_\pi + i_X r_\pi$$

$$-v_\pi \left(1 + g_m r_\pi\right) = i_X r_\pi$$

$$v_X \left(1 + \beta\right) = i_X r_\pi$$

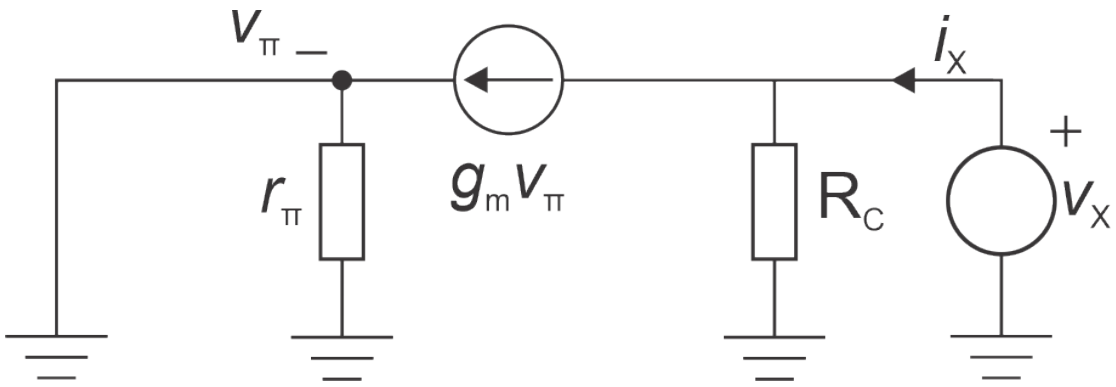
$$\boxed{R_{ul} = \frac{v_X}{i_X} = \frac{r_\pi}{1+\beta} \approx \frac{1}{g_m}}$$



Pojačavač sa zajedničkom bazom – iz. impedansa, R_{iz}

$$v_\pi = 0$$

$$\boxed{R_{iz} = R_C}$$



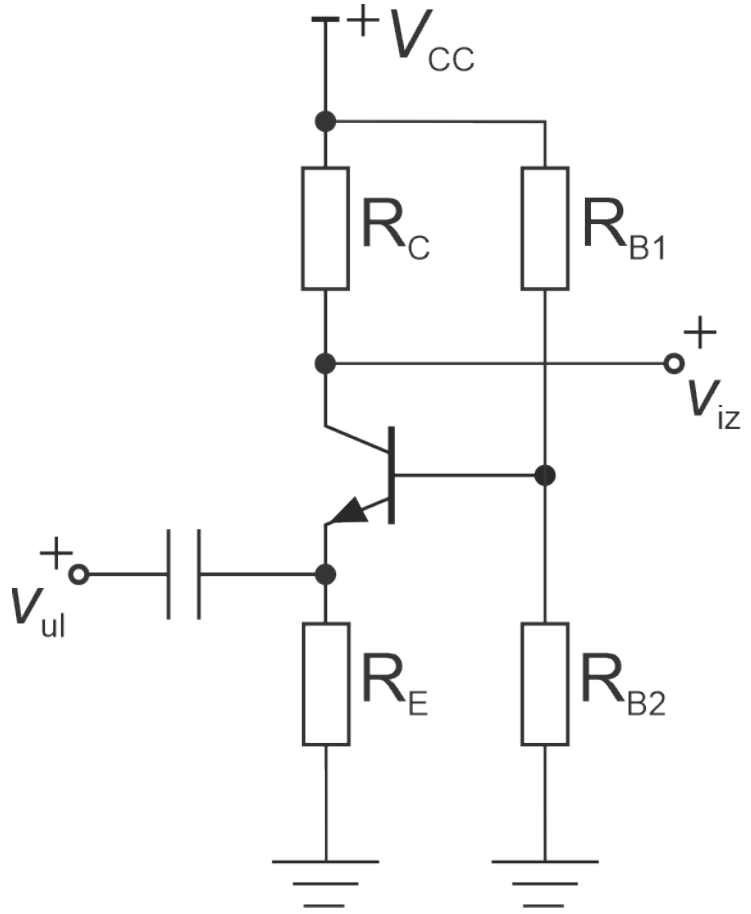
Pojačavač sa zajedničkom bazom – polarizacija

$$R_{\mathrm{E}} \gg 1/g_{\mathrm{m}}$$

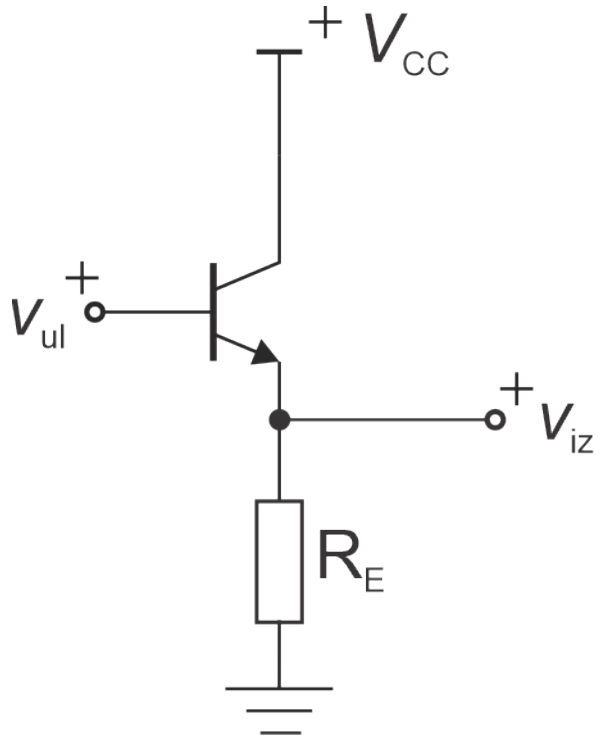
$$\frac{R_{\mathrm{B1}}}{R_{\mathrm{B1}}+R_{\mathrm{B2}}}V_{\mathrm{CC}} > I_{\mathrm{C}}R_{\mathrm{E}} + V_{\mathrm{BE}}$$

$$\frac{R_{\mathrm{B1}}}{R_{\mathrm{B1}}+R_{\mathrm{B2}}}V_{\mathrm{CC}} < V_{\mathrm{CC}} - I_{\mathrm{C}}R_{\mathrm{C}}$$

$$\boxed{R_{\mathrm{ul}} = 1/g_{\mathrm{m}} \parallel R_{\mathrm{E}}}$$



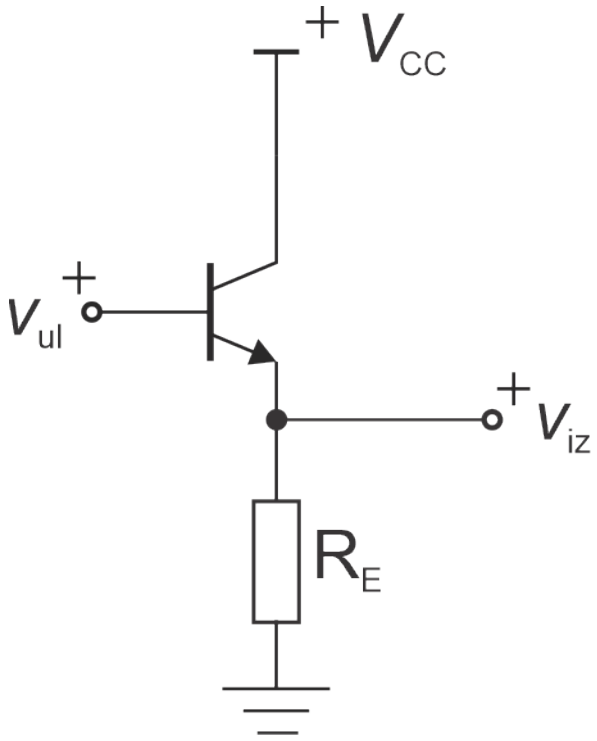
Pojačavač sa zajedničkim kolektorom

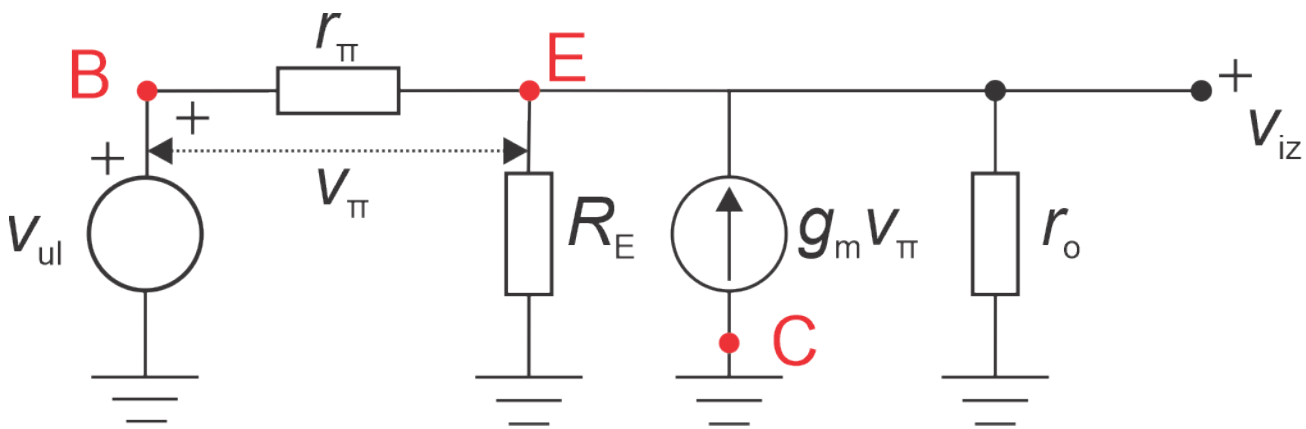


- **Pojačavač sa zajedničkom kolektorom** je konfiguracija pojačavača sa bipolarnim tranzistorom. Kolektor tranzistora je zajednički priključak ulaza i izlaza kola. **Ulazni priključak je baza, izlazni priključak emitor**.
- Značajni parametri su pojačanje, ulazna i izlazna impedansa.

Pojačavač sa zajedničkim kolektorom

- Ekvivalentno kolo za male signale:





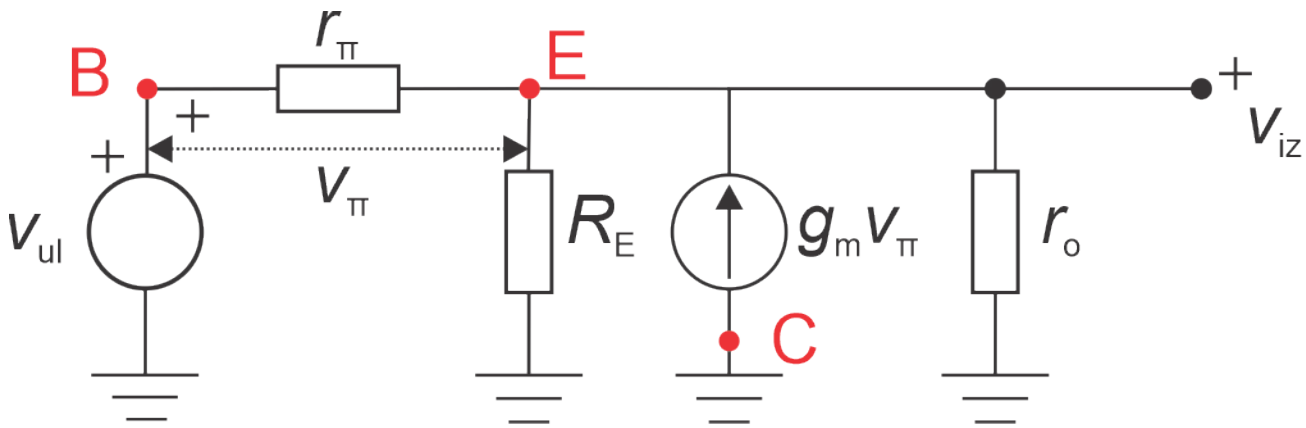
Pojačavač sa zajedničkim kolektorom – pojačanje A

$$v_{\mathrm{iz}}\left(\frac{1}{r_{\mathrm{o}}}+\frac{1}{R_{\mathrm{E}}}+\frac{1}{r_{\pi}}\right)-\frac{v_{\mathrm{ul}}}{r_{\pi}}=g_{\mathrm{m}}v_{\pi} \qquad \text{(E)}$$

$$v_{\pi}=v_{\mathrm{ul}}-v_{\mathrm{iz}}$$

$$v_{\mathrm{iz}}\left(\frac{1}{r_{\mathrm{o}}}+\frac{1}{R_{\mathrm{E}}}+\frac{1}{r_{\pi}}\right)-\frac{v_{\mathrm{ul}}}{r_{\pi}}=g_{\mathrm{m}}\left(v_{\mathrm{ul}}-v_{\mathrm{iz}}\right)$$

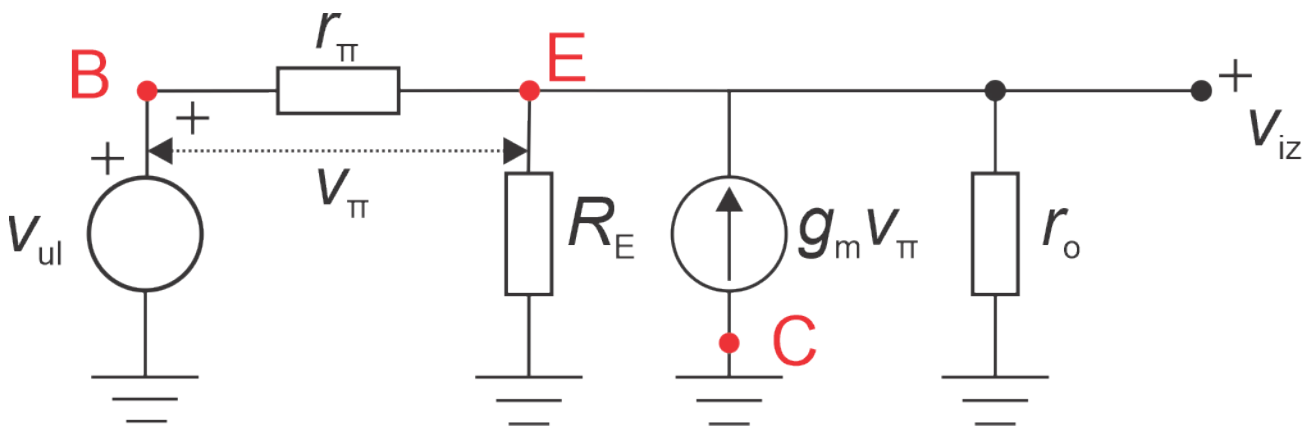
$$v_{\mathrm{iz}}\left(\frac{1}{r_{\mathrm{o}}}+\frac{1}{R_{\mathrm{E}}}+\frac{1}{r_{\pi}}+g_{\mathrm{m}}\right)=v_{\mathrm{ul}}\left(\frac{1}{r_{\pi}}+g_{\mathrm{m}}\right)$$



Pojačavač sa zajedničkim kolektorom – pojačanje

$$A = \frac{v_{iz}}{v_{ul}} = \frac{\frac{1}{r_\pi} + g_m}{\frac{1}{r_o} + \frac{1}{R_E} + \frac{1}{r_\pi} + g_m}$$

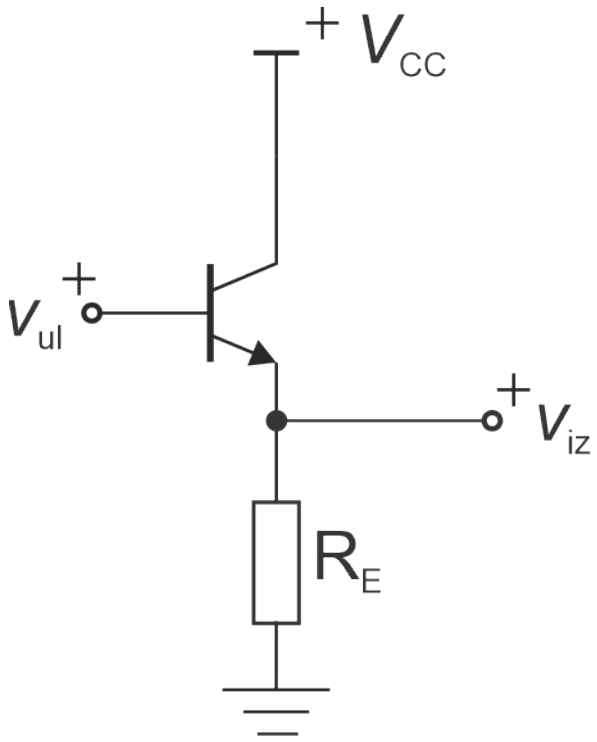
$$A = \frac{\left(\frac{1}{\beta} + 1\right) g_m}{\frac{1}{r_o} + \frac{1}{R_E} + \left(\frac{1}{\beta} + 1\right) g_m} \approx \frac{g_m}{\frac{1}{r_o} + \frac{1}{R_E} + g_m}$$



$$\boxed{A = \frac{g_m \cdot R_E \parallel r_o}{1 + g_m \cdot R_E \parallel r_o} < 1}$$

Pojačavač sa zajedničkim kolektorom – ulazna imp.

- Kolo je identično pojačavaču sa degenerisanim emitorom kada je R_C=0.



$$\boxed{R_{ul} = (\beta + 1) R_E + r_\pi}$$

Pojačavač sa zajedničkim kolektorom – izlazna impedansa

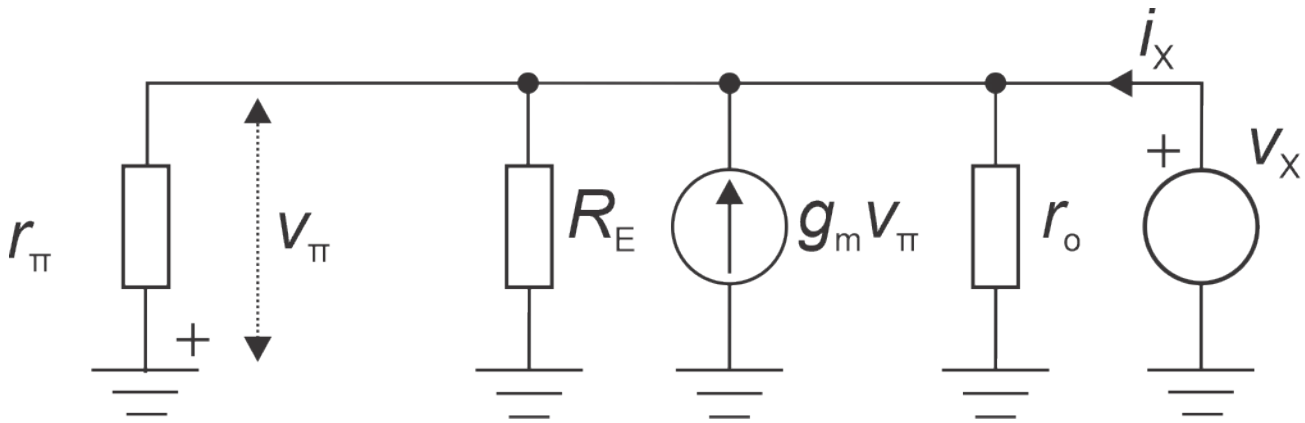
$$v_\pi = -v_X$$

$$i_X + g_m v_\pi = \frac{v_X}{r_\pi} + \frac{v_X}{R_E} + \frac{v_X}{r_o}$$

$$i_X = v_X \left(\frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{r_o} + g_m \right)$$

$$R_{iz} = \frac{v_X}{i_X} = \frac{1}{\frac{1}{r_\pi} + \frac{1}{R_E} + \frac{1}{r_o} + g_m}$$

$$\boxed{R_{iz} = \frac{v_X}{i_X} = r_\pi \,\|\, R_E \,\|\, r_o \,\|\, 1/g_m}$$

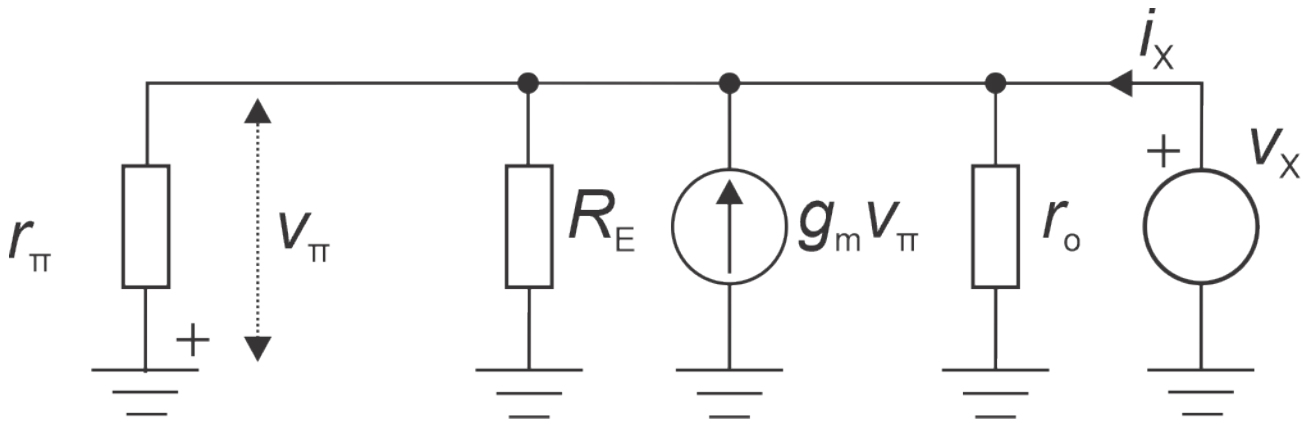


Pojačavač sa zajedničkim kolektorom – izlazna imp.

- Pojednostavljen izraz, $r_o=\infty$ i $g_m=\beta/r_\pi>>1/r_\pi$

$$R_{iz} \approx \frac{1}{\frac{1}{R_E}+g_m}$$

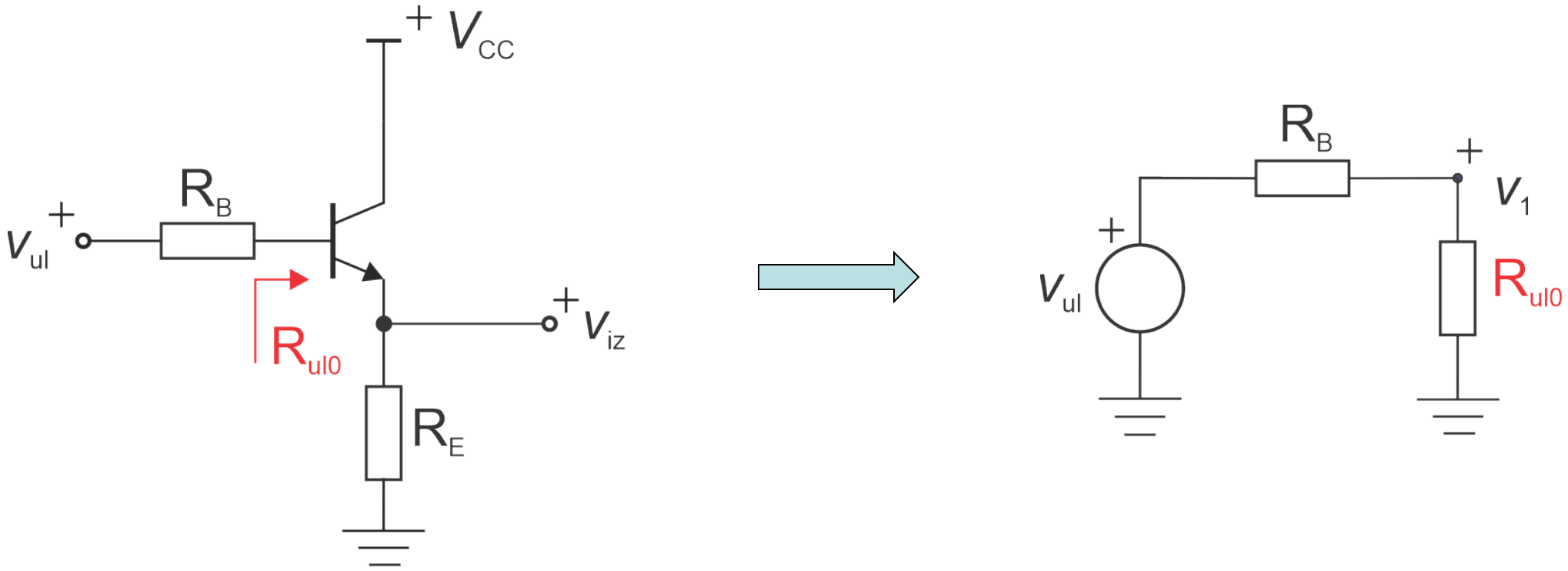
$$\boxed{R_{iz} \approx R_E \,\|\, 1/g_m}$$



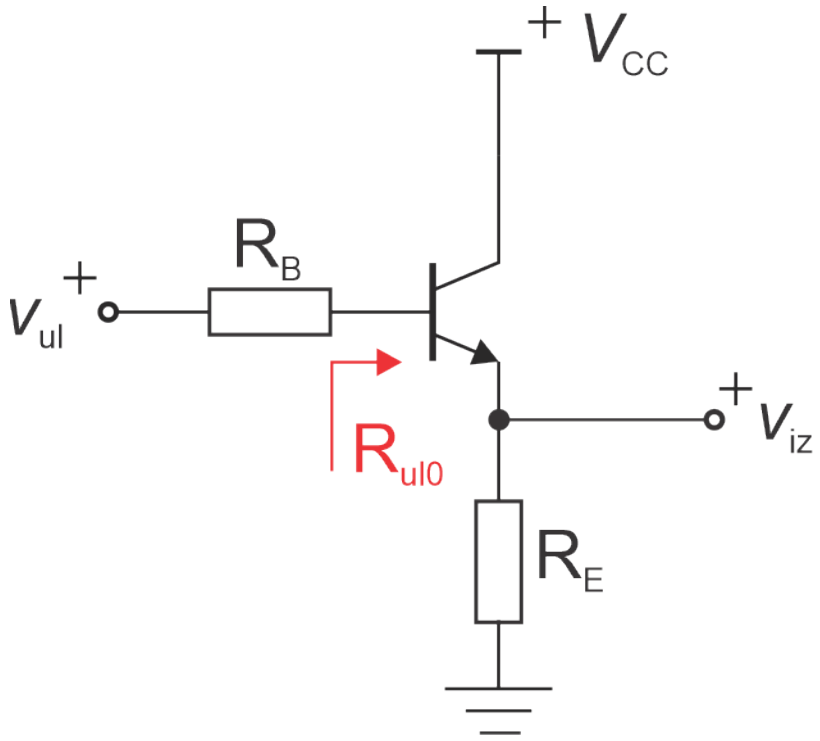
Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

- Otpornik u grani baze, pojačanje

$$V_1 = \frac{R_{ul0}}{R_{ul0} + R_B} V$$



Pojačavač sa zajedničkim kolektorom – polarizacija, R_B



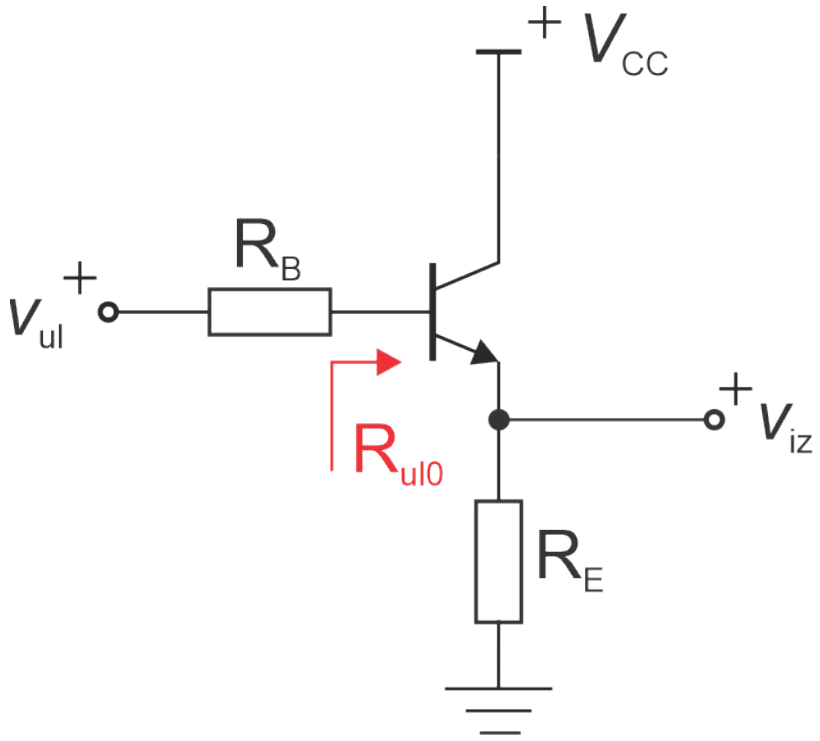
$$R_{ul0} = (\beta + 1) R_E + r_\pi$$

$$A_0 = \frac{R_E}{1/g_m + R_E}, \quad r_o = \infty$$

$$A = \frac{R_E}{1/g_m + R_E} \frac{R_{ul0}}{R_{ul0} + R_B}$$

$$A = \frac{R_E}{1/g_m + R_E} \frac{(\beta + 1) R_E + r_\pi}{(\beta + 1) R_E + r_\pi + R_B}$$

Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

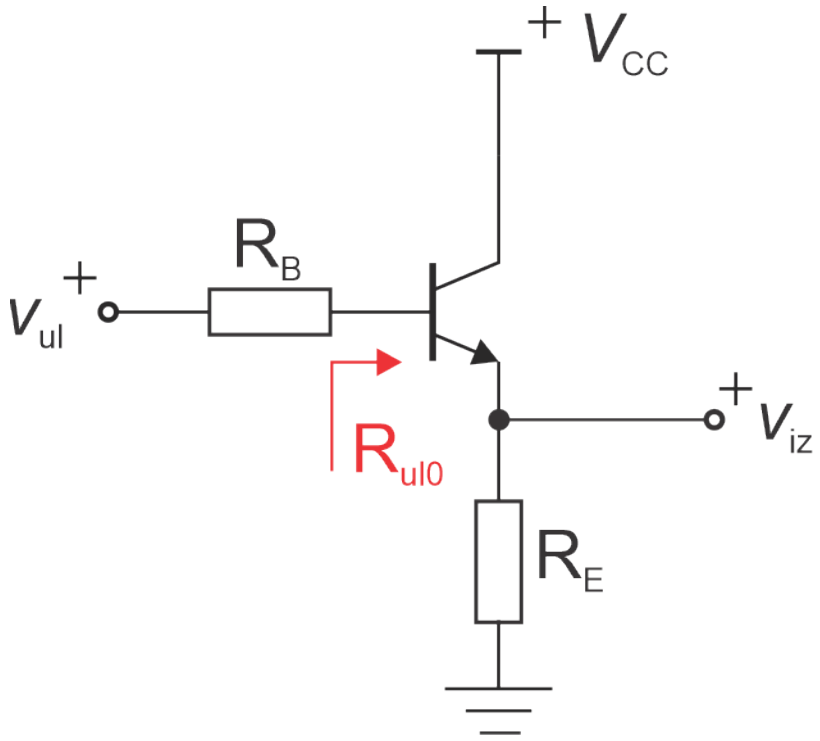


$$A = \frac{R_E}{1/g_m + R_E} \frac{R_E + \frac{r_\pi}{\beta+1}}{R_E + \frac{r_\pi}{\beta+1} + \frac{R_B}{\beta+1}}$$

$$\frac{r_\pi}{\beta+1} \approx \frac{r_\pi}{\beta} = \frac{1}{g_m}$$

$$A = \frac{R_E}{1/g_m + R_E} \frac{R_E + 1/g_m}{R_E + 1/g_m + \frac{R_B}{\beta+1}}$$

Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

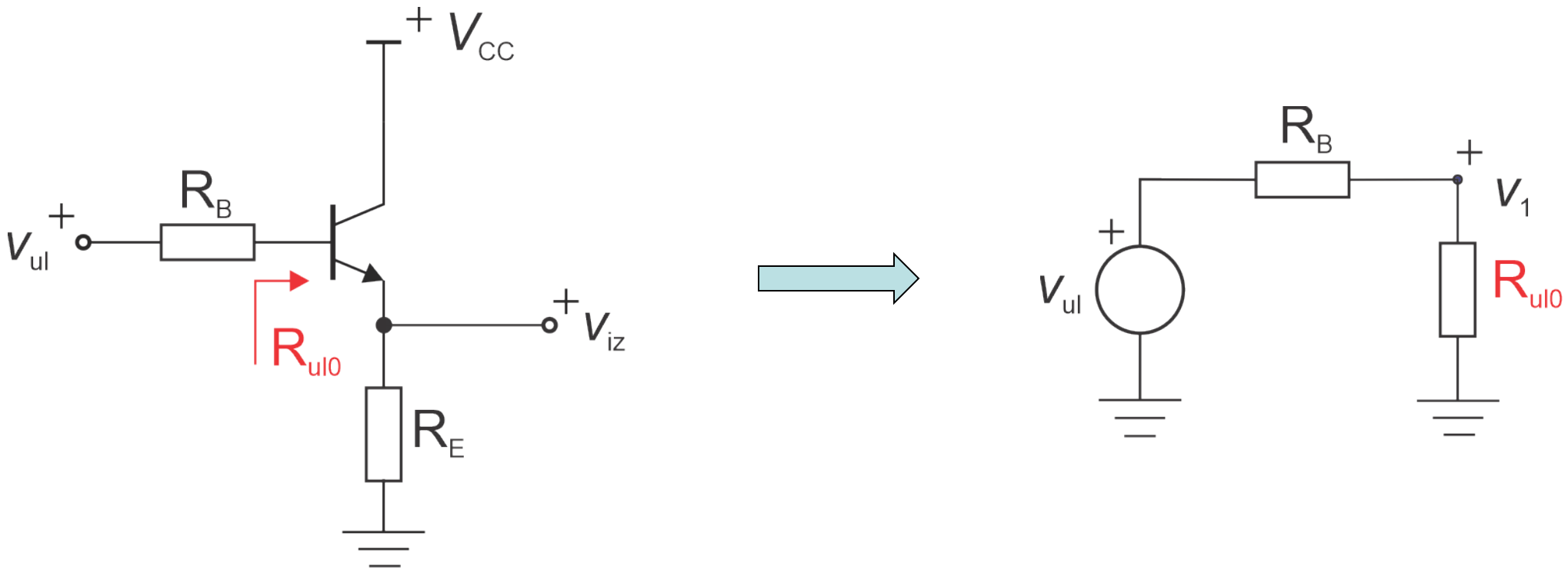


$$A = \frac{R_E}{R_E + 1/g_m + \frac{R_B}{\beta + 1}}$$

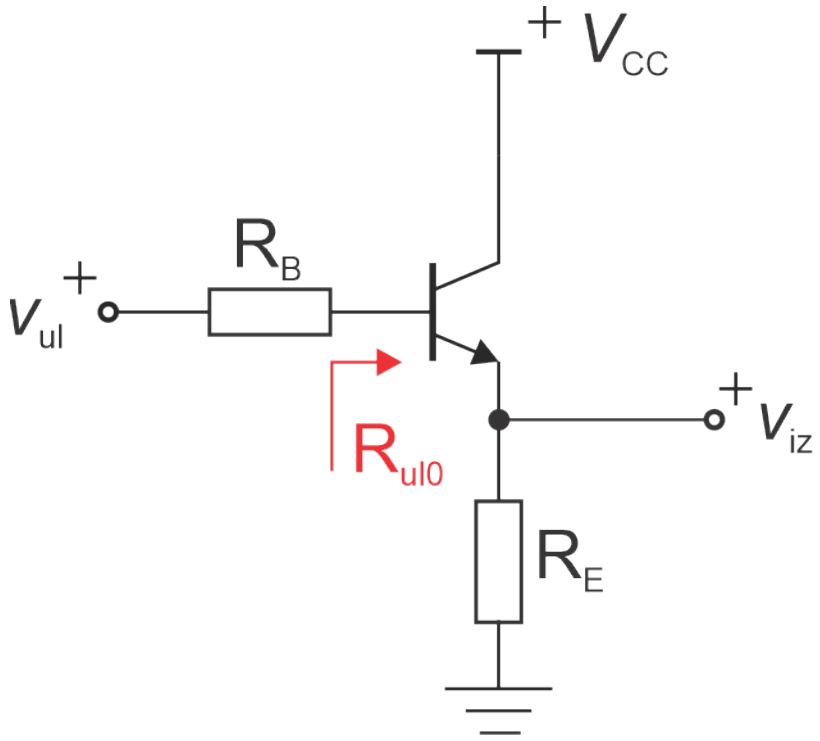
$$A < A_0 < 1$$

Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

- Otpornik u grani baze, ulazna impedansa



Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

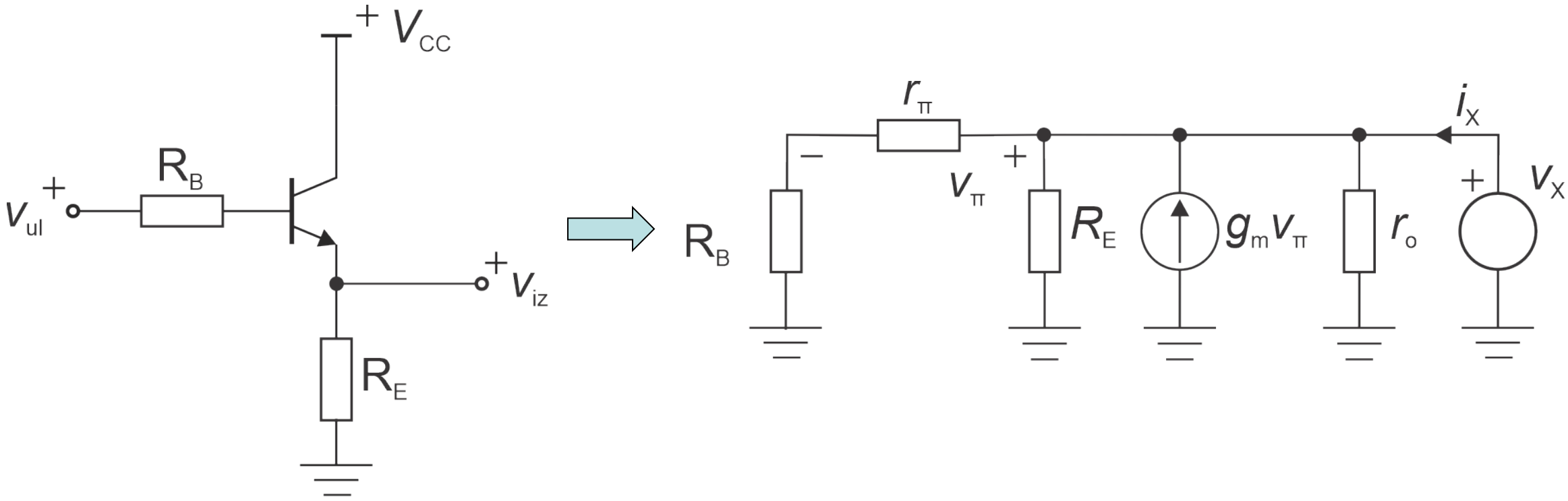


$$R_{ul0} = (\beta + 1) R_E + r_\pi$$

$$\boxed{R_{ul} = (\beta + 1) R_E + r_\pi + R_B}$$

Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

- Otpornik u grani baze, izlazna impedansa



Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

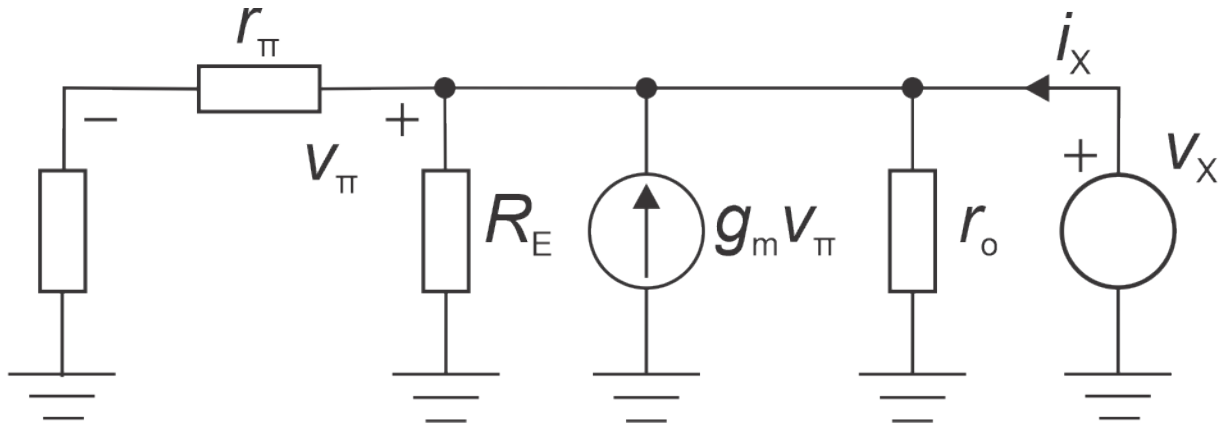
$$v_\pi = -\frac{r_\pi}{r_\pi + R_B} v_X$$

$$i_X + g_m v_\pi = \frac{v_X}{r_\pi + R_B} + \frac{v_X}{R_E} + \frac{v_X}{r_o}$$

$$i_X = v_X \left(\frac{1}{r_\pi + R_B} + \frac{1}{R_E} + \frac{1}{r_o} + \frac{g_m r_\pi}{r_\pi + R_B} \right) R_B$$

$$R_{iz} = \frac{v_X}{i_X} = \frac{1}{\frac{\beta+1}{R_E + r_\pi} + \frac{1}{R_E} + \frac{1}{r_o}}$$

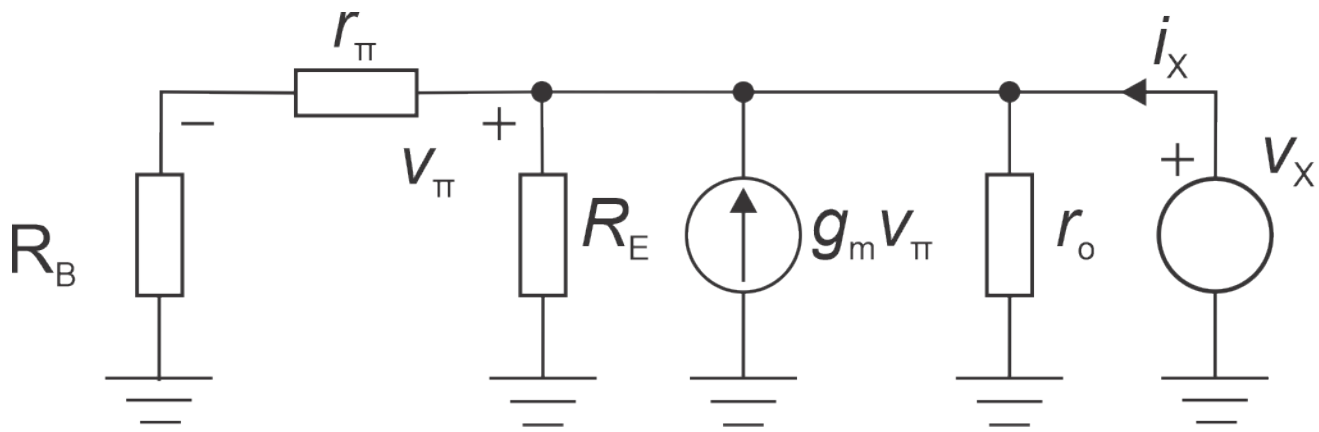
$$\boxed{R_{iz} = \frac{v_X}{i_X} = \frac{R_B + r_\pi}{\beta+1} \parallel R_E \parallel r_o}$$



Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

- Pojednostavljen izraz, $r_o=\infty$ i $r_\pi/(\beta+1) \approx r_\pi/\beta = 1/g_m$

$$\boxed{R_{iz} \approx R_E \parallel \left(1/g_m + R_B/(\beta+1)\right)}$$



Poređenje topologija pojačavača sa bipolarnim t.

Topologija	Naponsko pojačanje *A*	Fazni pomeraj	Ulazna impedansa R_{ul}	Izlazna impedansa R_{iz}
Zajednički emitor	$-g_m \cdot (R_C \parallel r_o)$	π	r_π	$r_o \parallel R_C$
Degenerisani emitor, $r_o=\infty$	$-\frac{g_m R_C}{1+g_m R_E}$	π	$(\beta+1)R_E + r_\pi$	R_C
Zajednički emitor sa naponskim razdelnikom	$-g_m \cdot (R_C \parallel r_o)$	π	$R_{B1} \parallel R_{B2} \parallel r_\pi$	$r_o \parallel R_C$
Zajednička baza, $r_o=\infty$	$g_m \cdot R_C$	0	$\frac{r_\pi}{1+\beta} \approx \frac{1}{g_m}$	R_C
Zajednički kolektor	$\approx \frac{g_m \cdot R_E \parallel r_o}{1+g_m \cdot R_E \parallel r_o}$	0	$(\beta+1)R_E + r_\pi$	$\approx R_E \parallel 1/g_m$