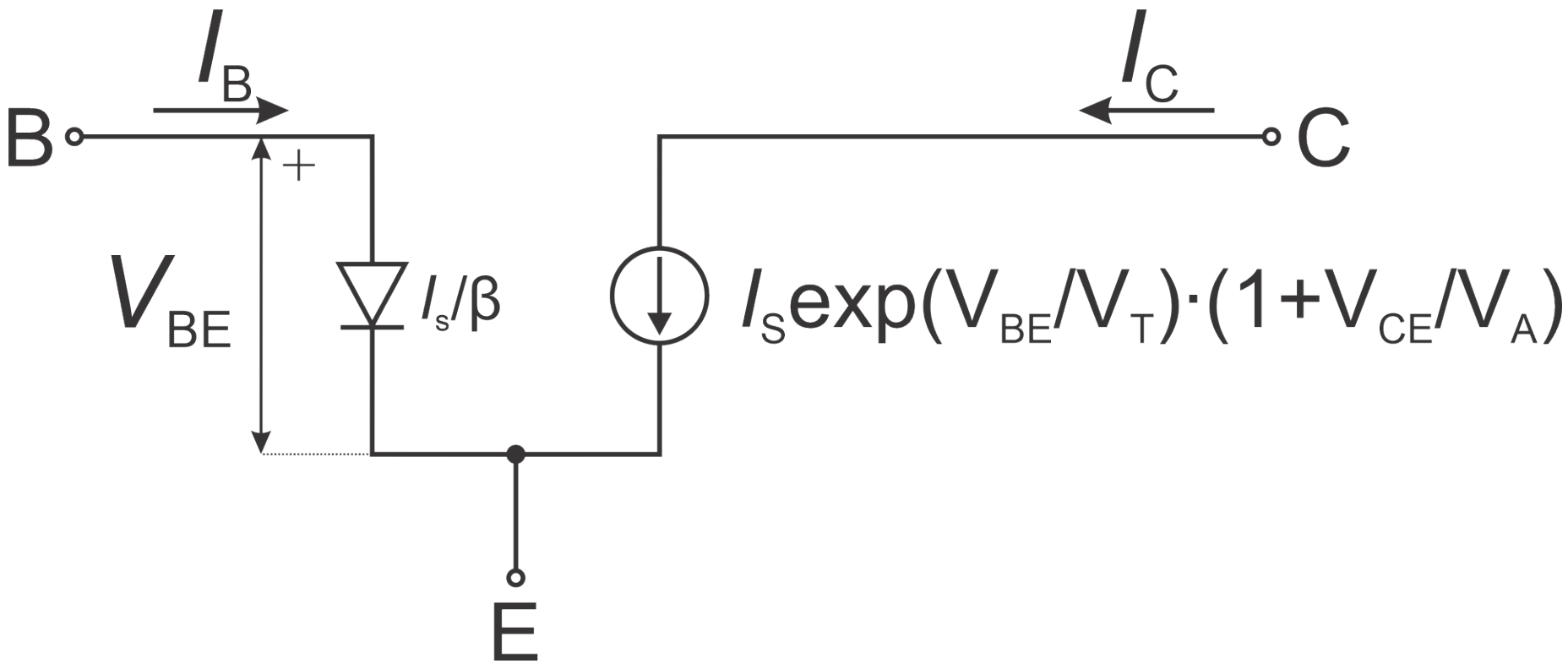
Pojačavači sa bipolarnim tranzistorima

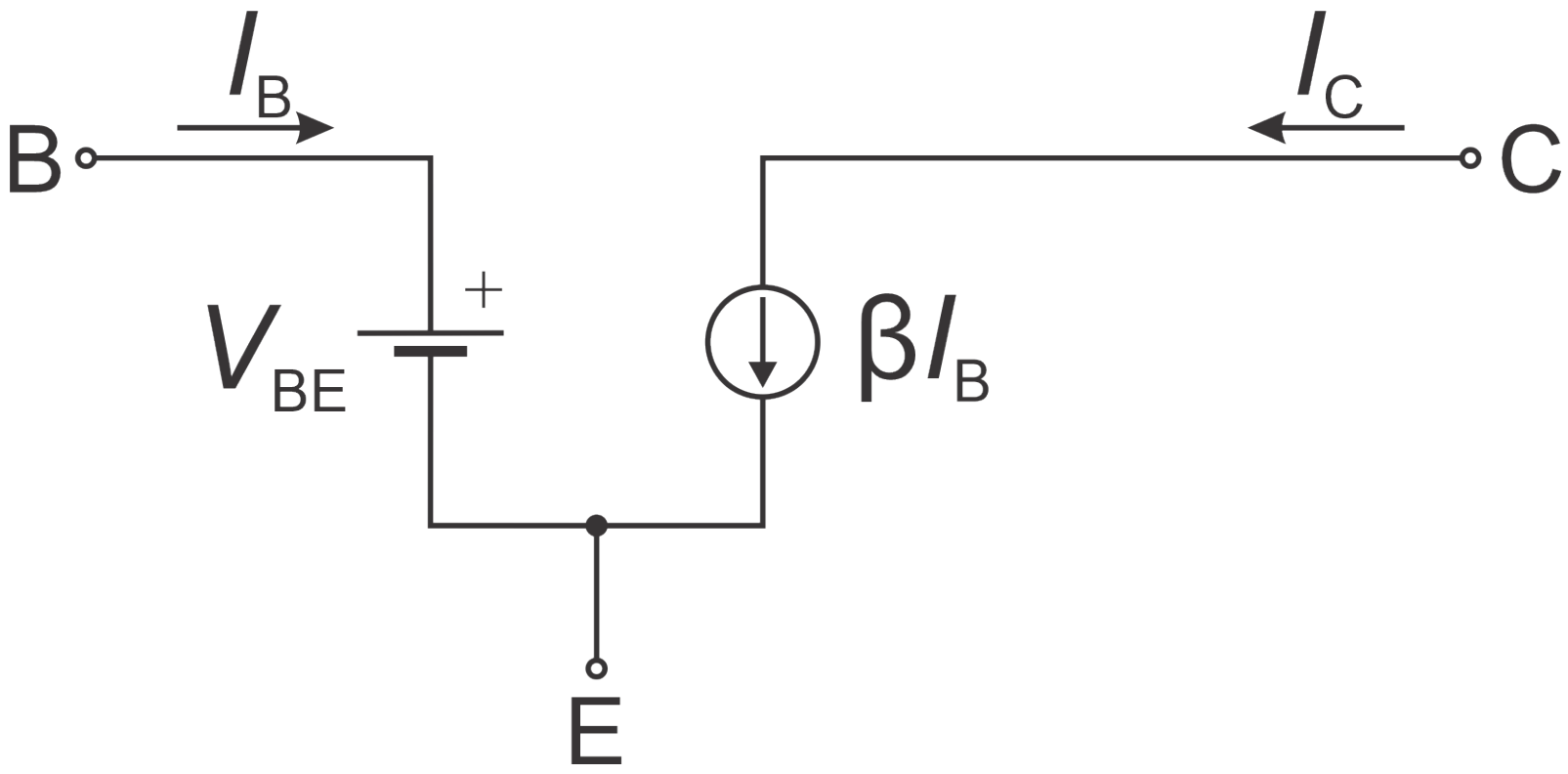
Model za velike signale (polarizacija)

Parametri: I_S, β, V_A



Model za velike signale (linearizovani)

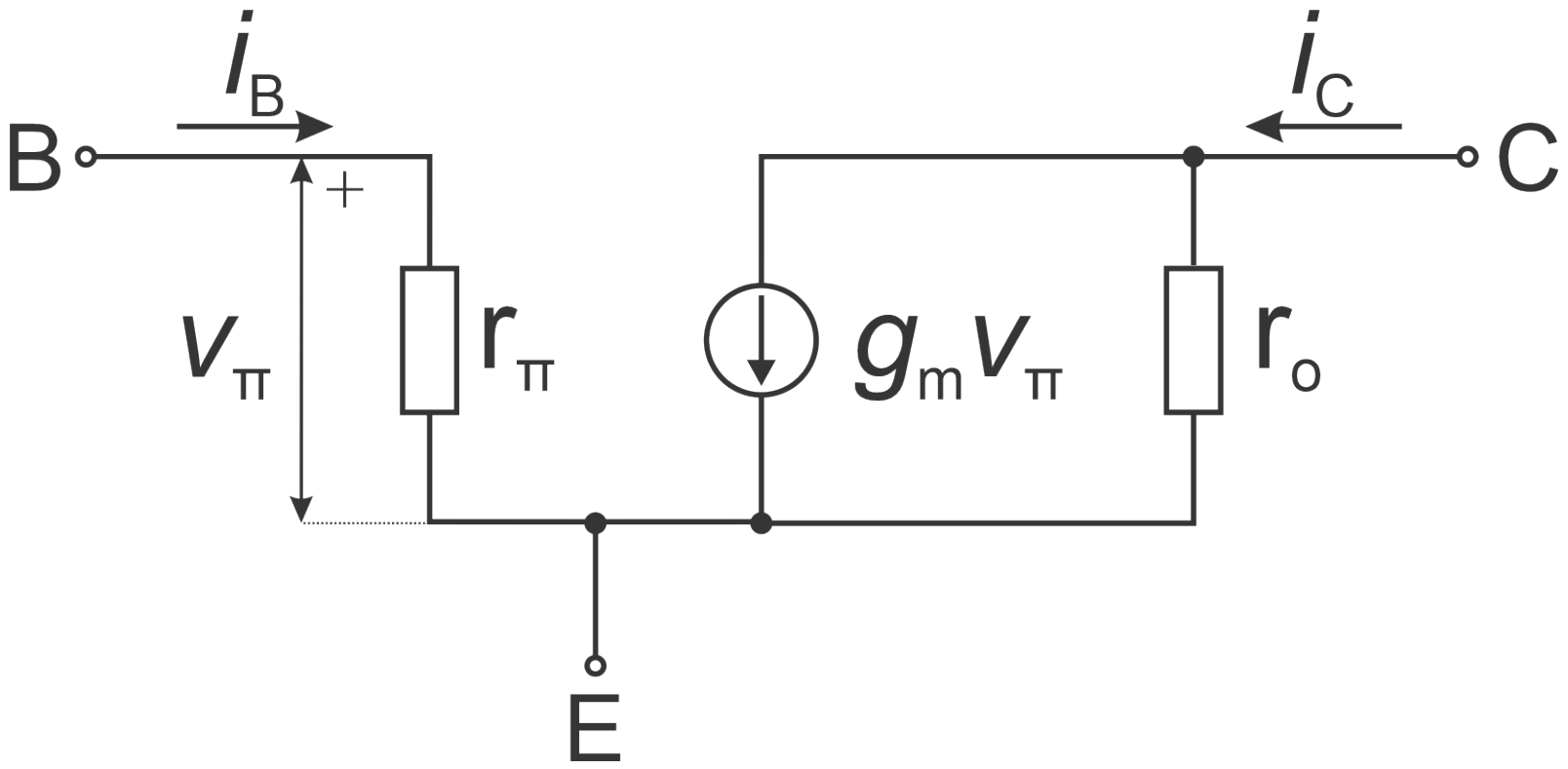
Parametri: β, V_{BE}



Model za male signale

Parametri: g_m, r_π, r_o

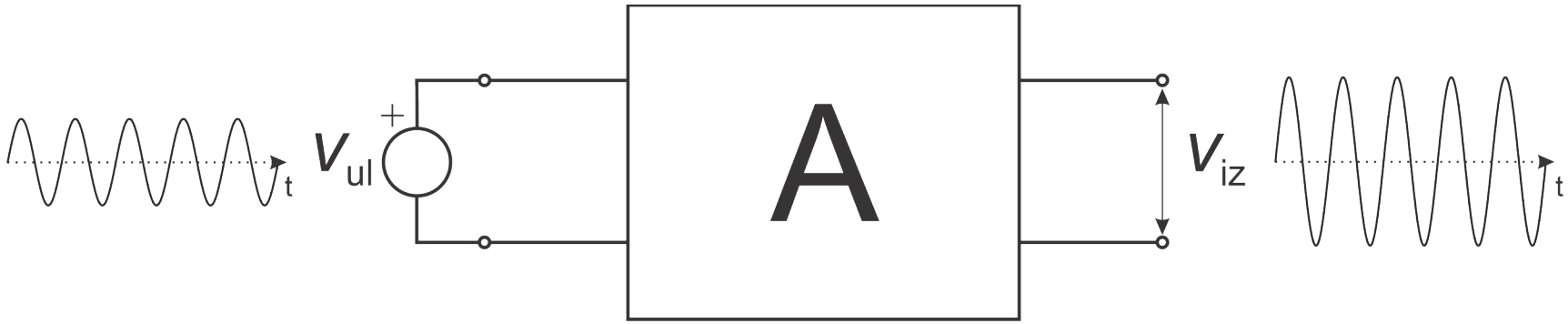
$$g_m = \frac{I_{C0}}{V_T}, \quad r_\pi = \frac{\beta \cdot V_T}{I_{C0}}, \quad r_o = \frac{V_A}{I_{C0}}$$



Pojačavač – analiza i sinteza

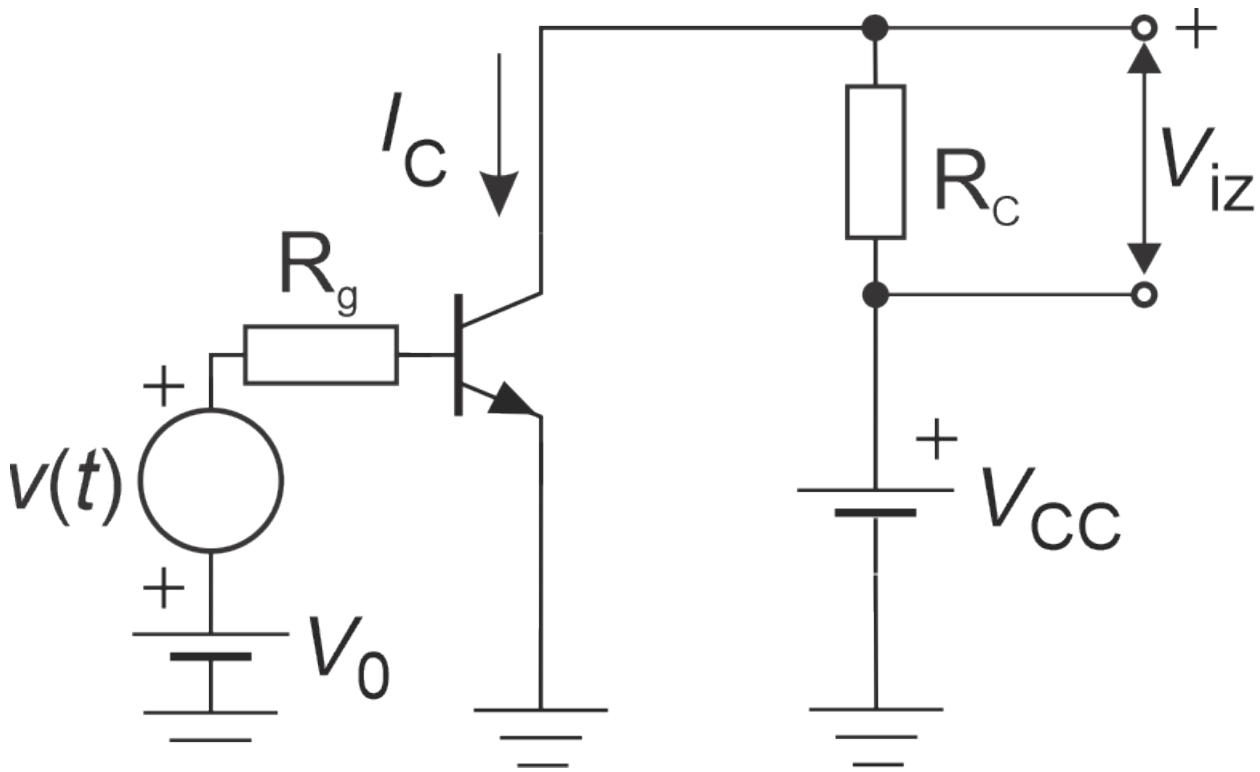
- Izbor topologije
- Obezbeđenje odgovarajuće polarizacija svih tranzistora u kolu
- Analiza ponašanja realizovanog kola za jednosmerni režim
- Analiza ponašanja realizovanog kola za male signale (pojačanje, amplitudska karakteristika, ulazna i izlazna impedansa)

Karakteristike pojačavača

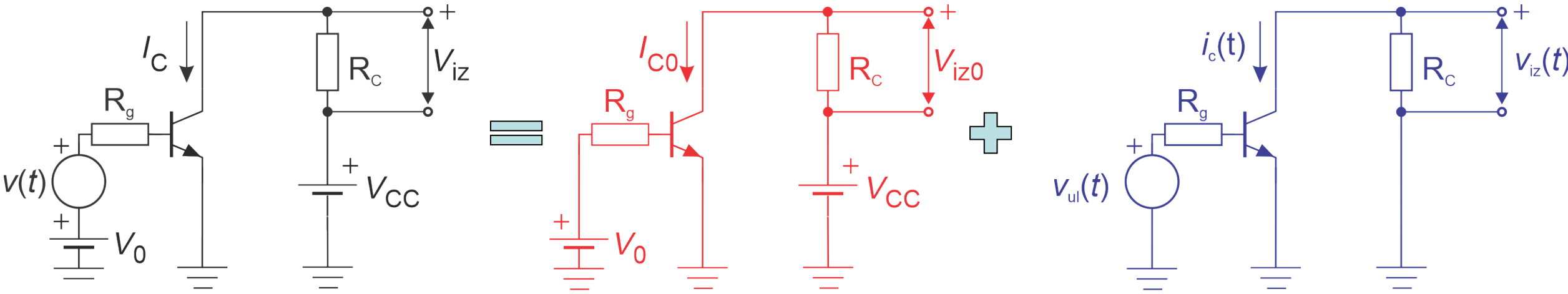


- Pojačanje A=v_{iz}/v_{ul}
- Potrošnja – polarizacija tranzistora zahteva energiju
- Ulazna i izlazna impedansa
- Zavisnost od temperature
- …

Pojačavač sa zajedničkim emitorom



Superpozicija – kola za velike i male signale

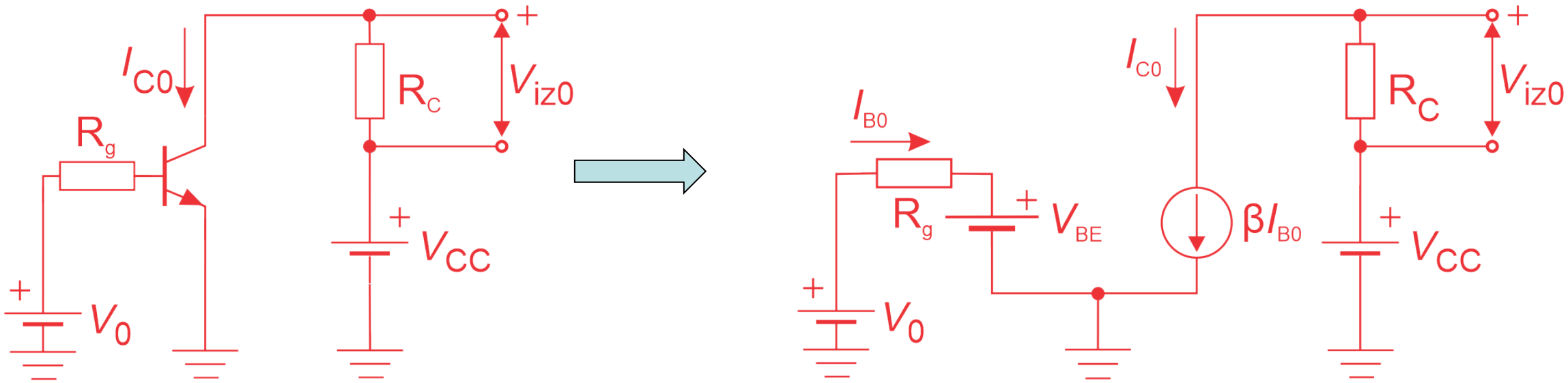


Veliki signali (polarizacija)

Signali malih amplituda

Jednosmerni režim (veliki signali)

- Pronalazi se se I_{C0}, izračunava g_m, r_π, r_o.

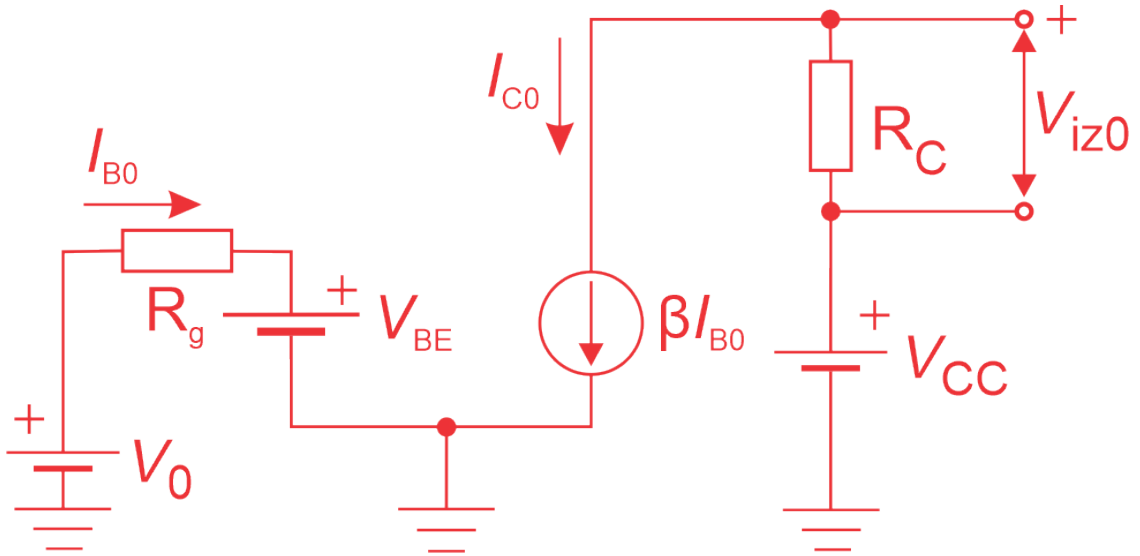


Jednosmerni režim (veliki signali)

- V_{BE}, β, V_A=∞

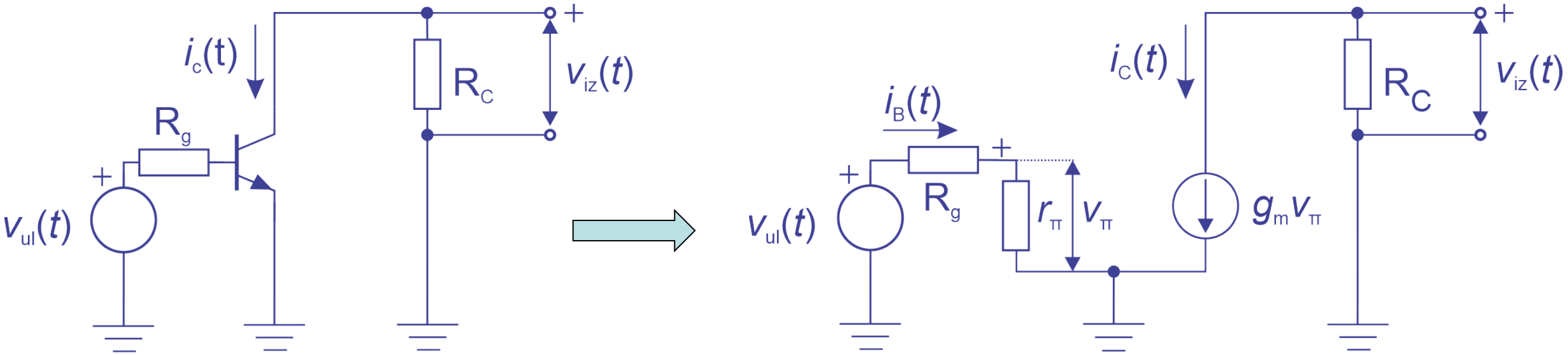
$$I_{B0} = \frac{V_0 - V_{BE}}{R_g}$$

$$I_{C0} = \beta \cdot I_{B0} = \beta \cdot \frac{V_0 - V_{BE}}{R_g}$$



Naizmenični režim (mali signali)

- g_m, r_π, $r_o=\infty$



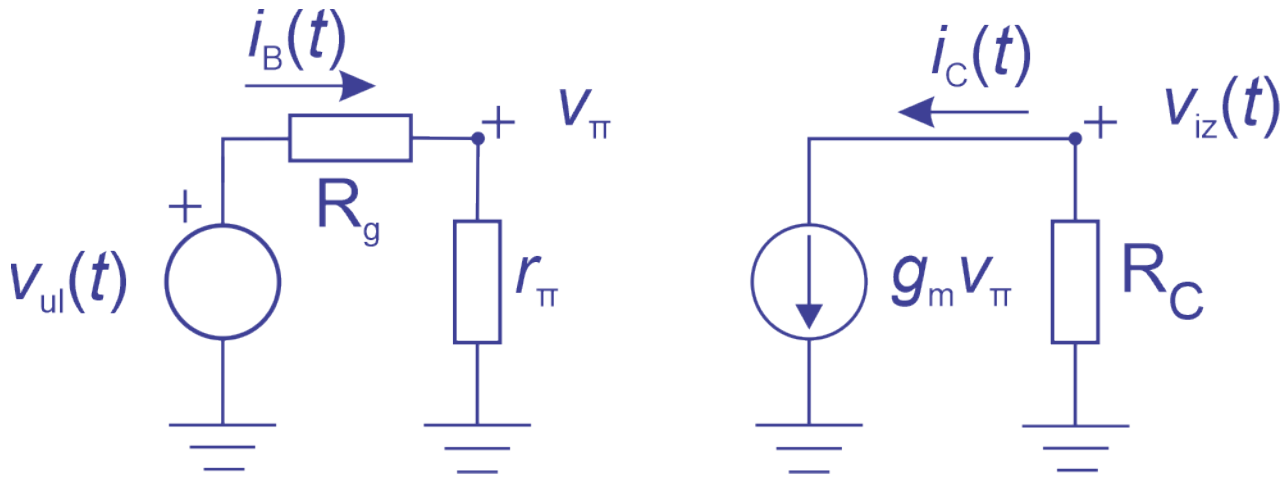
Naizmenični režim (mali signali)

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

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

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

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



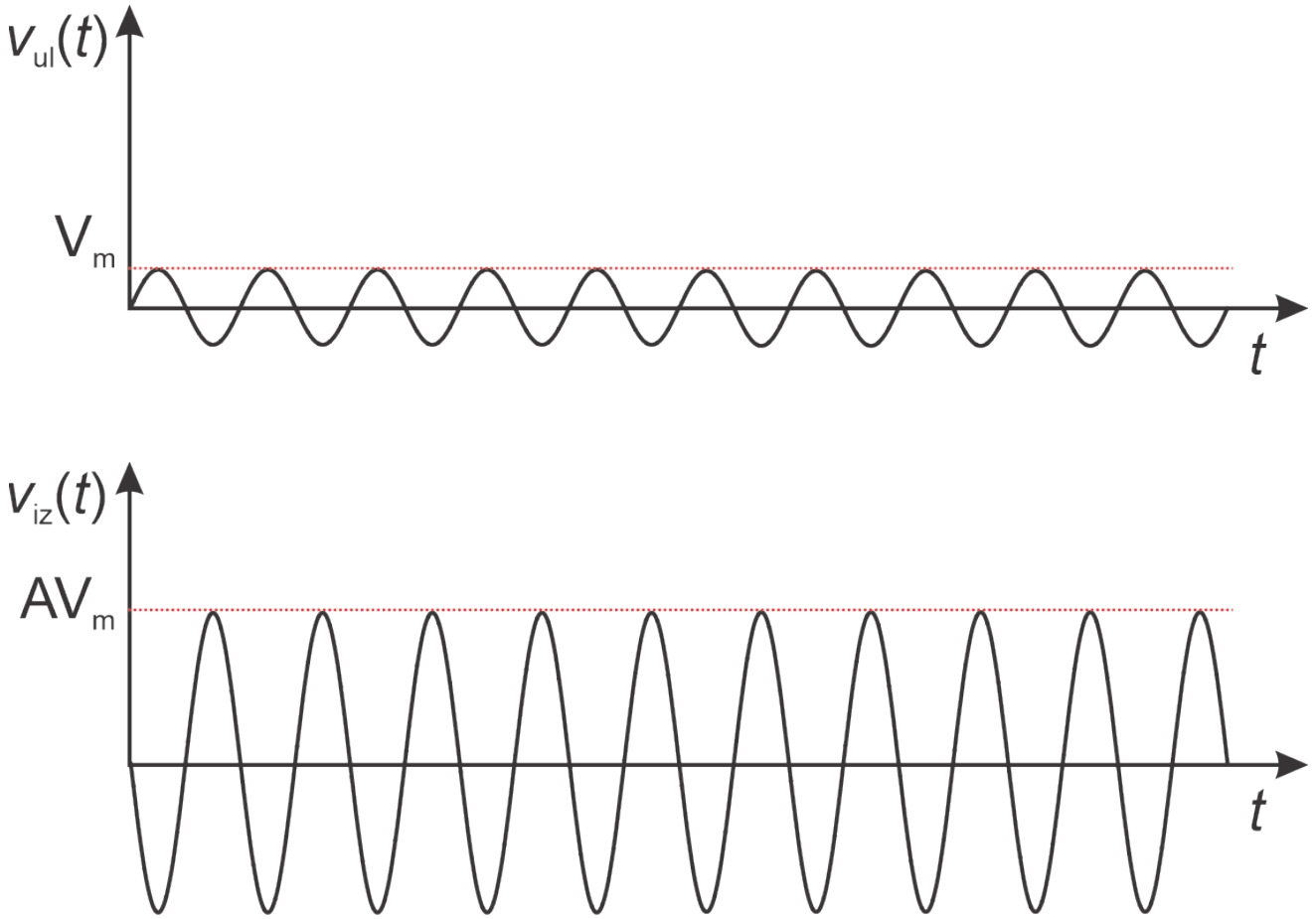
Pojačanje pojačavača

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

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

za $r_\pi \gg R_g$

$$A = -g_m \cdot R_C$$

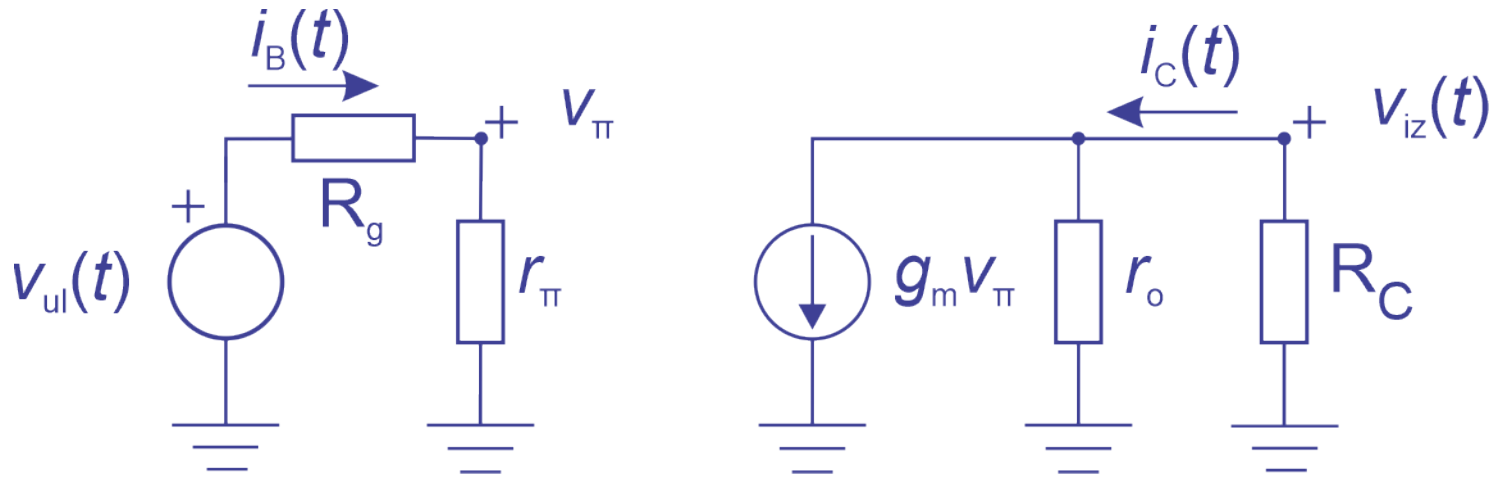


Uticaj Erlijevog efekta na pojačanje

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

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

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



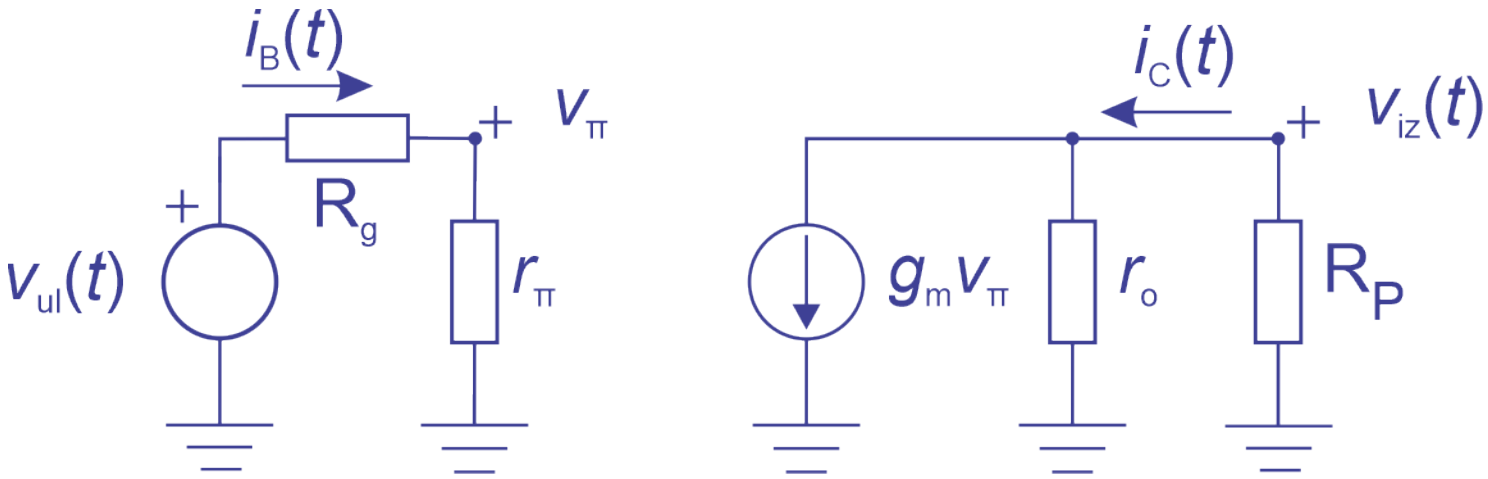
Uticaj Erlijevog efekta na pojačanje

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

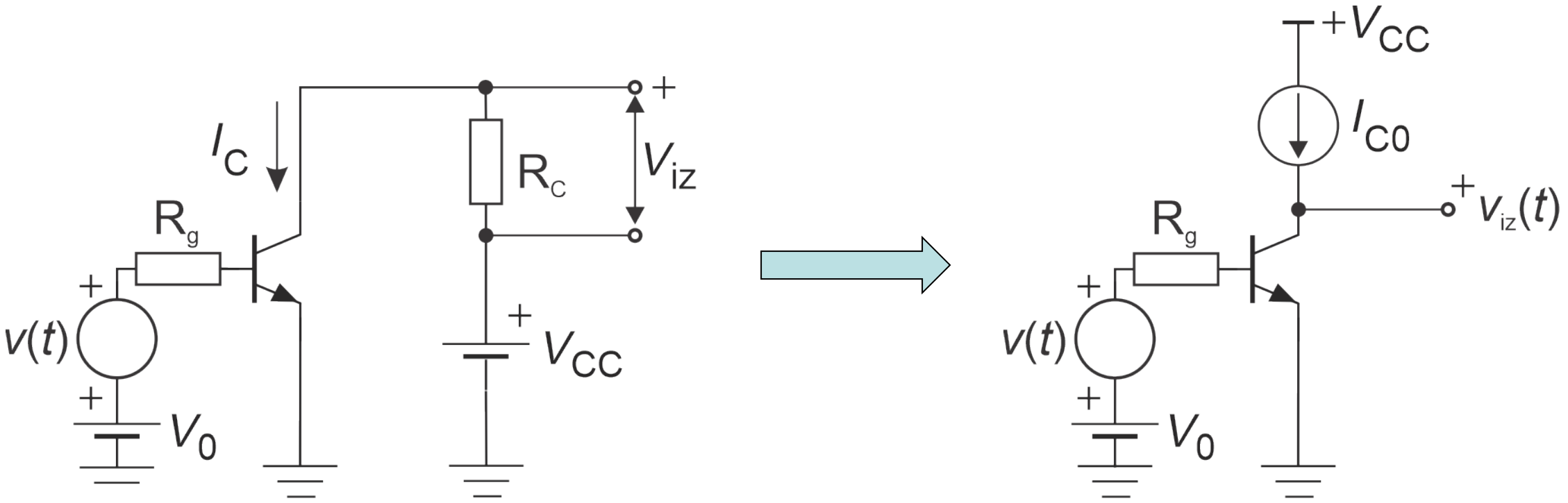
$$A = -g_{\text{m}} \cdot \left(R_{\text{C}} \parallel r_{\text{o}}\right) \cdot \frac{r_{\pi}}{r_{\pi} + R_{\text{g}}}$$

za $r_{\pi} \gg R_{\text{g}}$

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



Maksimalno pojačanje pojačavača

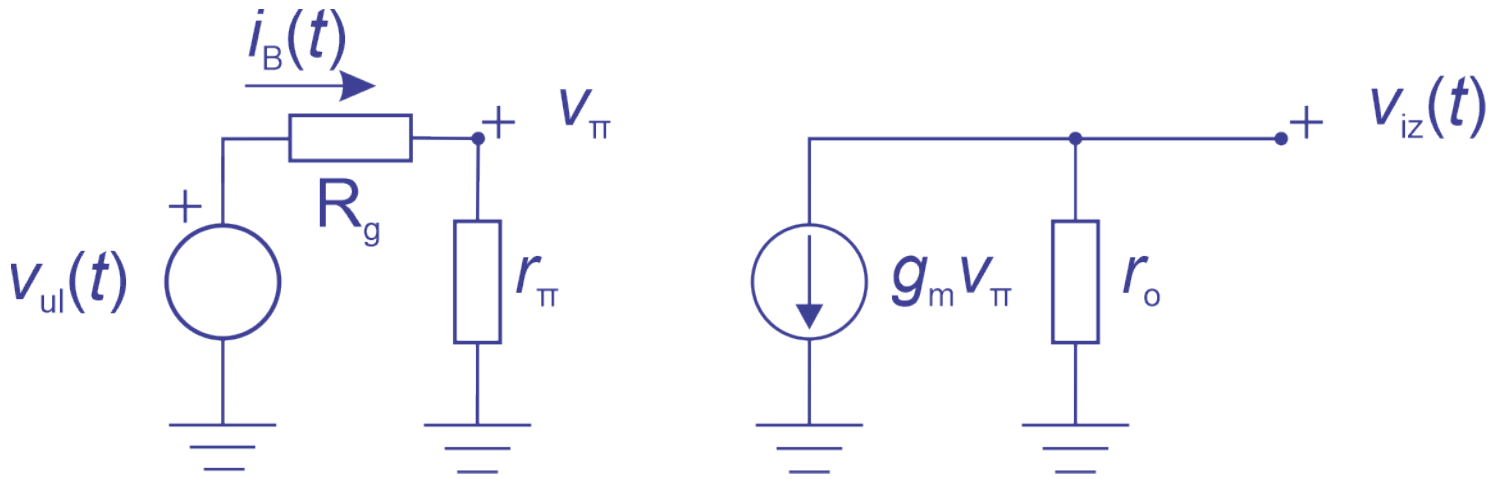


Maksimalno pojačanje pojačavača

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

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

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



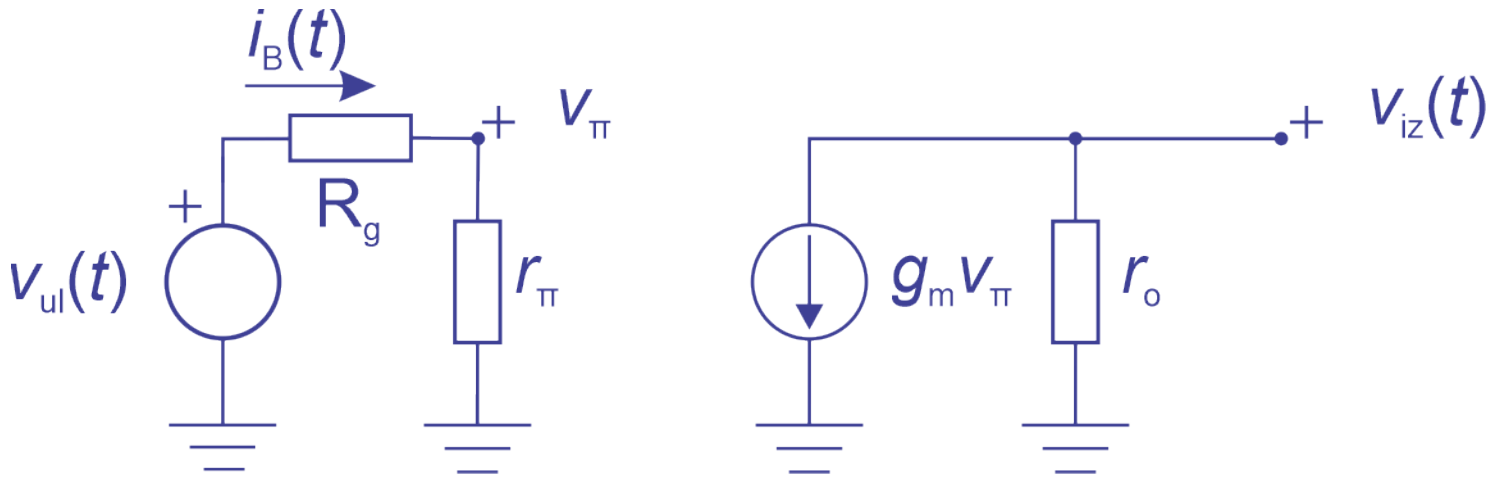
Maksimalno pojačanje pojačavača

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

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

za $r_\pi \gg R_g$

$$A = -g_m \cdot r_o$$

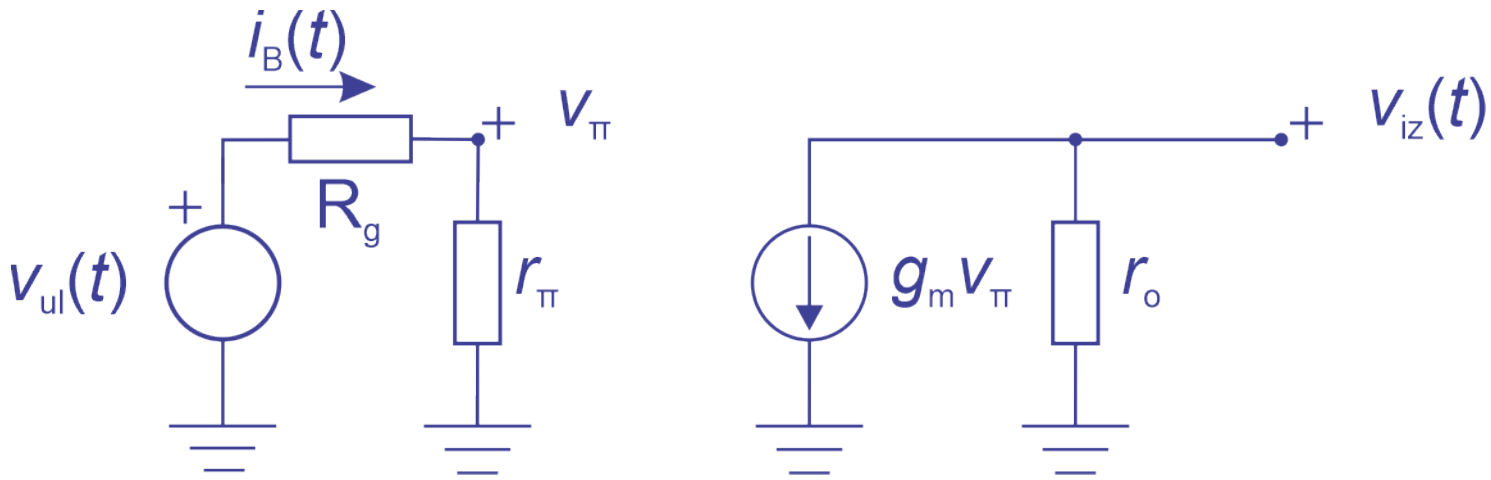


Intrisično (maksimalno) pojačanje

$$A = -g_m \cdot r_o$$

$$A = -\frac{I_{C0}}{V_T} \cdot \frac{V_A}{I_{C0}}$$

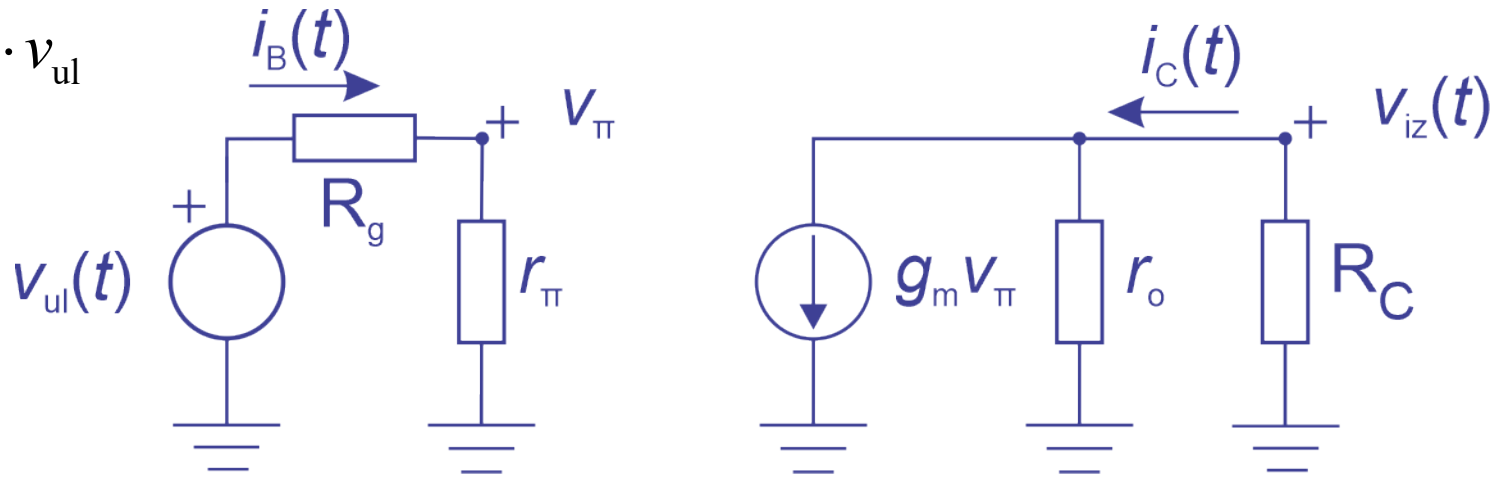
$$A = -\frac{V_A}{V_T}$$



Ulazna impedansa

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

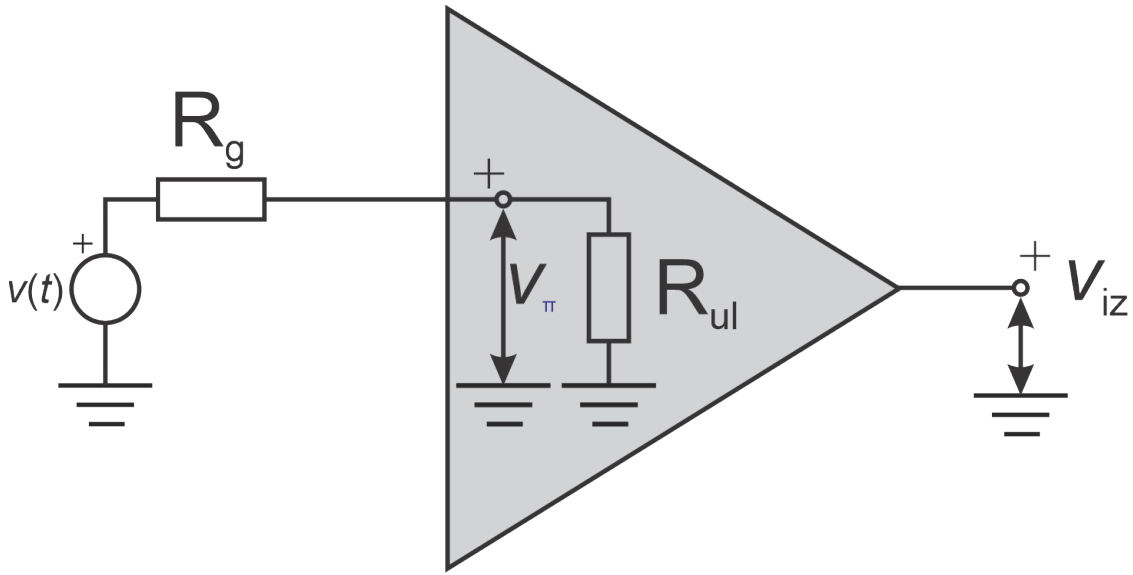
$$v_{iz} = -g_m \cdot \left(R_C \parallel r_o\right) \cdot \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$



Ulazna impedansa

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

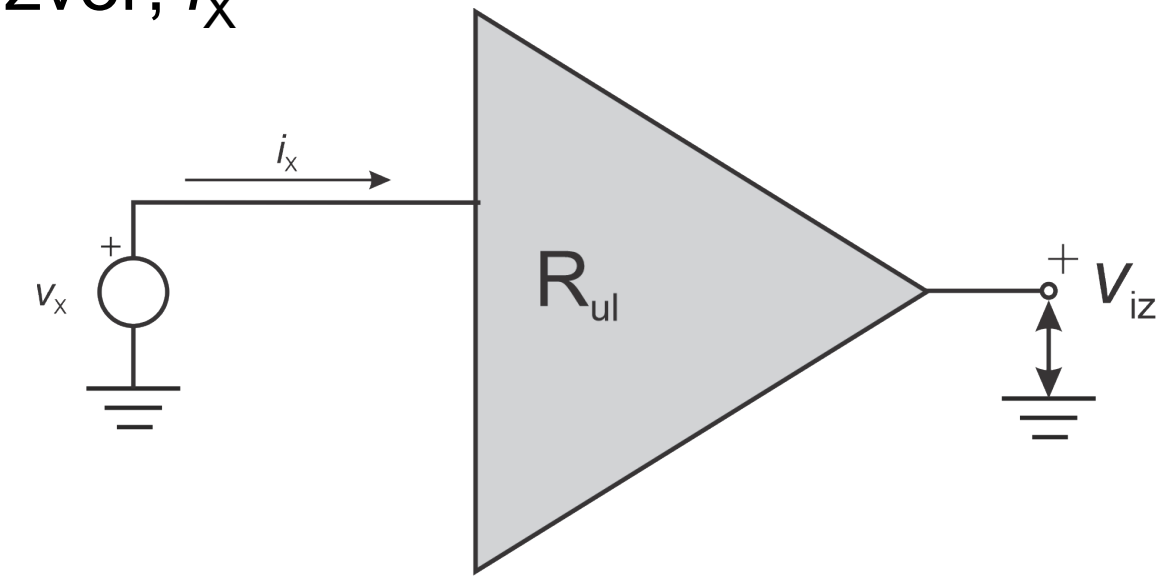
$$v_{iz} = -g_m \cdot \left(R_C \parallel r_o\right) \cdot \frac{r_\pi}{r_\pi + R_g} \cdot v_{ul}$$



Ulazna impedansa

- 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

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

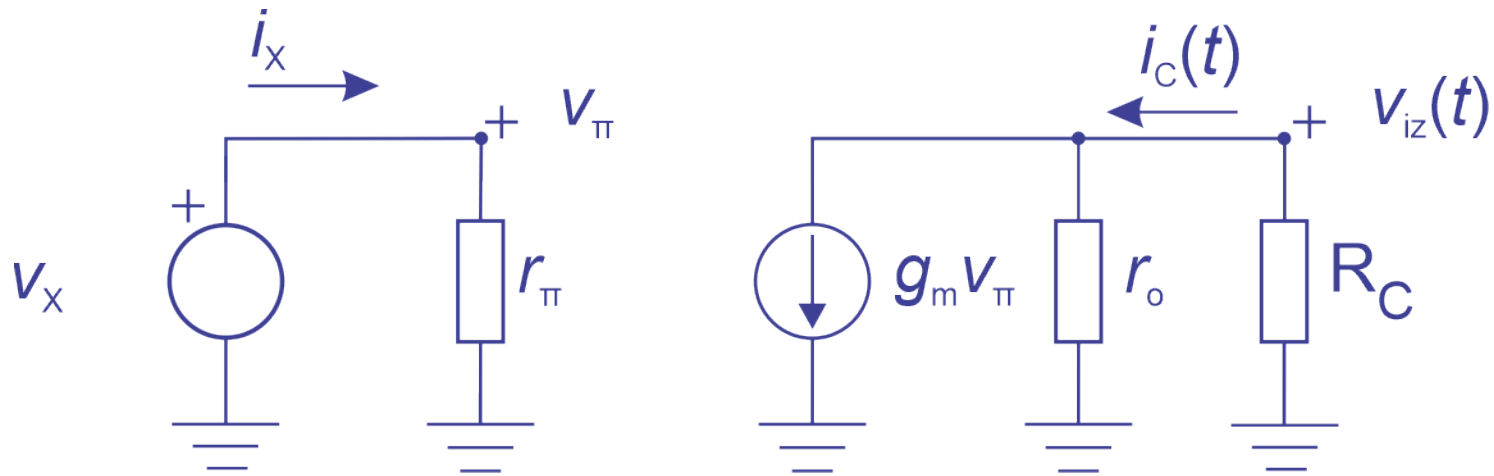


Ulazna impedansa

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

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

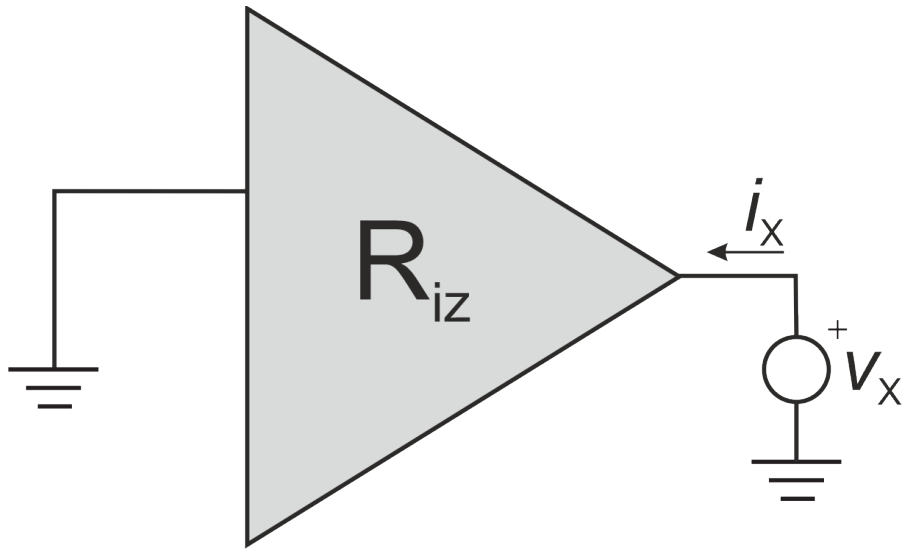
$$R_{ul} = r_\pi$$



Izlazna impedansa

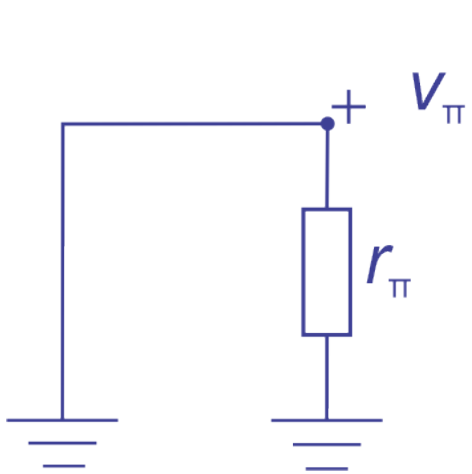
- Kratkospojiti sve nezavisne naponske generatore
- Odvezati sve nezavisne strujne generatore
- Odrediti ekvivalentnu Tevenenovu otpornost kola

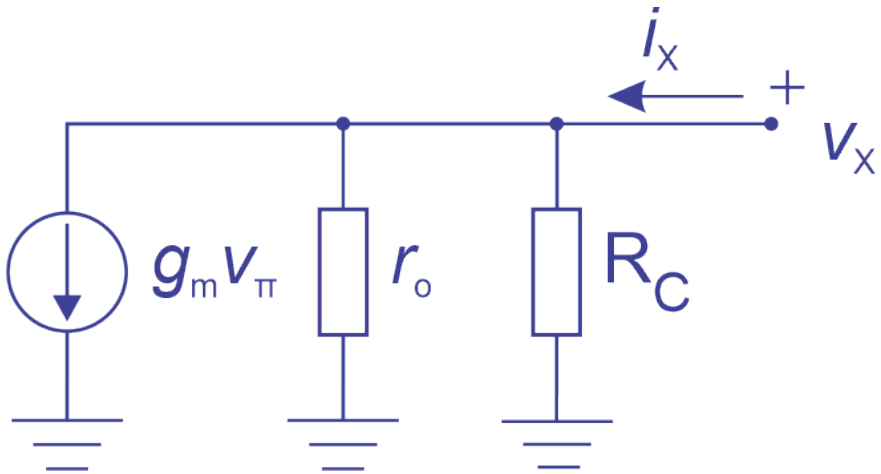
$$R_{iz} = \frac{v_X}{i_X}$$



Izlazna impedansa

$$v_\pi = 0$$

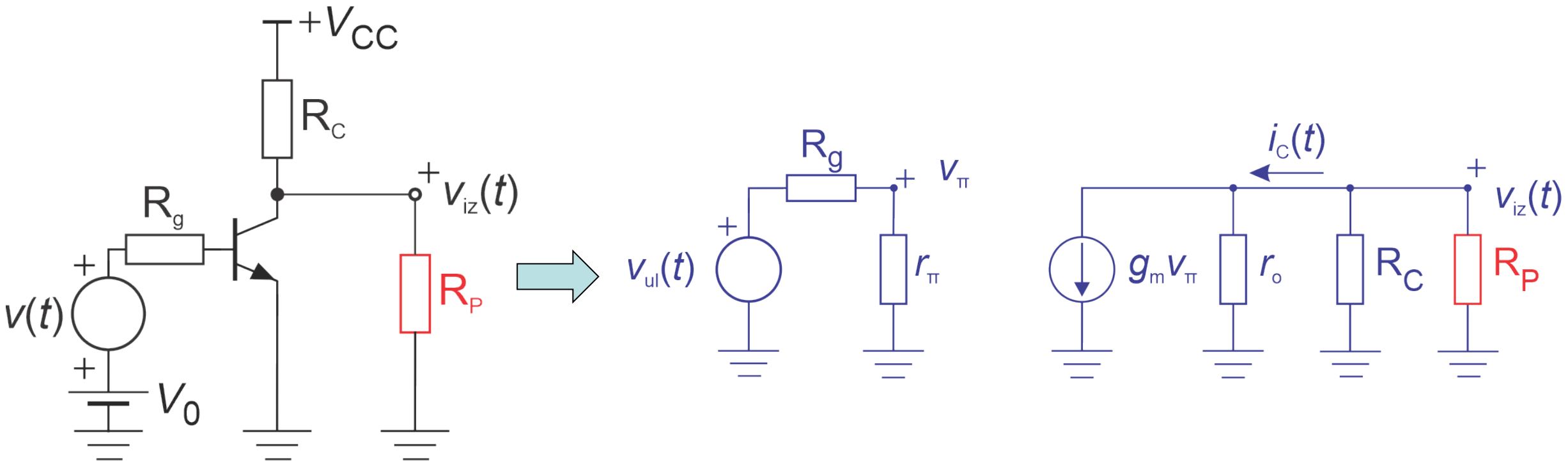




$$v_X = i_X \cdot r_o \parallel R_C$$

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

Uticaj otpornosti potrošača

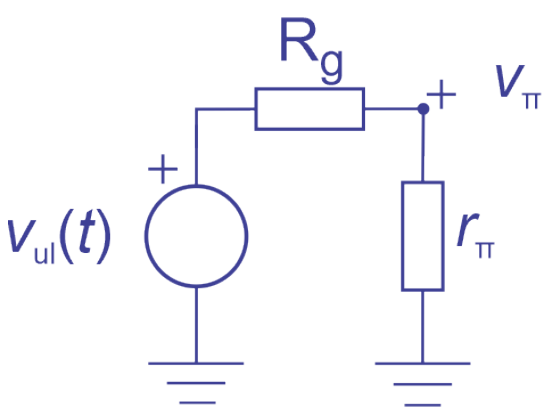


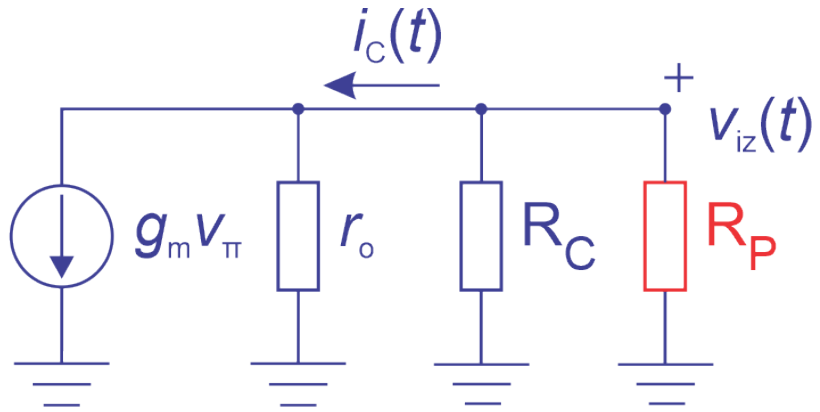
Uticaj otpornosti potrošača

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

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

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





za $r_\pi \gg R_g$

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

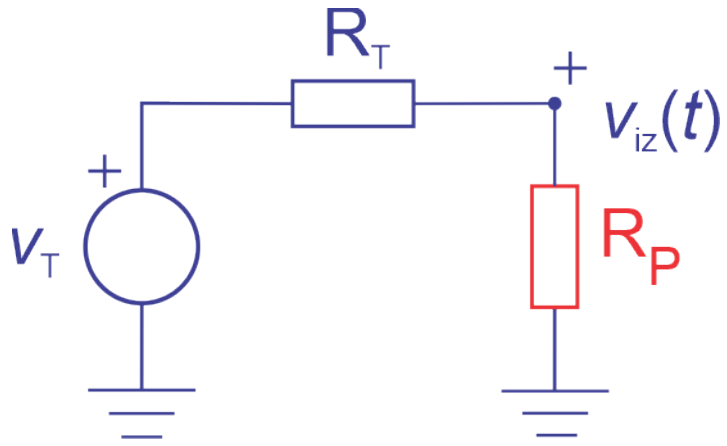
Uticaj otpornosti potrošača

$$v_T = -g_m \cdot v_\pi \cdot \left(R_C \parallel r_o\right) \qquad R_T = R_C \parallel r_o$$

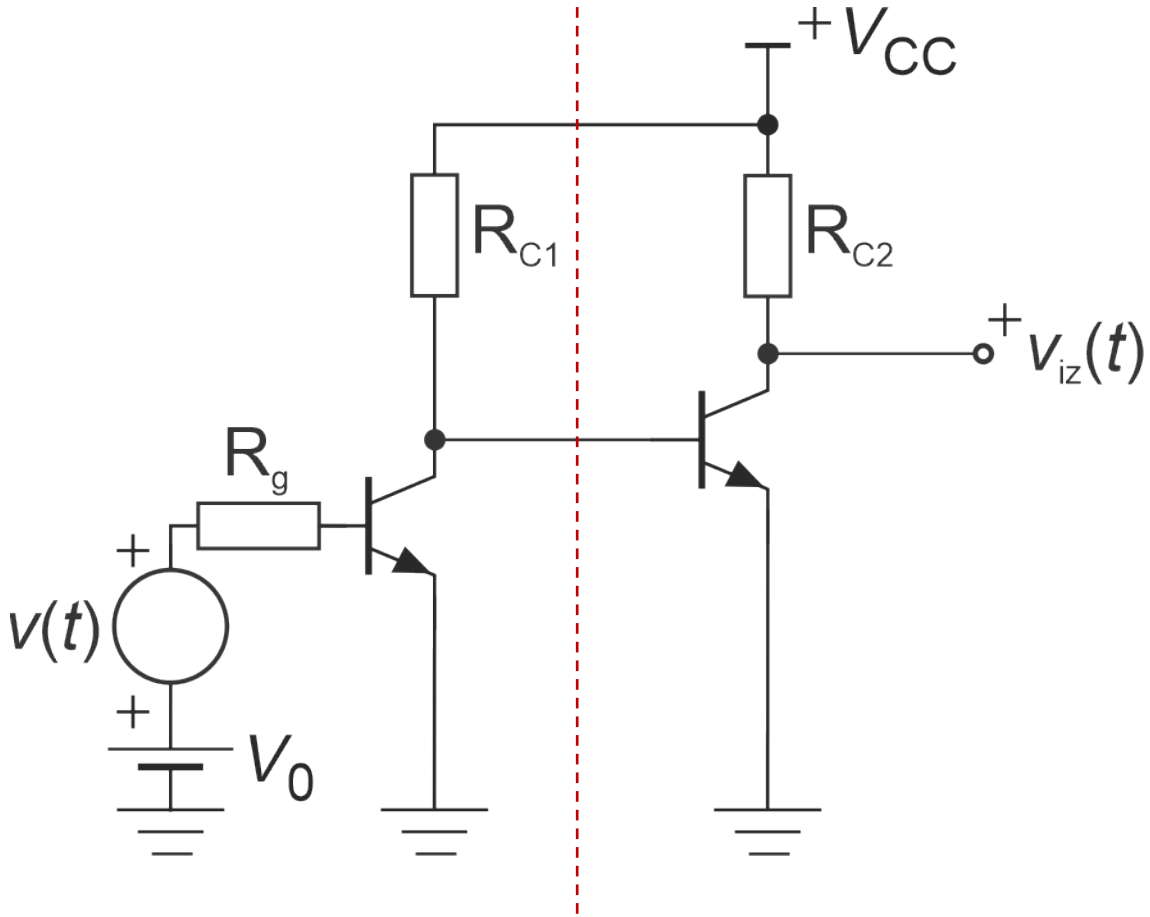
$$v_{iz} = \frac{R_P}{R_T + R_P} \cdot v_T$$

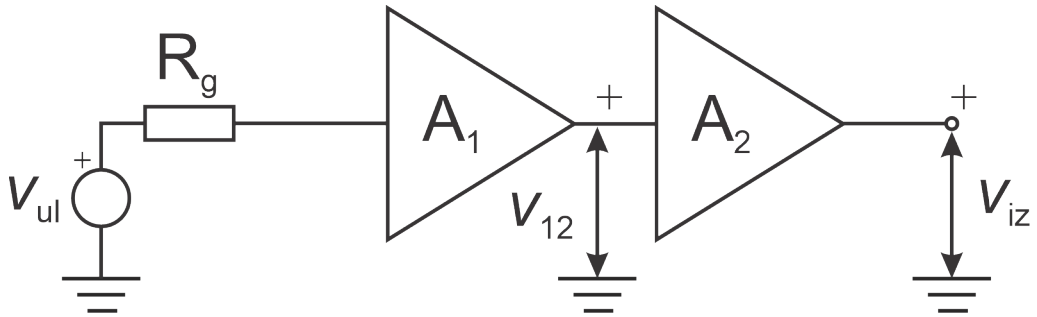
$$v_{iz} = -g_m \cdot v_\pi \cdot \frac{R_P R_C r_o}{R_C r_o + R_C R_P + r_o R_P}$$

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



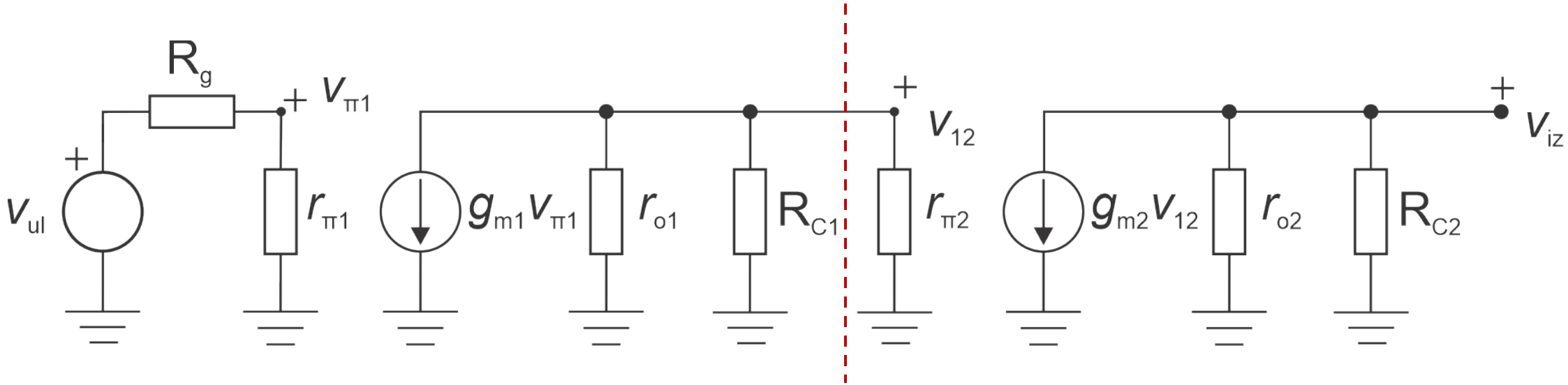
Kaskadna veza pojačavača





$A=A_1A_2$?

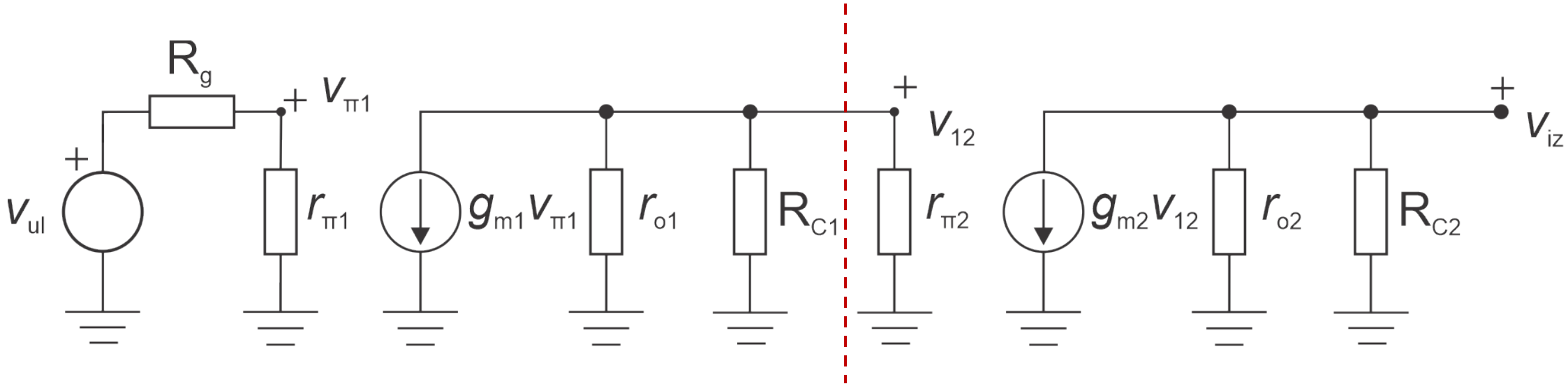
Kaskadna veza pojačavača



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

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

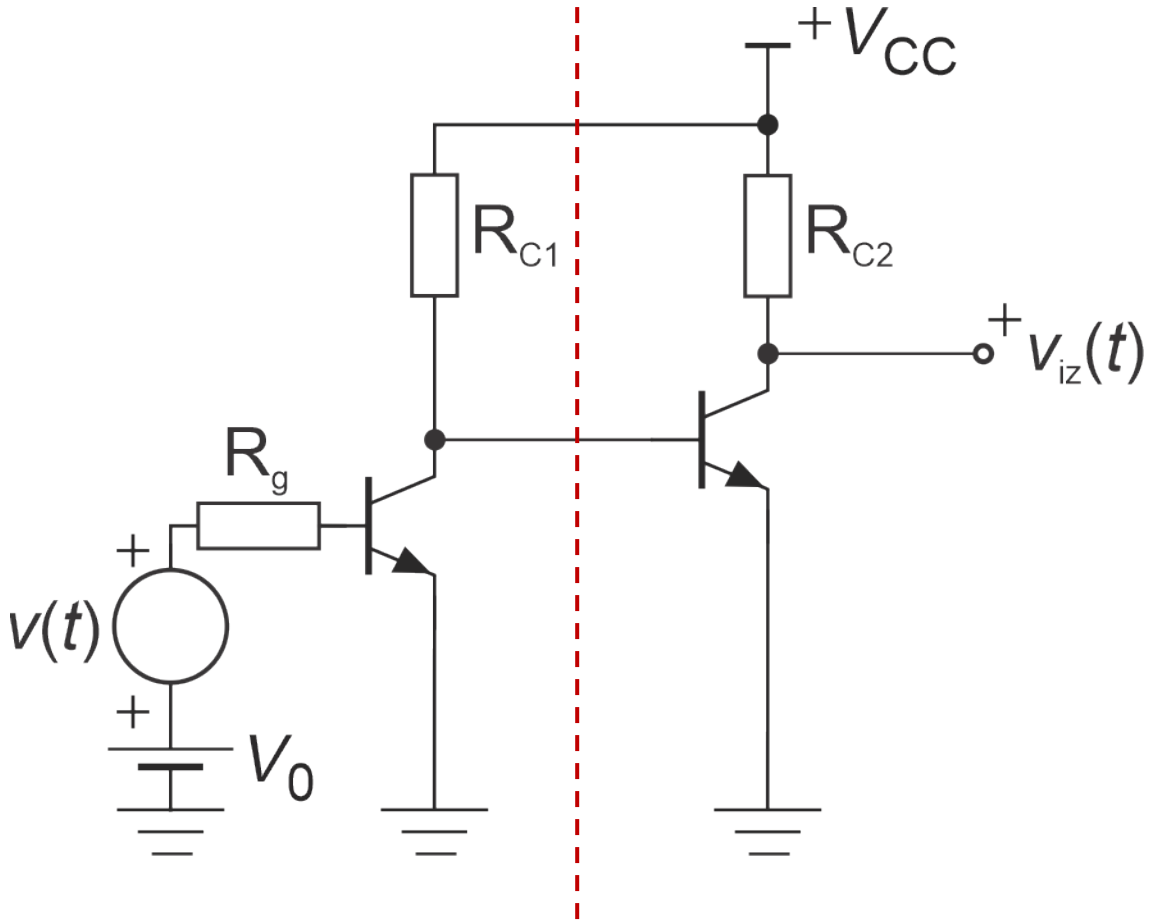
Kaskadna veza pojačavača

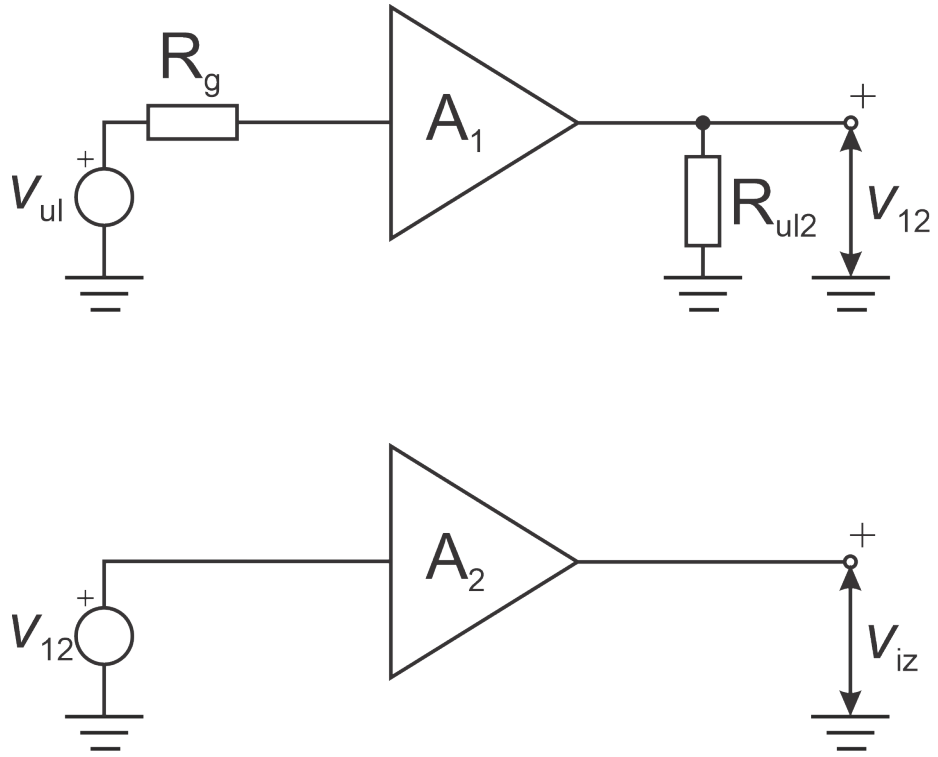


$$A_1 = -g_{m1} \cdot \left(r_{o1} \parallel R_{C1} \parallel r_{\pi 2} \right) \cdot \frac{r_\pi}{r_\pi + R_g}$$

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

Kaskadna veza pojačavača





Temperaturna zavisnost pojačavača

- Varijacija pojačanja usled promene temperature:

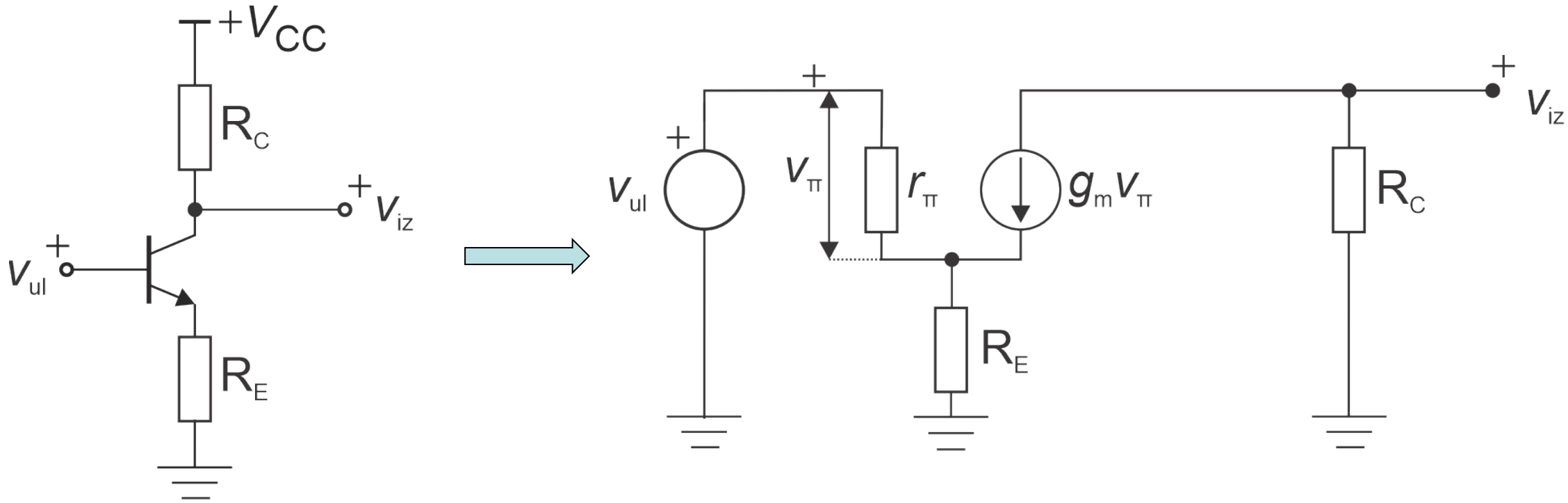
$$A = -g_{\mathrm{m}} \cdot \left(r_{\mathrm{o}} \parallel R_{\mathrm{C}} \right)$$

$$g_{\mathrm{m}} = \frac{I_{\mathrm{C0}}}{V_{\mathrm{T}}}, \quad I_{\mathrm{C0}} = I_{\mathrm{S}} \exp\left(\frac{V_{\mathrm{BE}}}{V_{\mathrm{T}}} \right), \quad V_{\mathrm{T}} = \frac{\mathrm{k}T}{\mathrm{q_e}}$$

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

Degenerisani emitor

- Otpornik u grani emitora (r_o=∞)

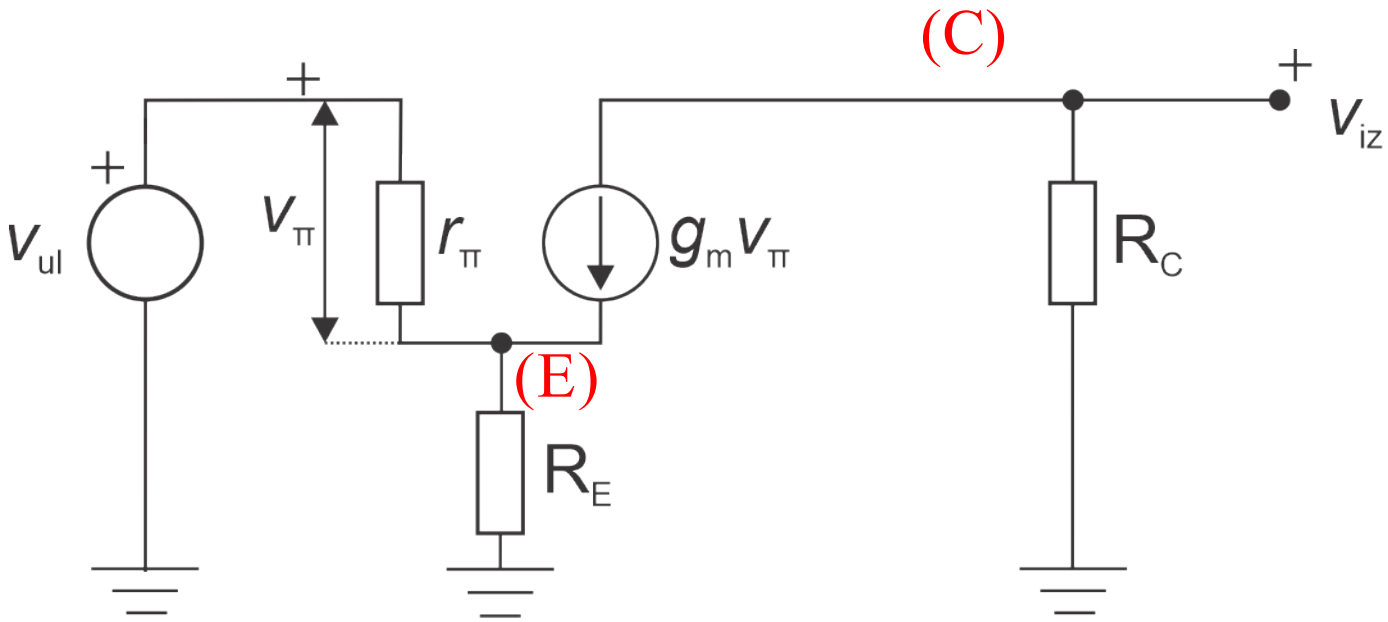


Degenerisani emitor – pojačanje

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

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

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

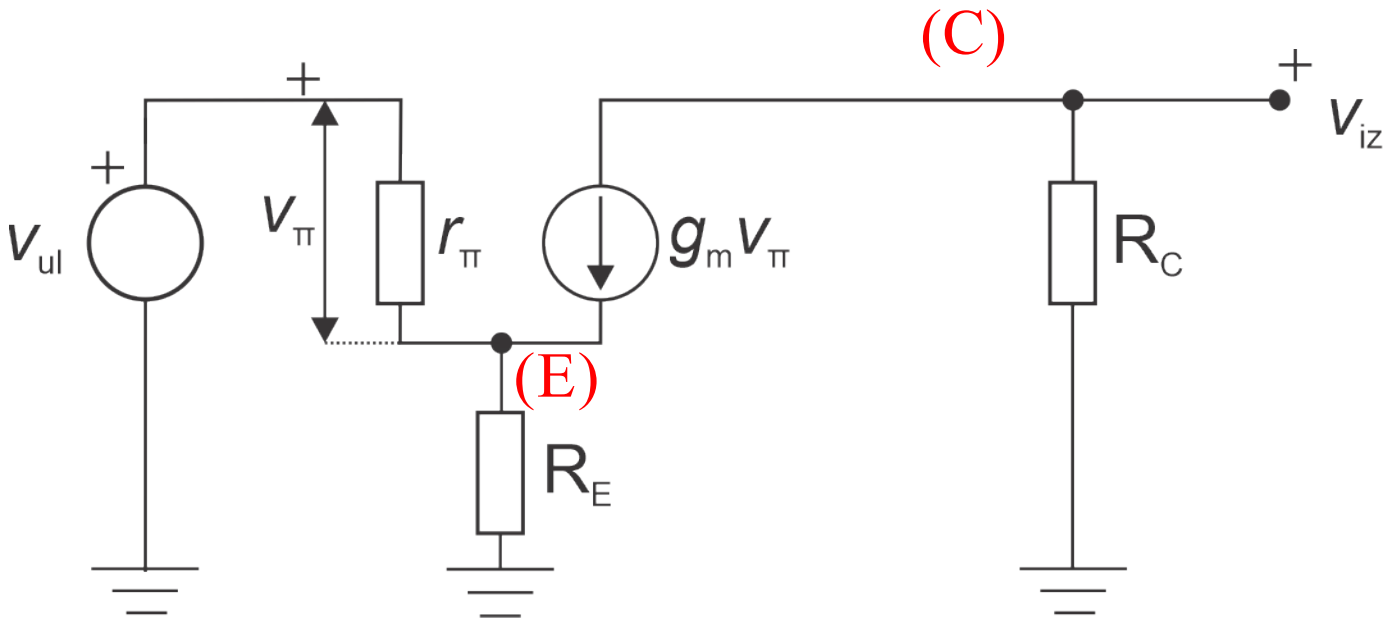


Degenerisani emitor – pojačanje

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

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

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



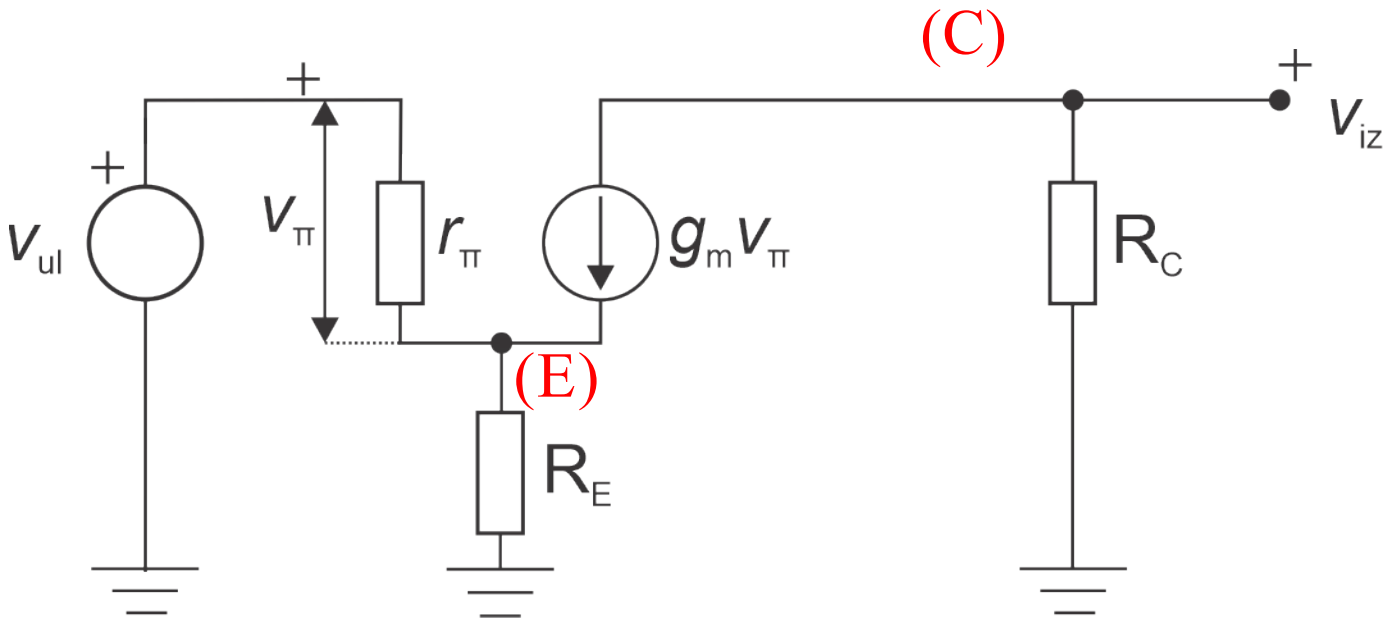
Degenerisani emitor – pojačanje

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

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

$$A = -\frac{\beta g_m R_C}{R_E g_m(1+\beta)+\beta}$$

$$A \approx -\frac{g_m R_C}{1+g_m R_E}$$

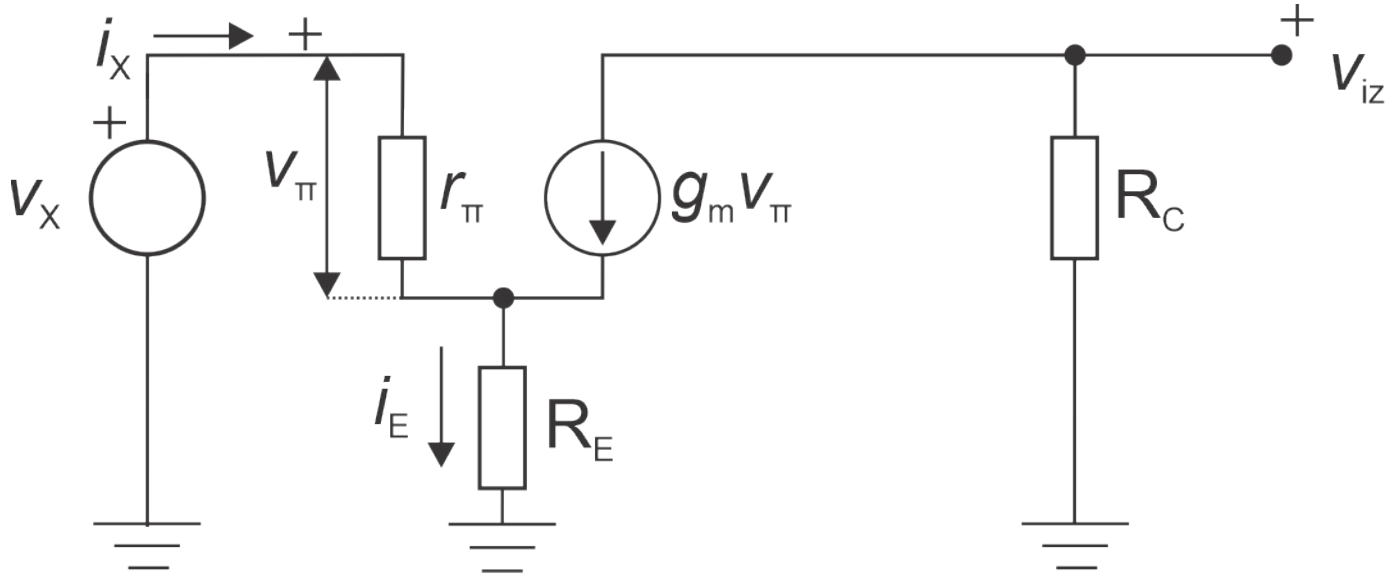


Degenerisani emitor – ulazna impedansa

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

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

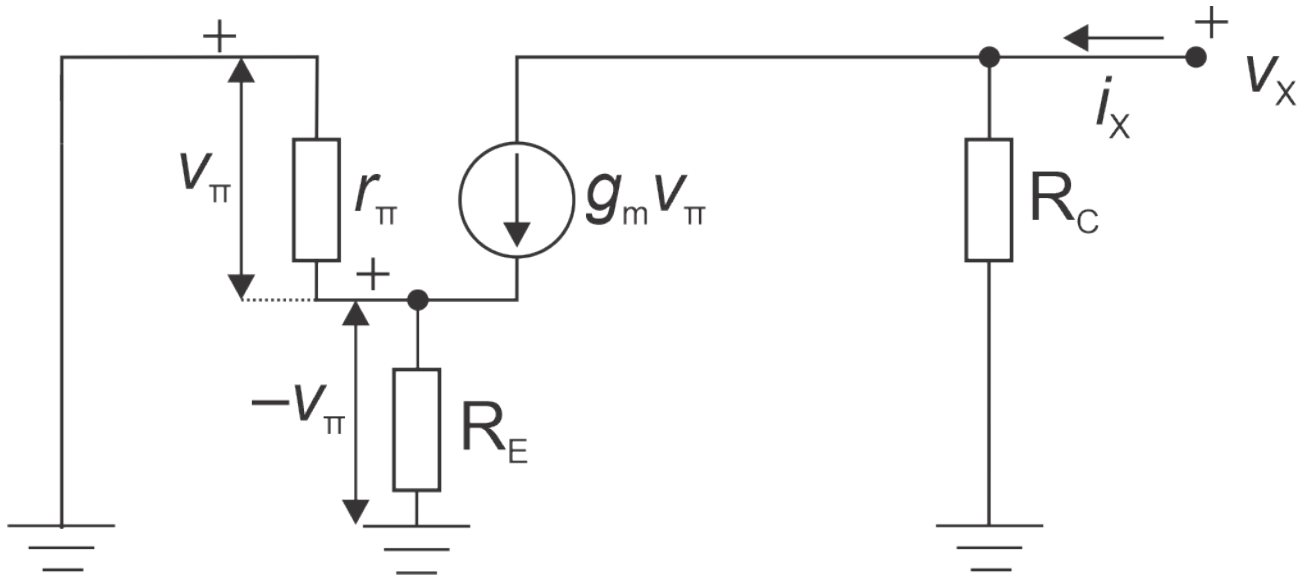
$$R_{ul} = \frac{v_X}{i_X} = (\beta + 1) R_E + r_\pi$$



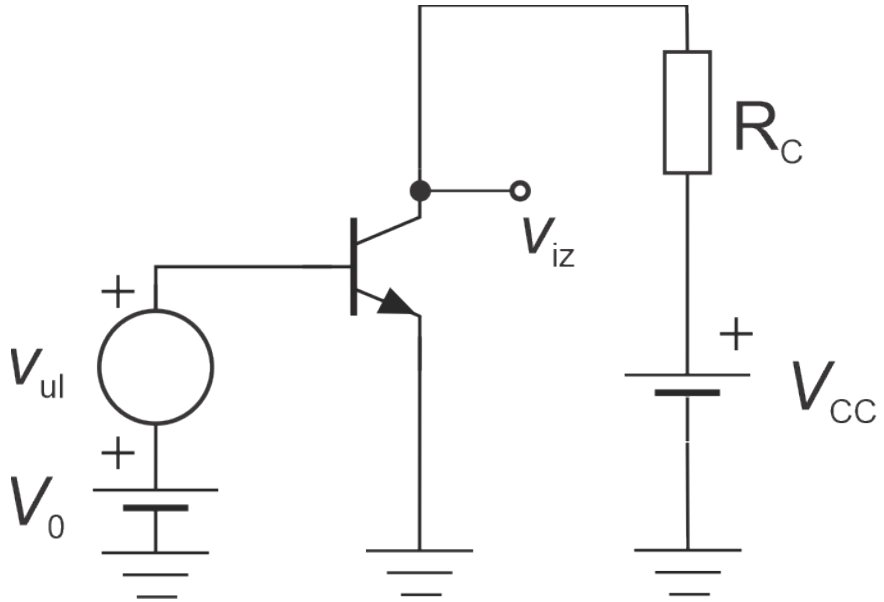
Degenerisani emitor – izlazna impedansa

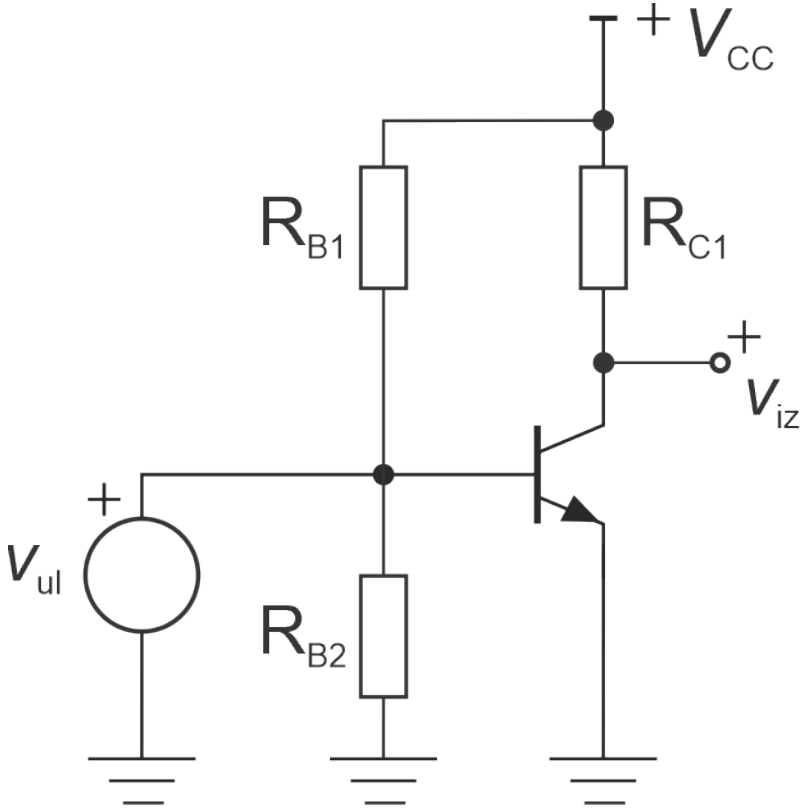
$$\frac{v_\pi}{r_\pi} + g_\mathrm{m} v_\pi = -R_\mathrm{E} v_\pi \Rightarrow v_\pi = 0$$

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



Kola za polarizaciju



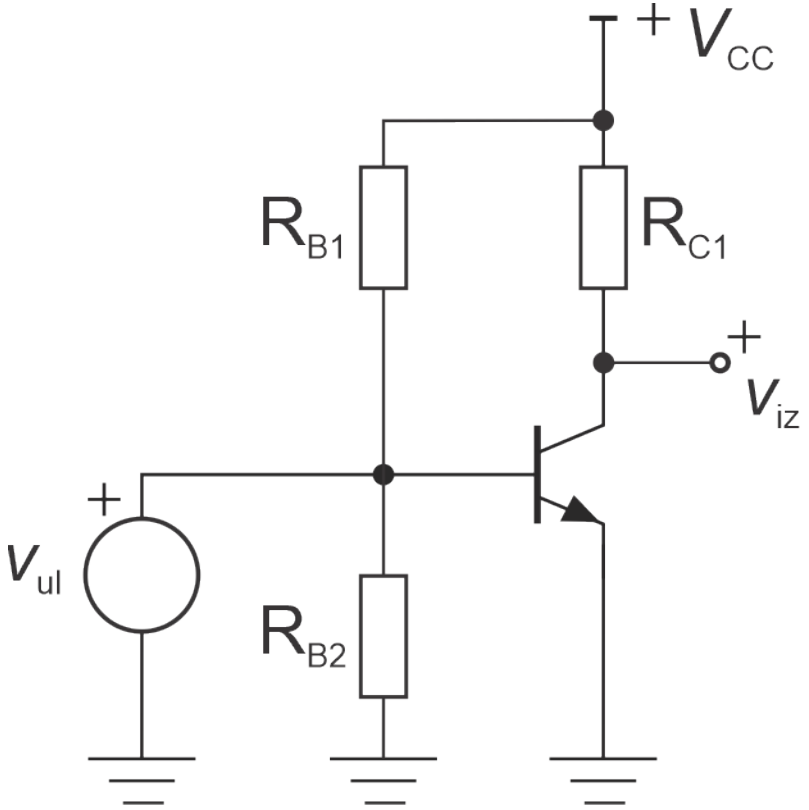


Kola za polarizaciju

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

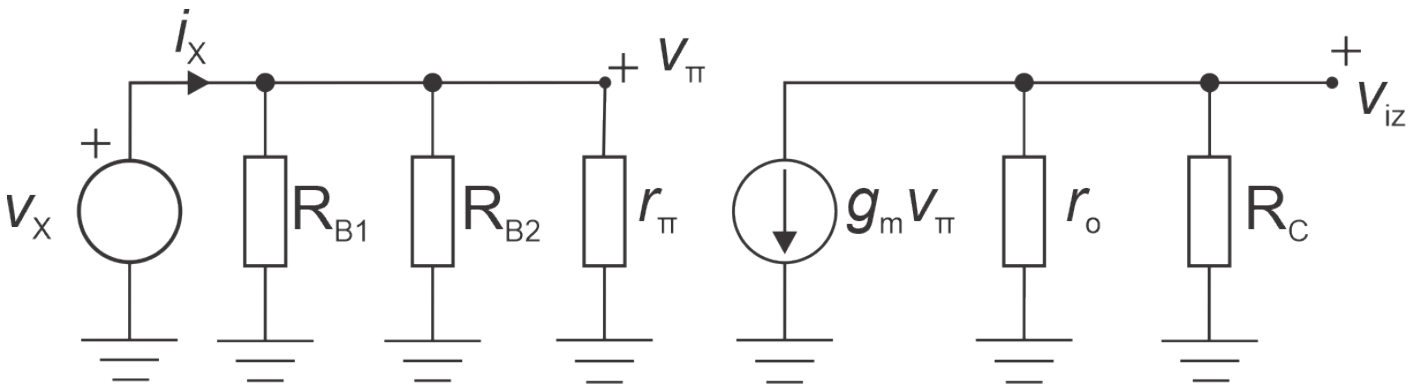
$$I_{B2} = \frac{V_{BE}}{R_{B2}}$$

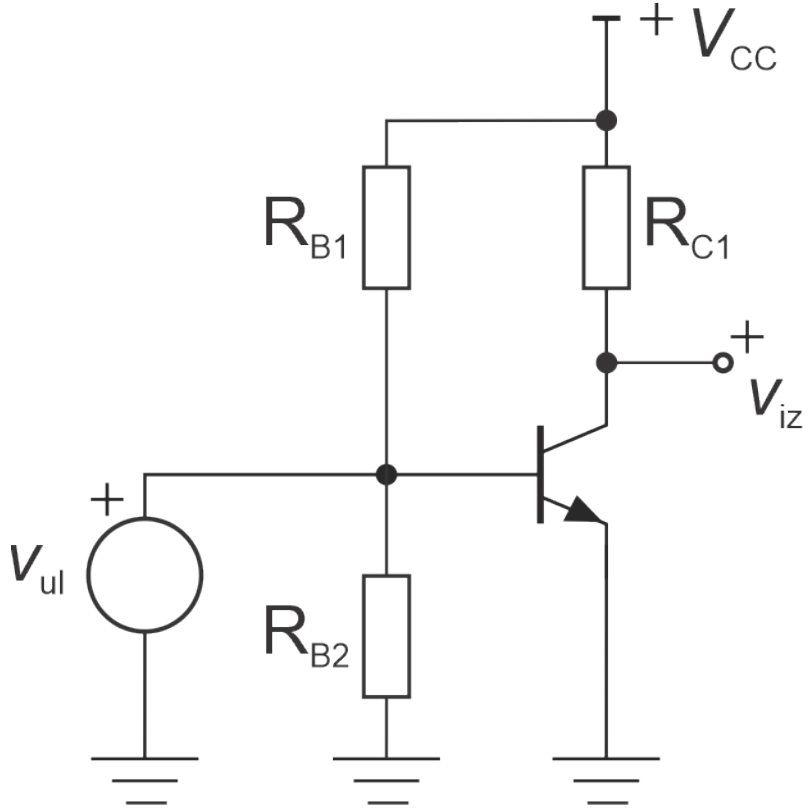
$$I_B = I_{B1} - I_{B2}$$



Kola za polarizaciju

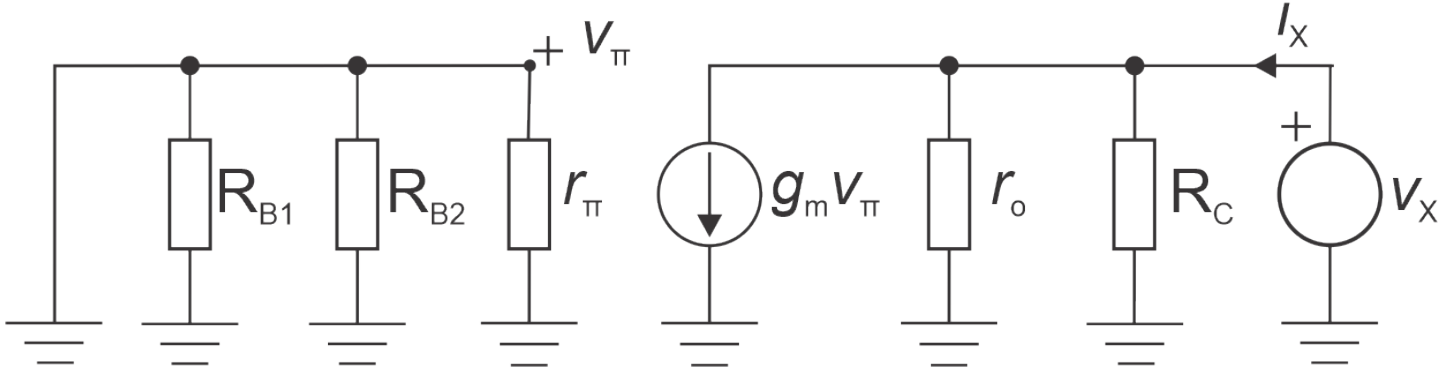
$$R_{ul} = R_{B1} \parallel R_{B2} \parallel r_{\pi}$$

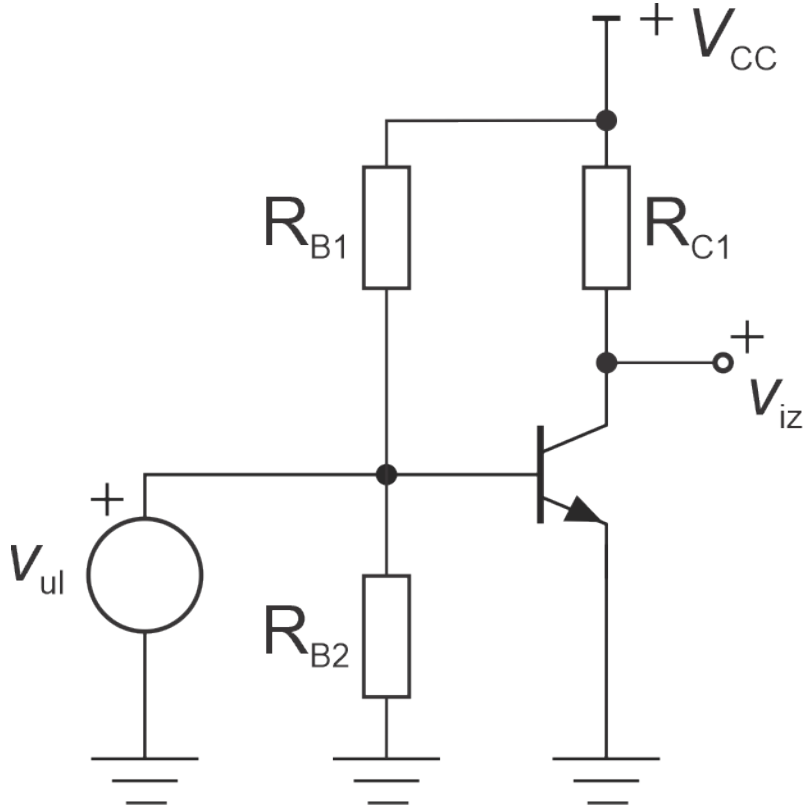




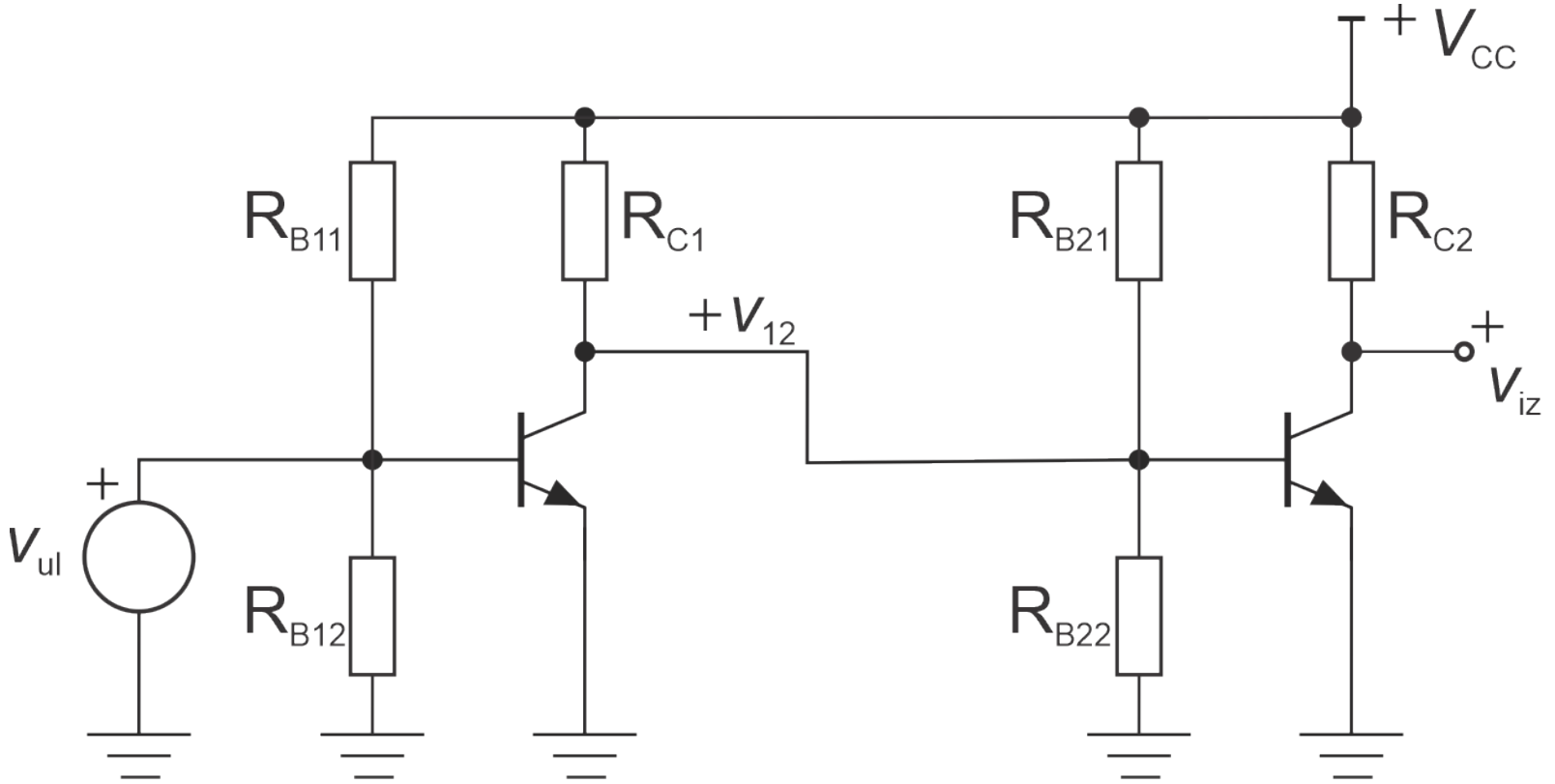
Kola za polarizaciju

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



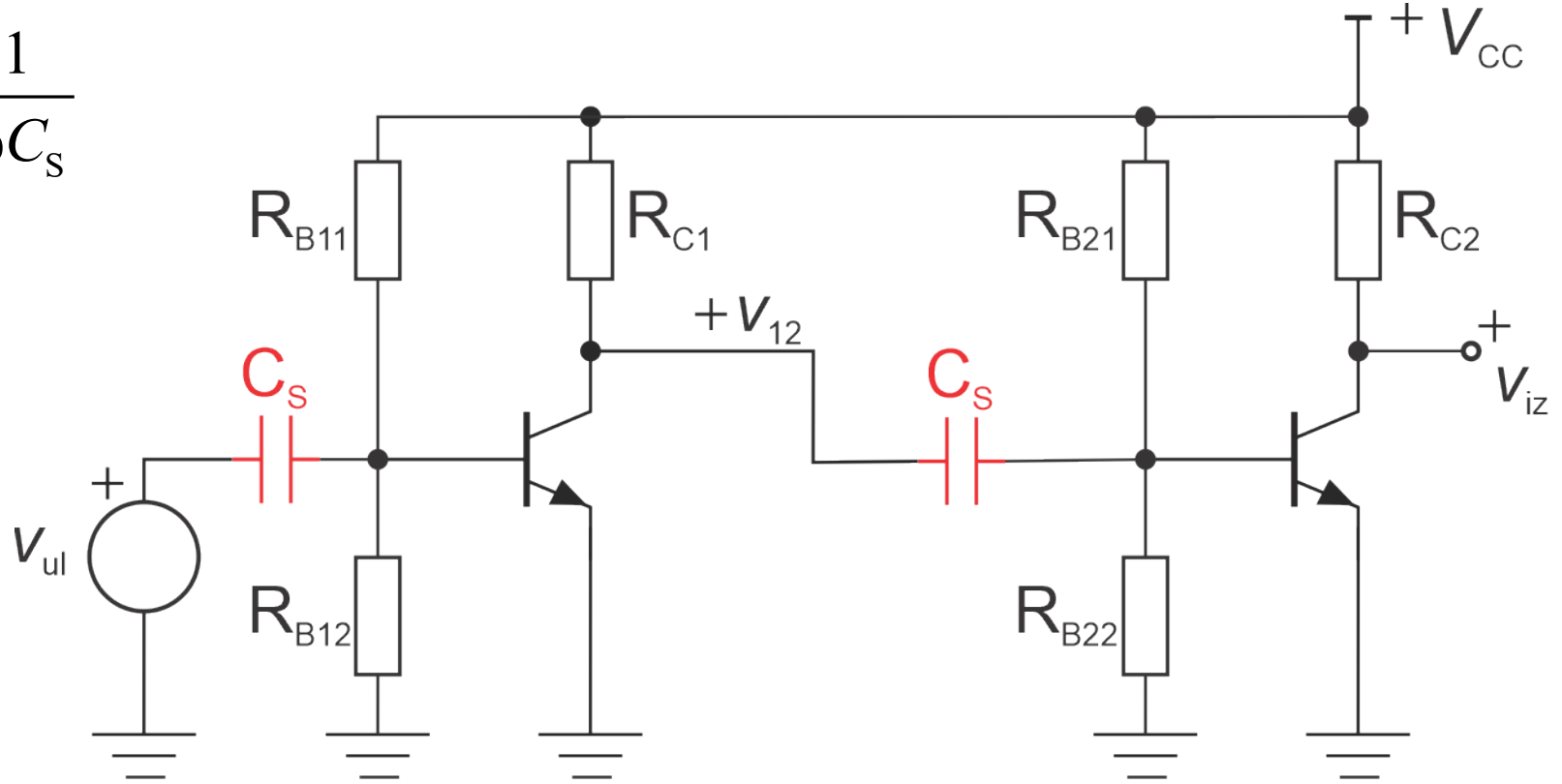


Kola za polarizaciju



Kola za polarizaciju

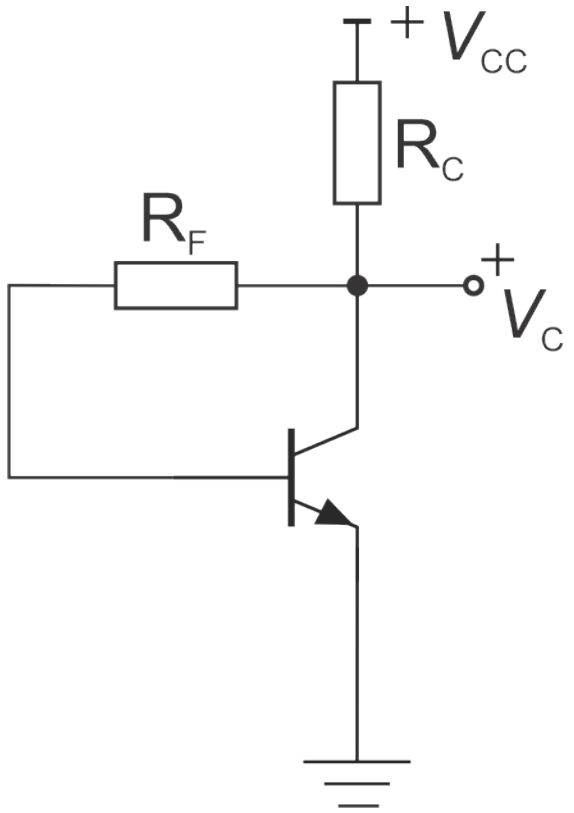
$$R_{ul2}, R_{ul2} \gg \frac{1}{\omega C_S}$$



Kola za polarizaciju

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

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



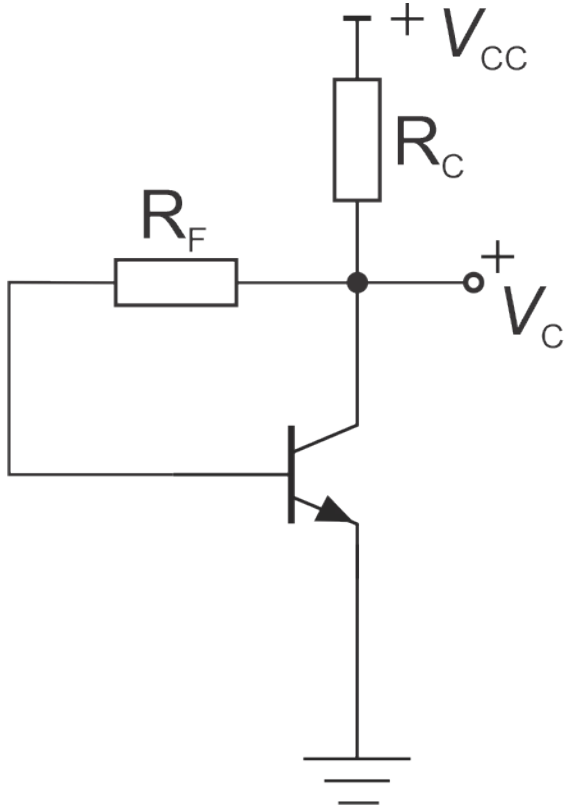
Kola za polarizaciju

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

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

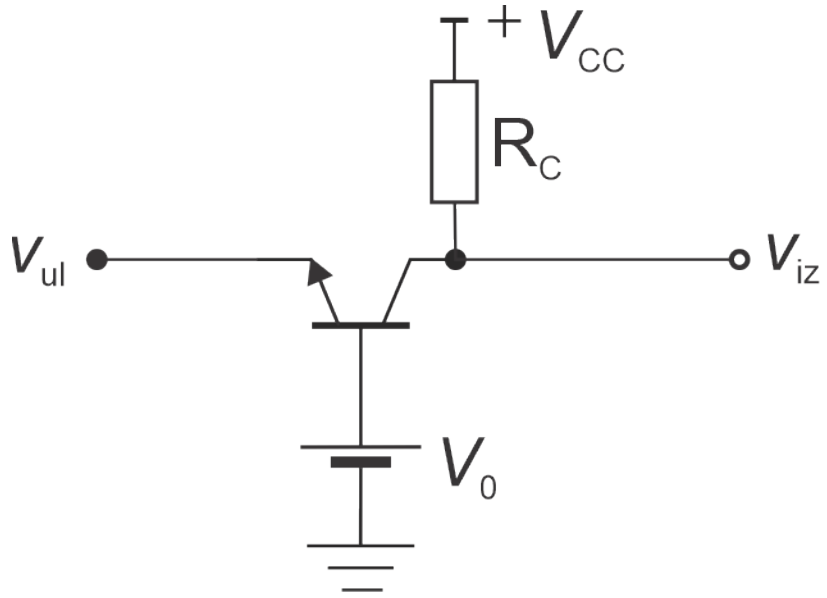
$$V_{BE} = V_{CC} - I_C R_C - I_B R_F$$

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



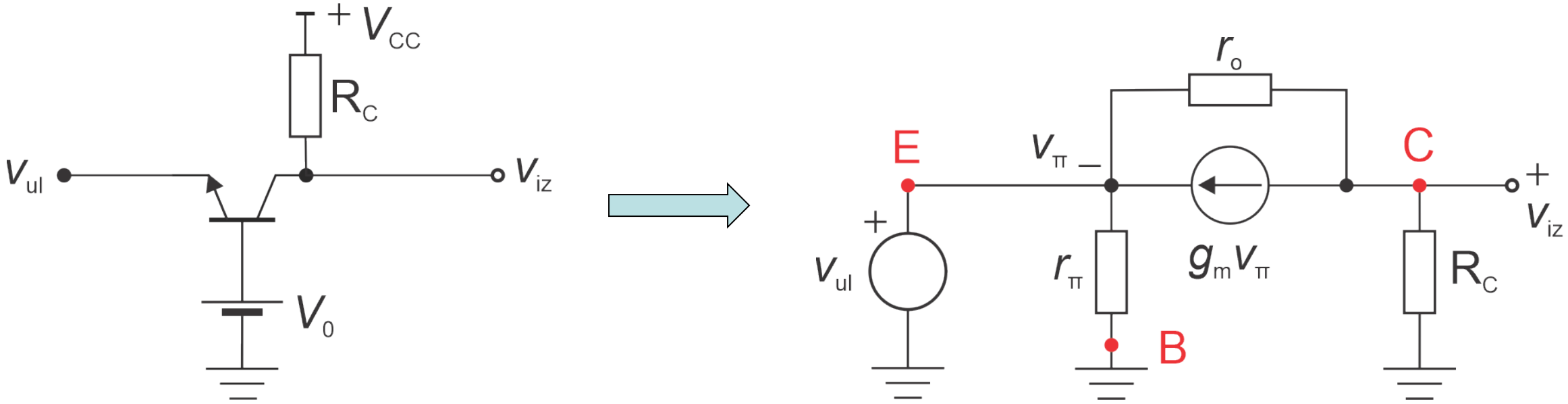
Pojačavač sa zajedničkom bazom

- Pojačanje, ulazna i izlazna impedansa



Pojačavač sa zajedničkom bazom

- Kolo za male signale



Pojačavač sa zajedničkom bazom – pojačanje

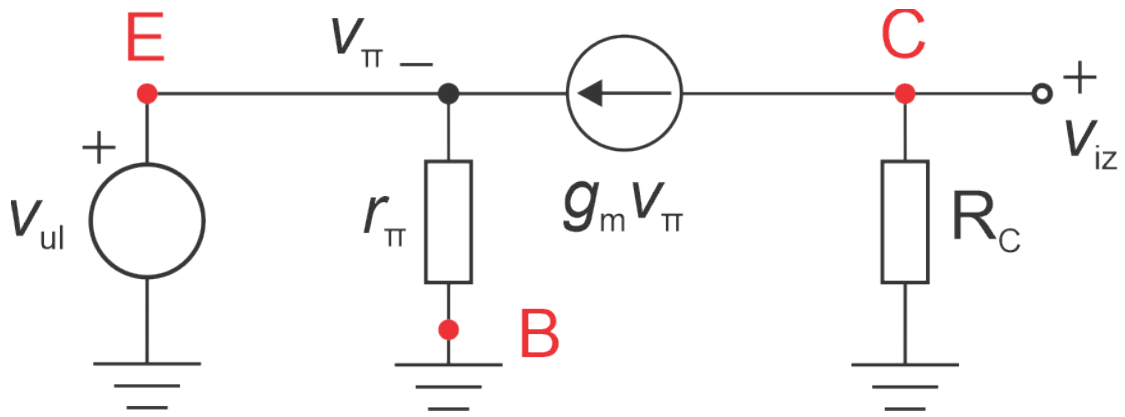
- Kolo za male signale, zanemarićemo Erlijev efekat (r_o=∞)

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

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

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

$$A = g_m R_C$$



Pojačavač sa zajedničkom bazom – ul. impedansa

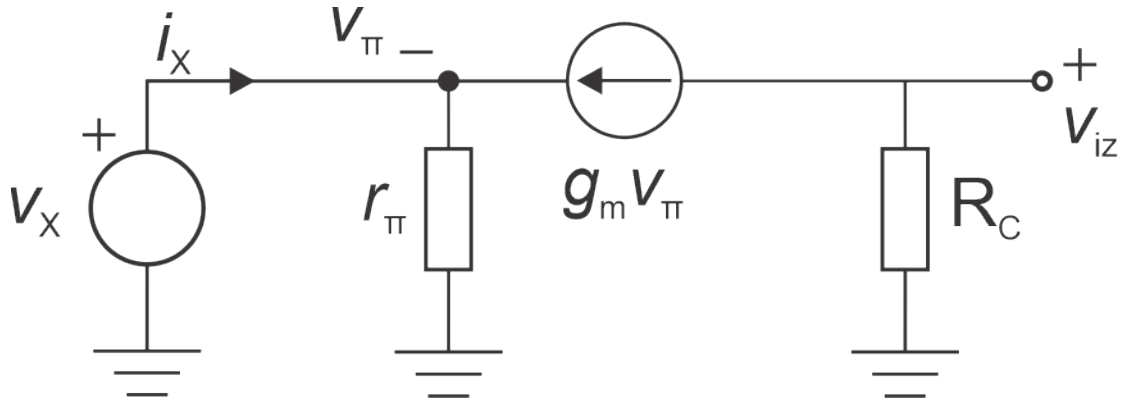
- Kolo za male signale, zanemarićemo Erlijev efekat (r_o=∞)

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

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

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

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

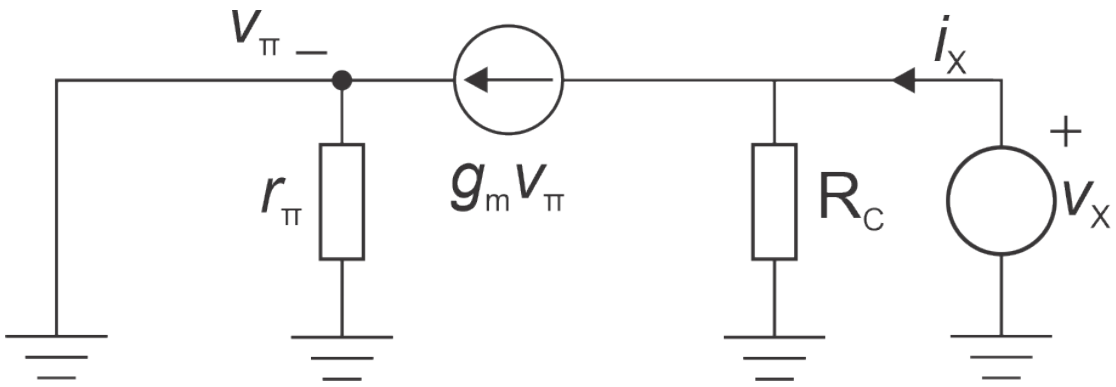


Pojačavač sa zajedničkom bazom – iz. impedansa

- Kolo za male signale, zanemarićemo Erlijev efekat (r_o=∞)

$$v_\pi = 0$$

$$R_{iz} = R_C$$



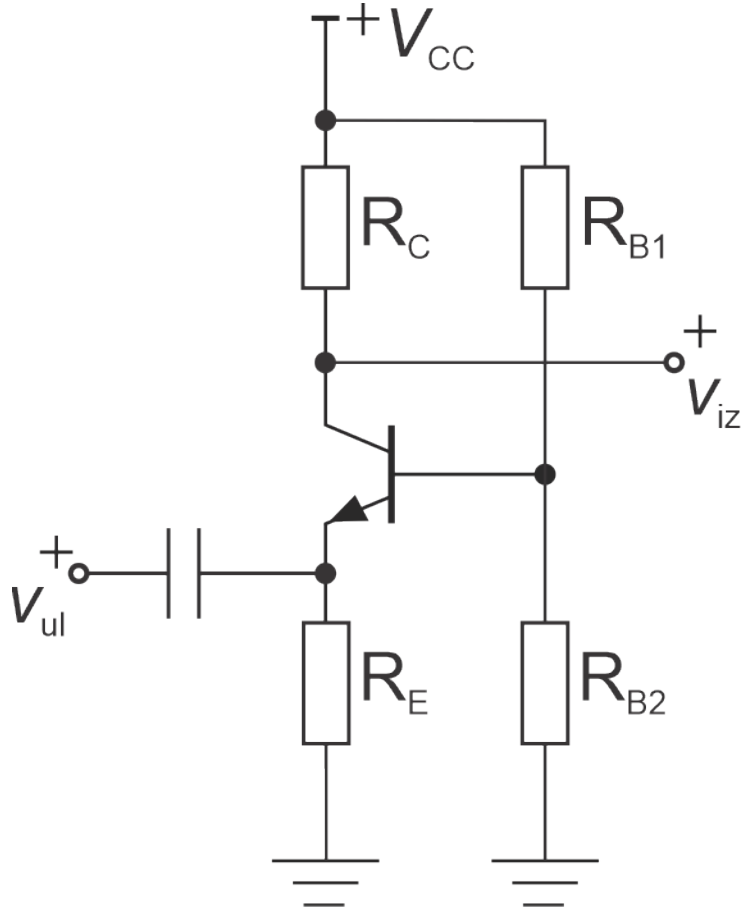
Pojačavač sa zajedničkom bazom – polarizacija

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

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

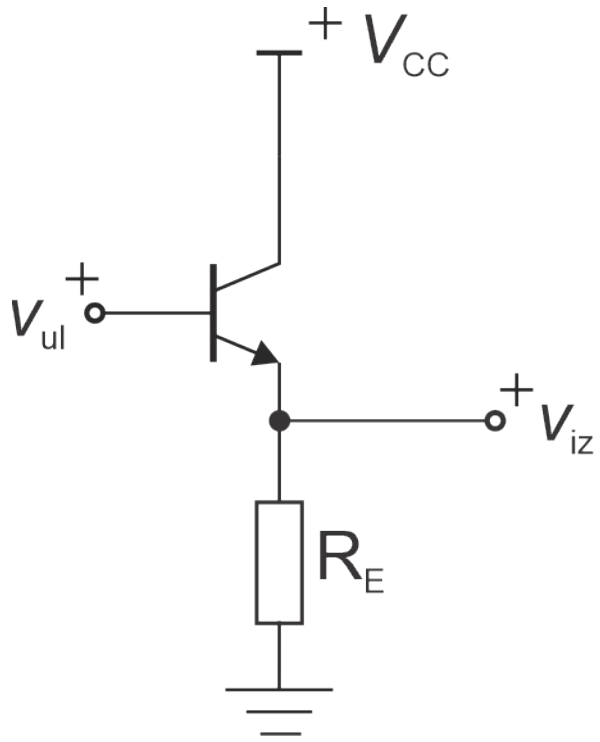
$$\frac{R_{\mathrm{B1}}}{R_{\mathrm{B1}}+R_{\mathrm{B2}}}V_{\mathrm{CC}} < V_{\mathrm{CC}} - I_{\mathrm{C}}R_{\mathrm{C}}$$

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



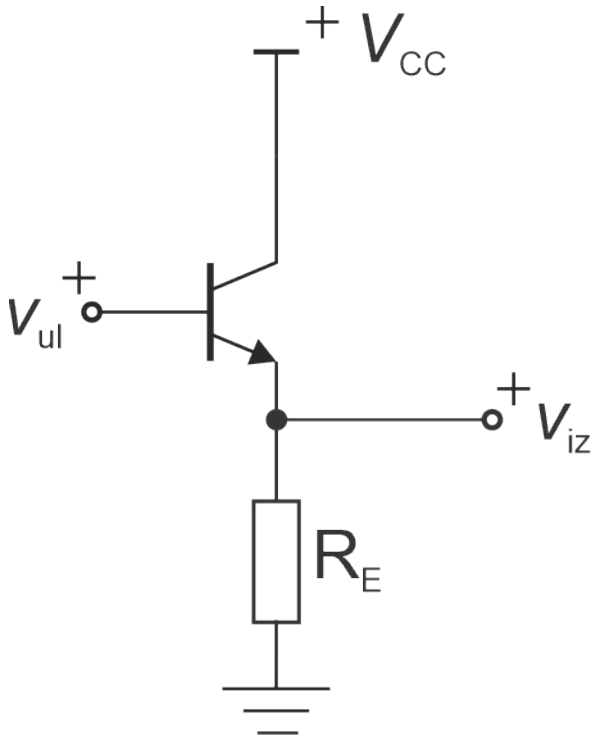
Pojačavač sa zajedničkim kolektorom

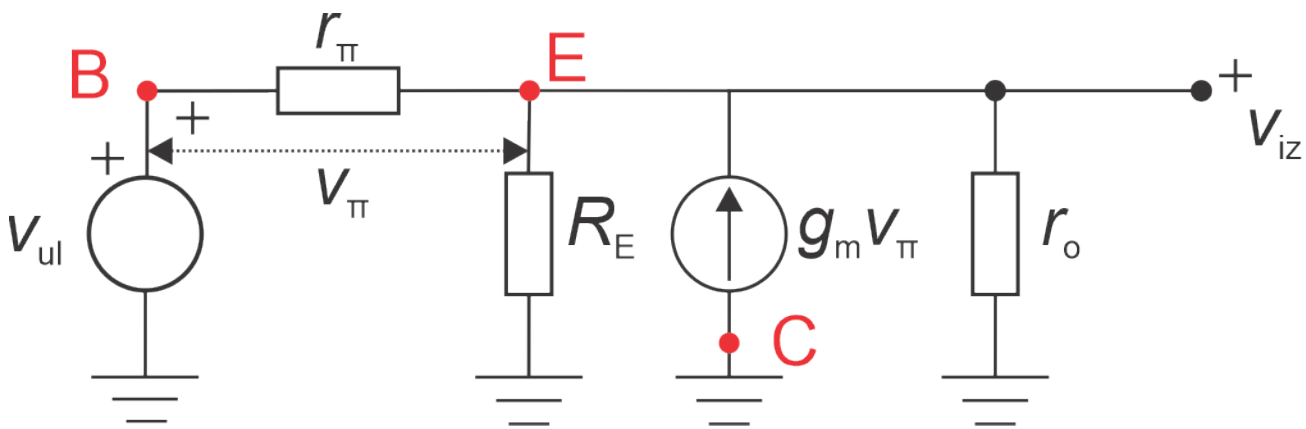
- Pojačanje, ulazna i izlazna impedansa



Pojačavač sa zajedničkim kolektorom

- Kolo za male signale





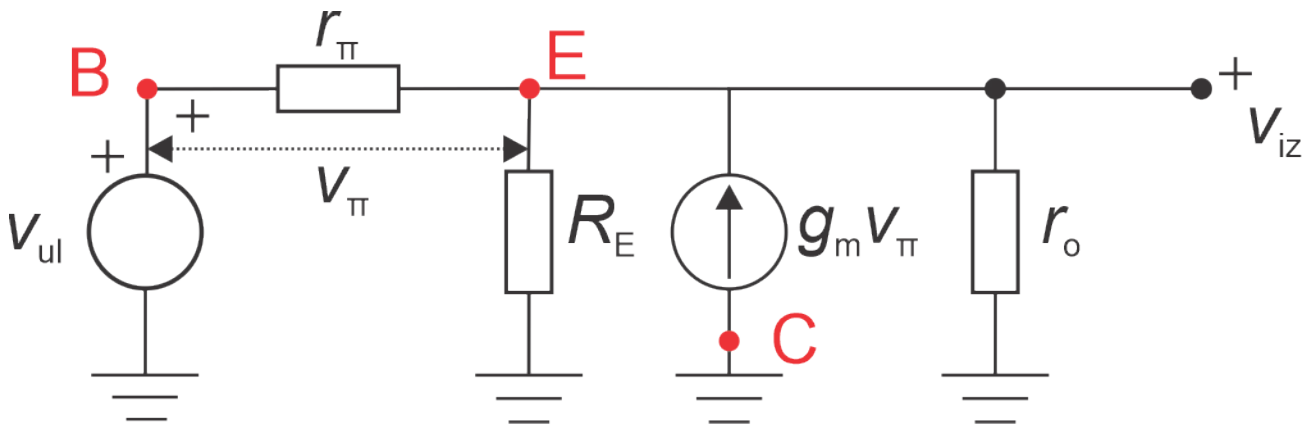
Pojačavač sa zajedničkim kolektorom – pojačanje

$$i_E = \frac{v_{iz}}{R_E}, i_o = \frac{v_{iz}}{r_o}$$

$$\frac{v_\pi}{r_\pi} = \frac{v_{iz}}{R_E} - g_m v_\pi + \frac{v_{iz}}{r_o}$$

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

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



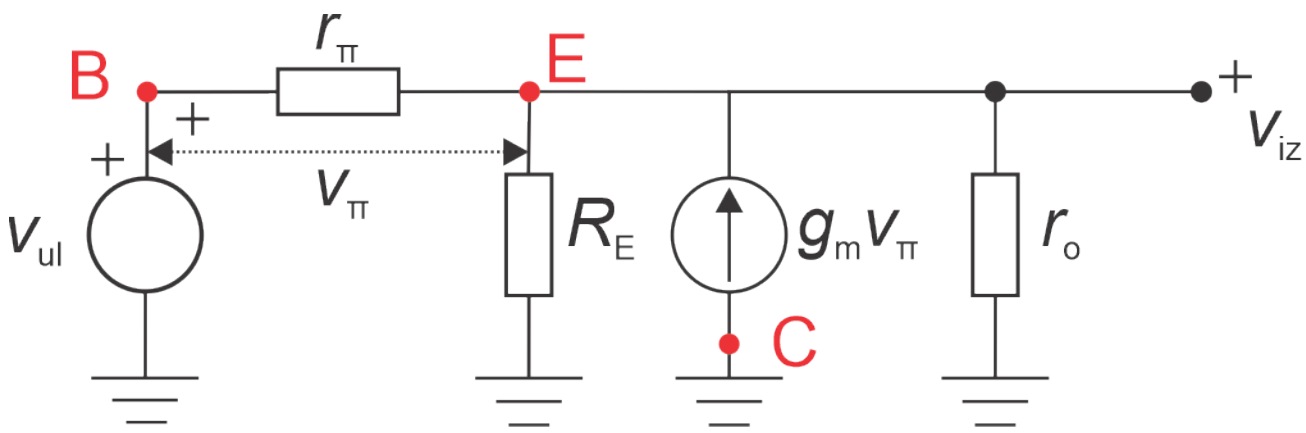
Pojačavač sa zajedničkim kolektorom – pojačanje

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

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

$$\frac{v_{iz}}{v_{ul}} = \frac{\left(1/r_\pi + g_m\right)}{\left(1/\left(R_E \parallel r_o\right) + g_m\right)}$$

$$\frac{v_{iz}}{v_{ul}} = \frac{\left(R_E \parallel r_o\right)\left(1 + r_\pi g_m\right)}{r_\pi + g_m r_\pi \left(R_E \parallel r_o\right)} = \frac{\left(R_E \parallel r_o\right)\left(1 + \beta\right)}{r_\pi + \beta\left(R_E \parallel r_o\right)}$$

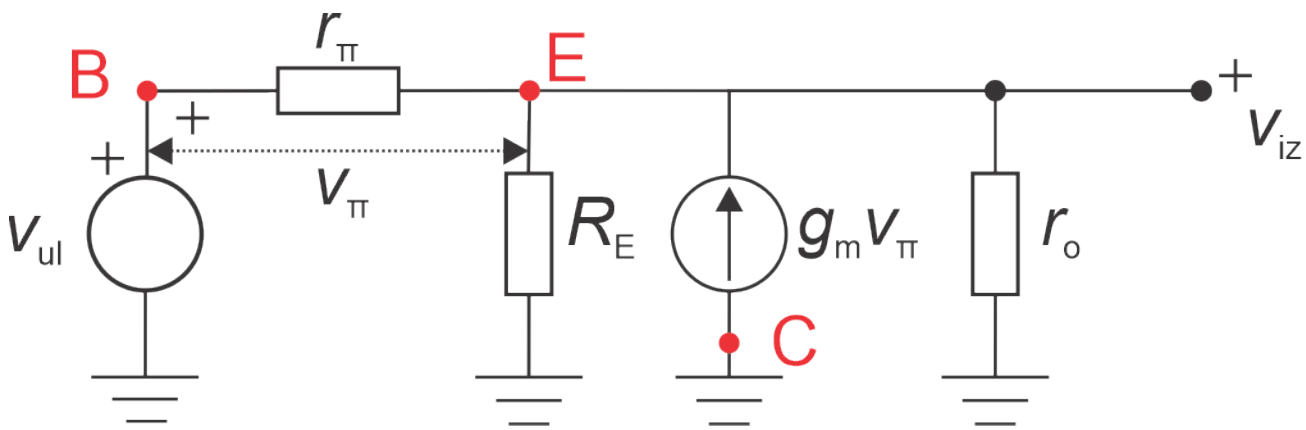


Pojačavač sa zajedničkim kolektorom – pojačanje

$$A = \frac{(R_E \parallel r_o)(1+\beta)}{r_\pi + \beta(R_E \parallel r_o)} \approx \frac{\beta(R_E \parallel r_o)}{r_\pi + \beta(R_E \parallel r_o)}$$

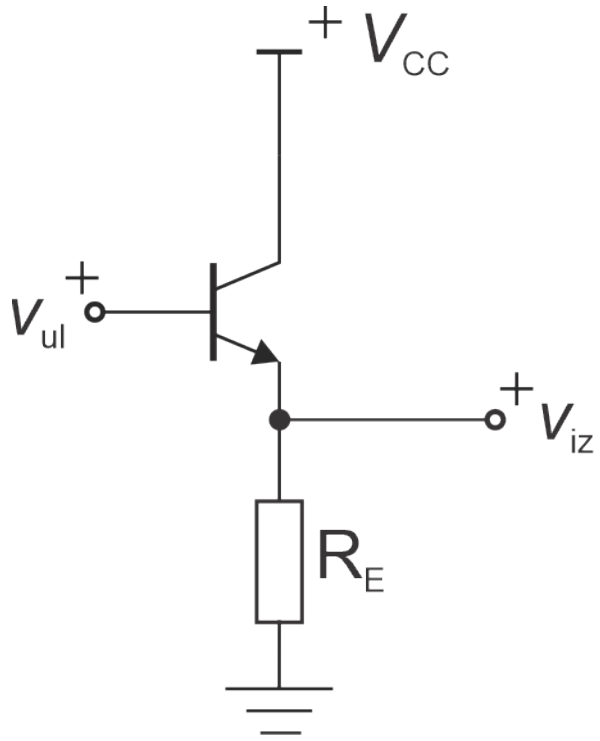
$$A \approx \frac{R_E \parallel r_o}{1/g_m + R_E \parallel r_o} < 1$$

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



Pojačavač sa zajedničkim kolektorom – ulazna imp.

- Kolo je ekvivalentno degenerisanom emitoru, za R_C=0.



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

Pojačavač sa zajedničkim kolektorom – izlazna imp.

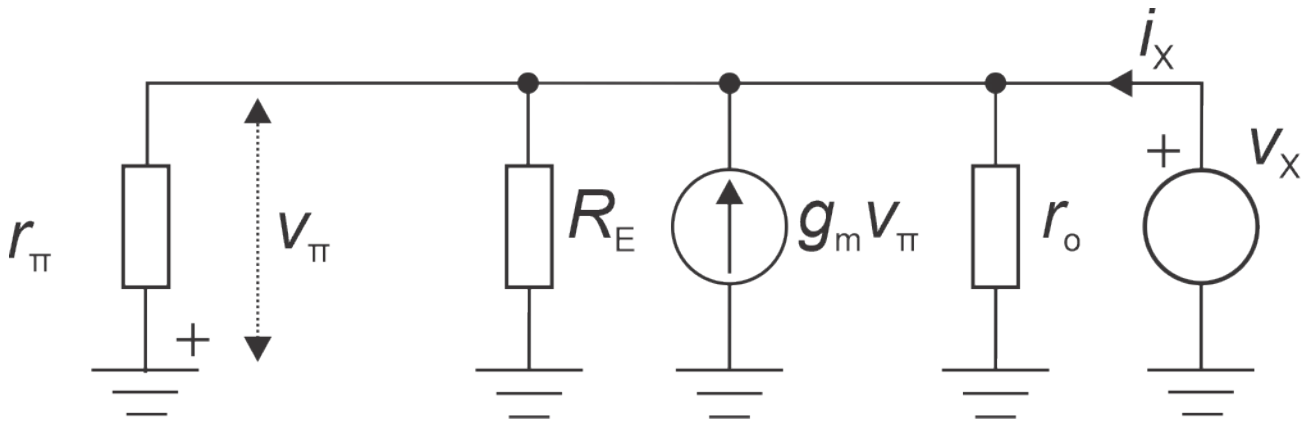
$$v_\pi = -v_X$$

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

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

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

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

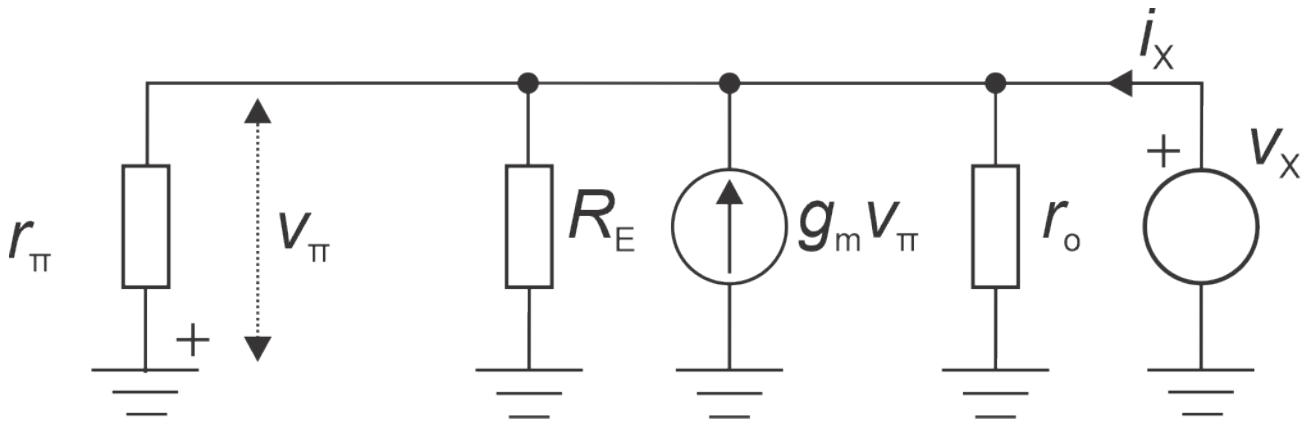


Pojačavač sa zajedničkim kolektorom – izlazna imp.

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

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

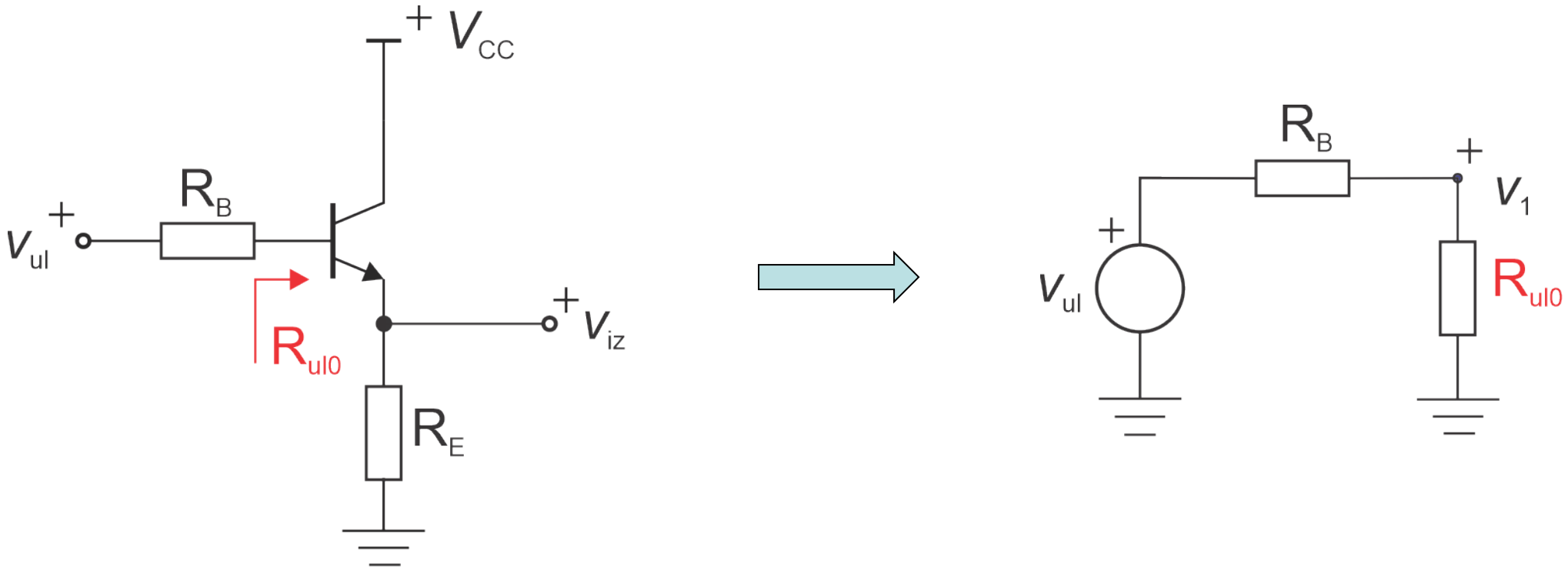
$$R_{iz} \approx R_E \,\|\, 1/g_m$$



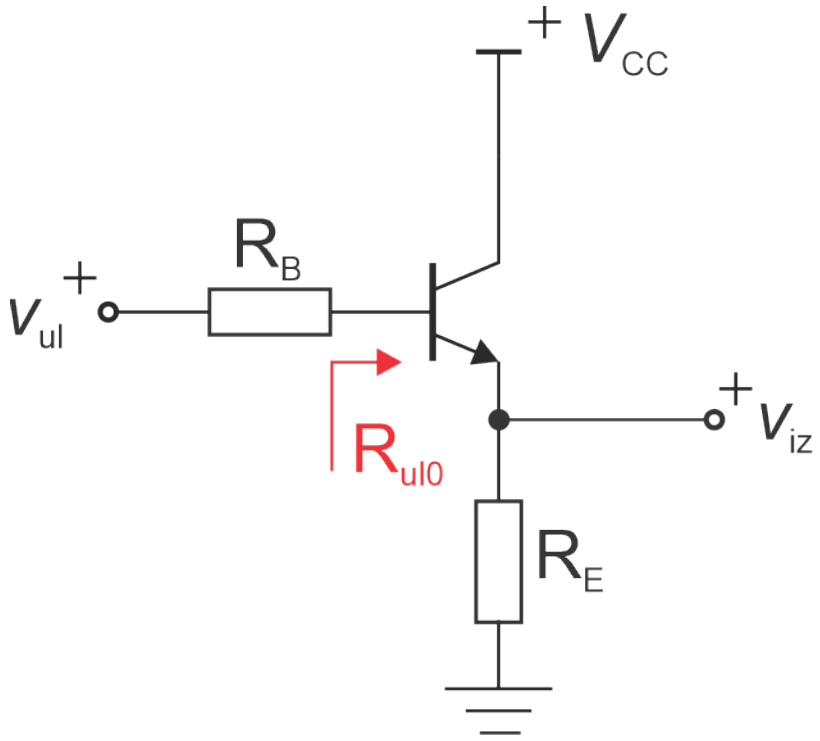
Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

- Otpornik u grani baze, pojačanje

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



Pojačavač sa zajedničkim kolektorom – polarizacija, R_B



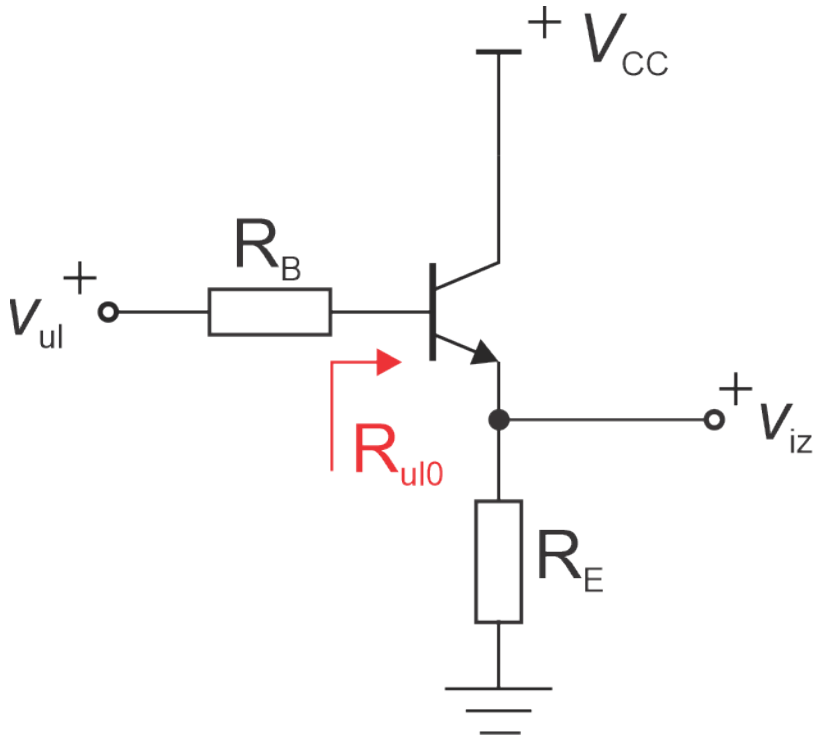
$$R_{ul0} = (\beta + 1) R_E + r_\pi$$

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

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

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

Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

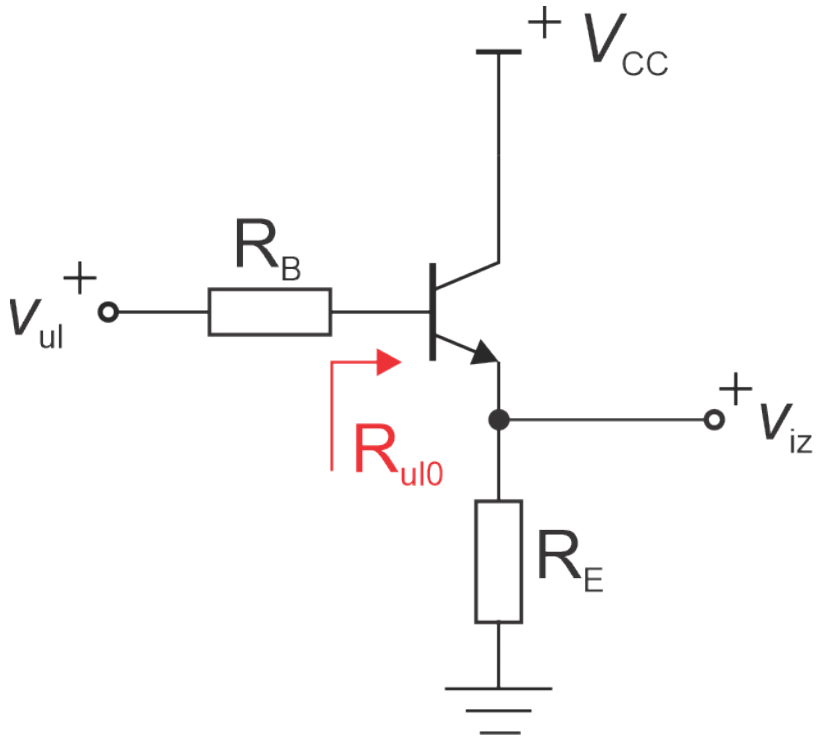


$$A = \frac{R_E}{1/g_m + R_E} \frac{R_E + \frac{r_\pi}{\beta+1}}{R_E + \frac{r_\pi}{\beta+1} + \frac{R_B}{\beta+1}}$$

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

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

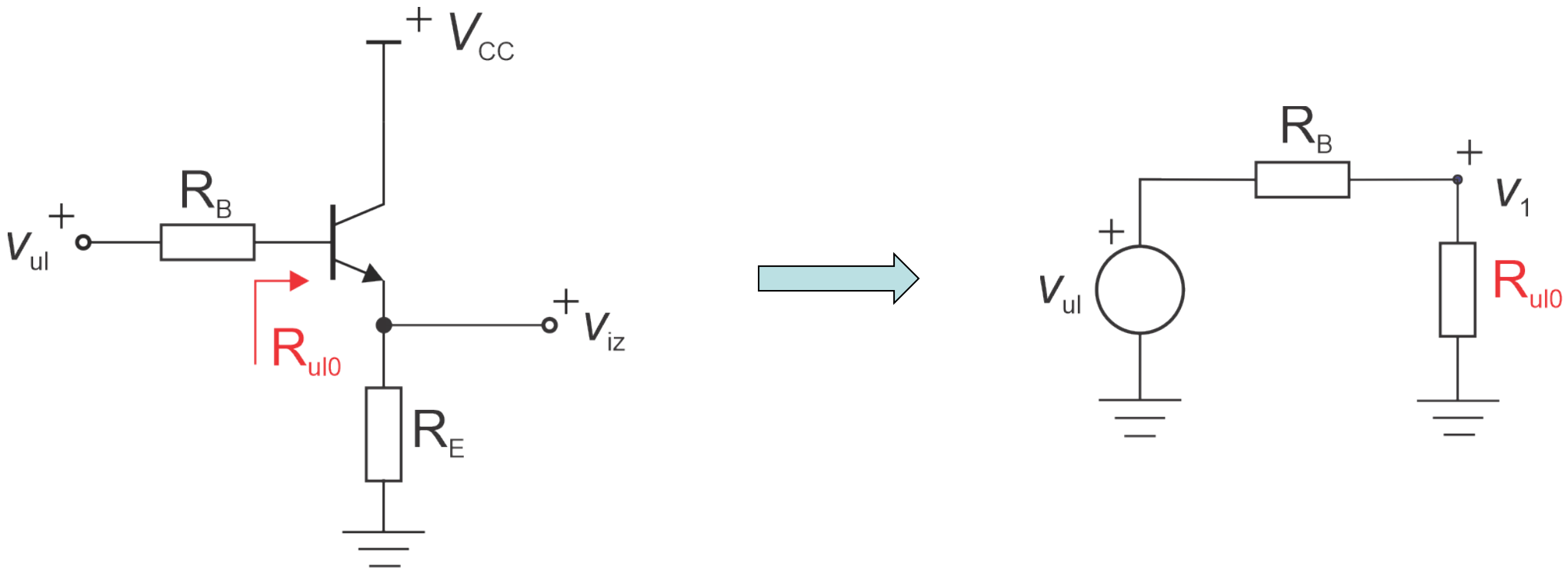
Pojačavač sa zajedničkim kolektorom – polarizacija, R_B



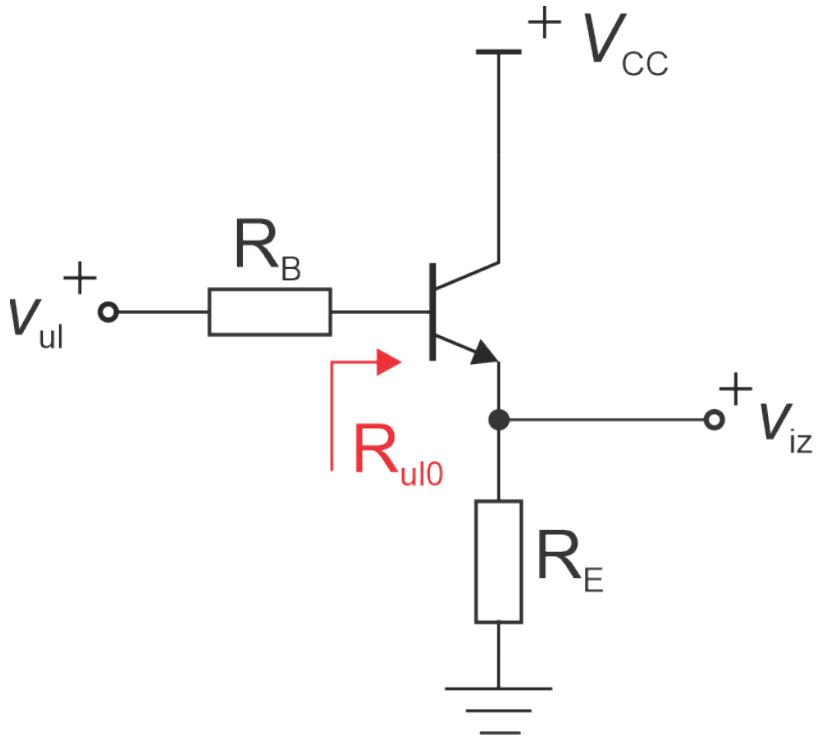
$$A = \frac{R_E}{R_E + 1/g_m + \frac{R_B}{\beta + 1}}$$

Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

- Otpornik u grani baze, ulazna impedansa



Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

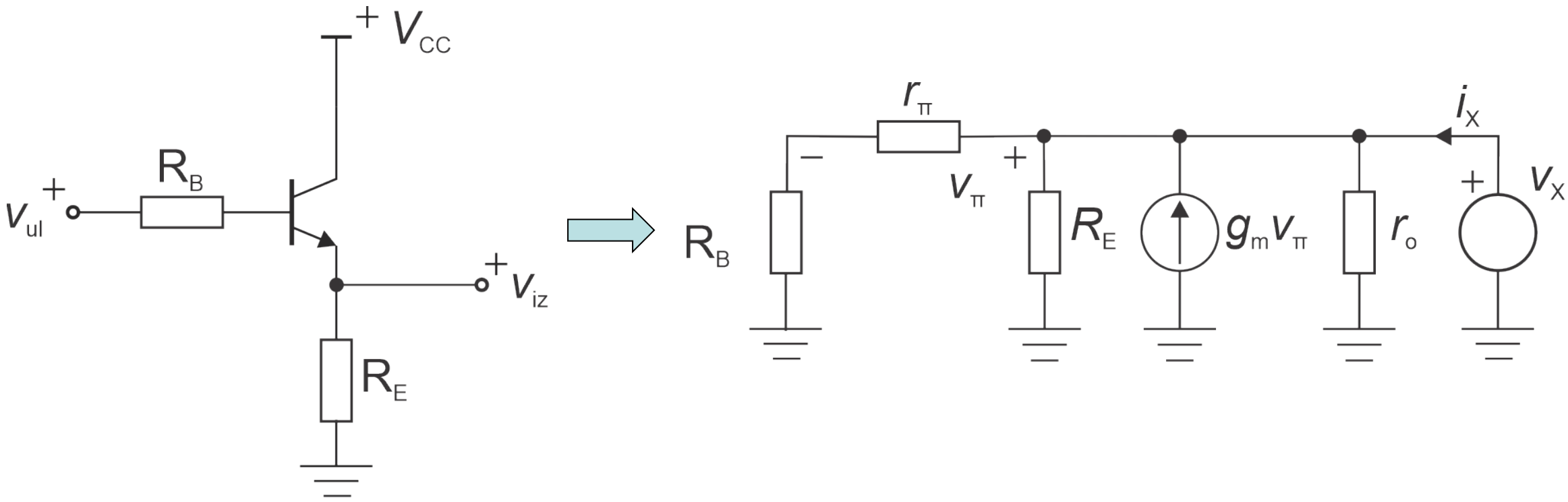


$$R_{ul0} = (\beta + 1) R_E + r_\pi$$

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

Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

- Otpornik u grani baze, izlazna impedansa



Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

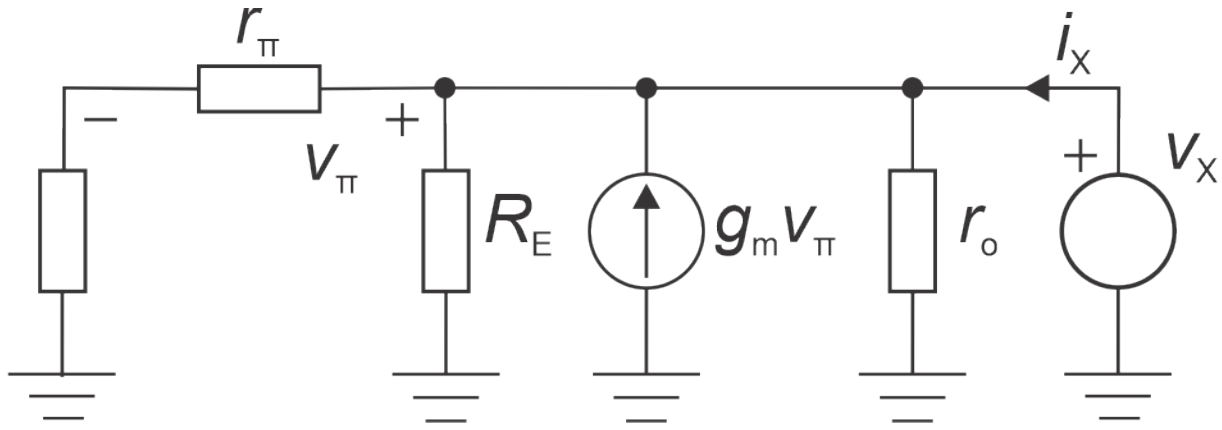
$$v_\pi = -\frac{r_\pi}{r_\pi + R_B} v_X$$

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

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

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

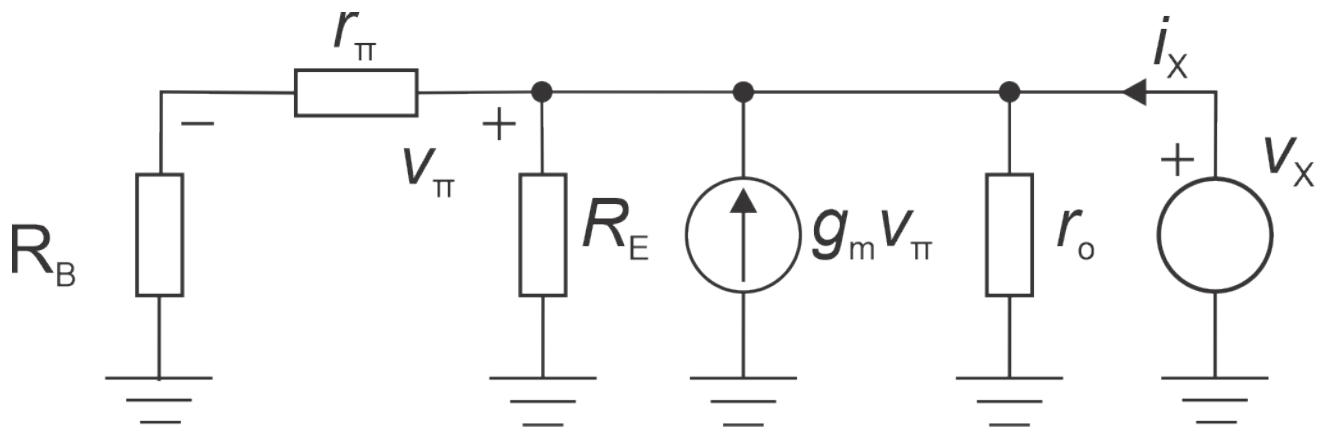
$$R_{iz} = \frac{v_X}{i_X} = \frac{R_B + r_\pi}{\beta + 1} \parallel R_E \parallel r_o$$



Pojačavač sa zajedničkim kolektorom – polarizacija, R_B

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

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



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	$\approx \frac{R_E \parallel r_o}{1/g_m + R_E \parallel r_o}$	0	$(\beta+1)R_E + r_\pi$	$\approx R_E \parallel 1/g_m$