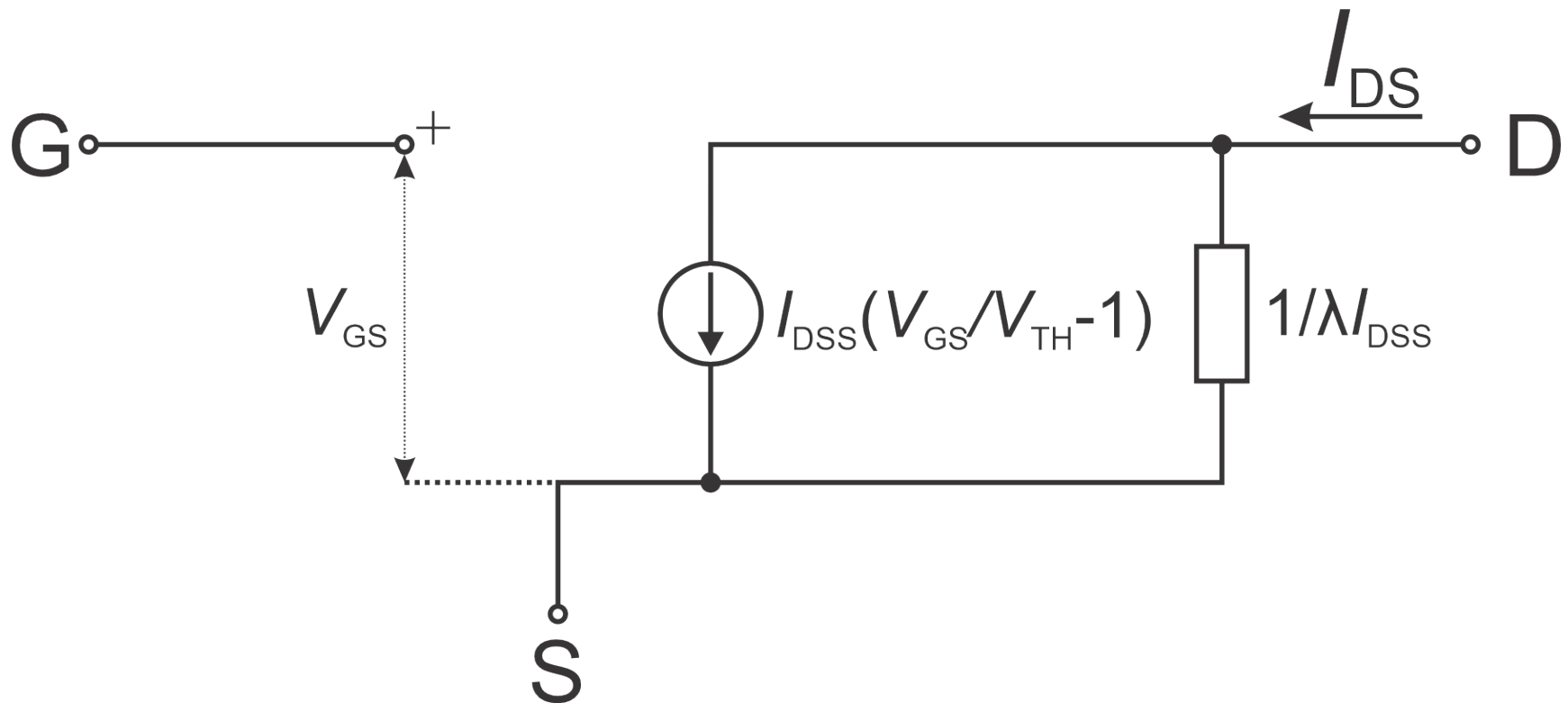
Pojačavači sa MOS tranzistorima

Model za velike signale (polarizacija)

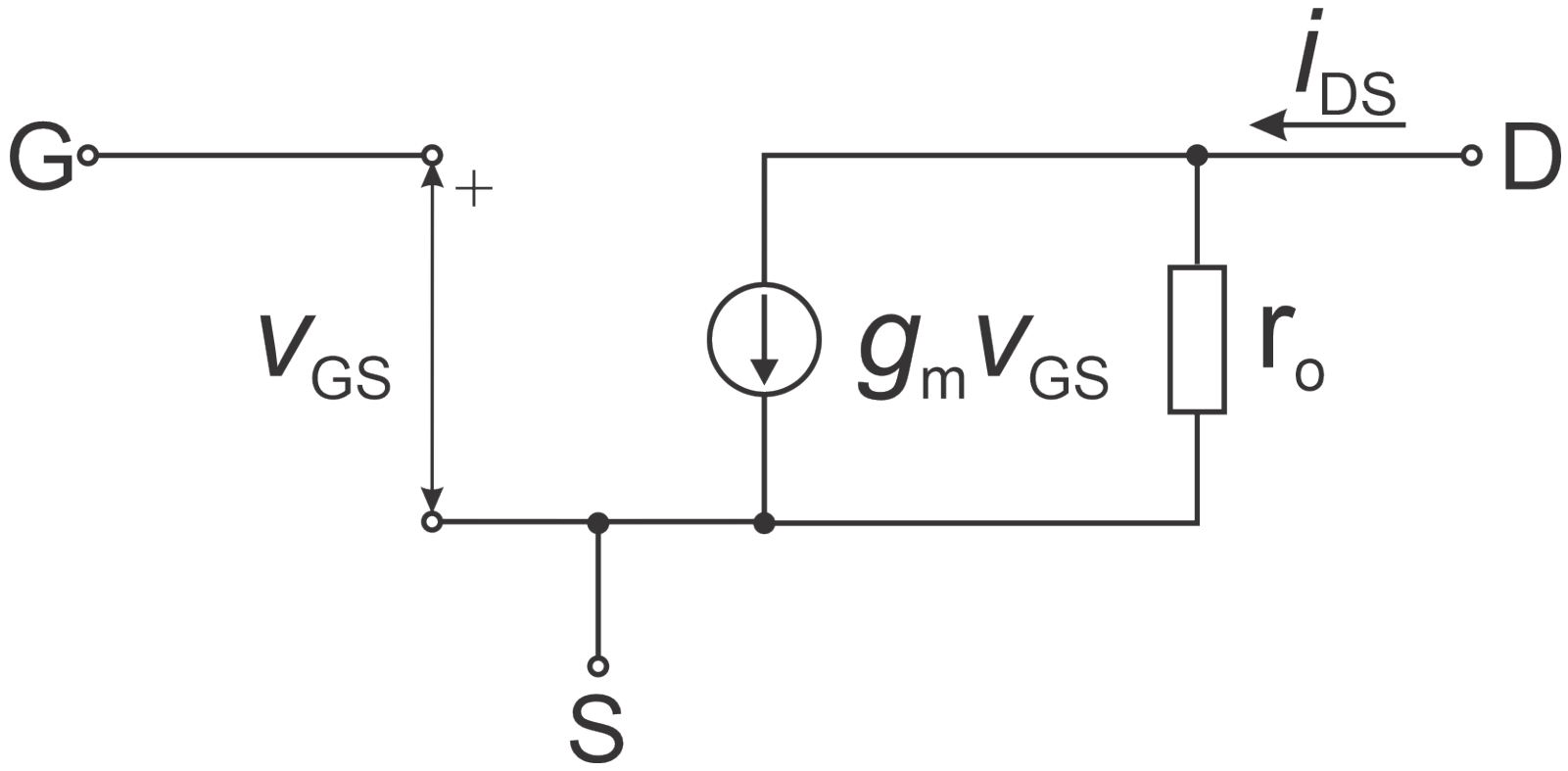
Parametri: I_{DSS}, λ, V_{TH}



Model za male signale

Parametri: g_m, r_o

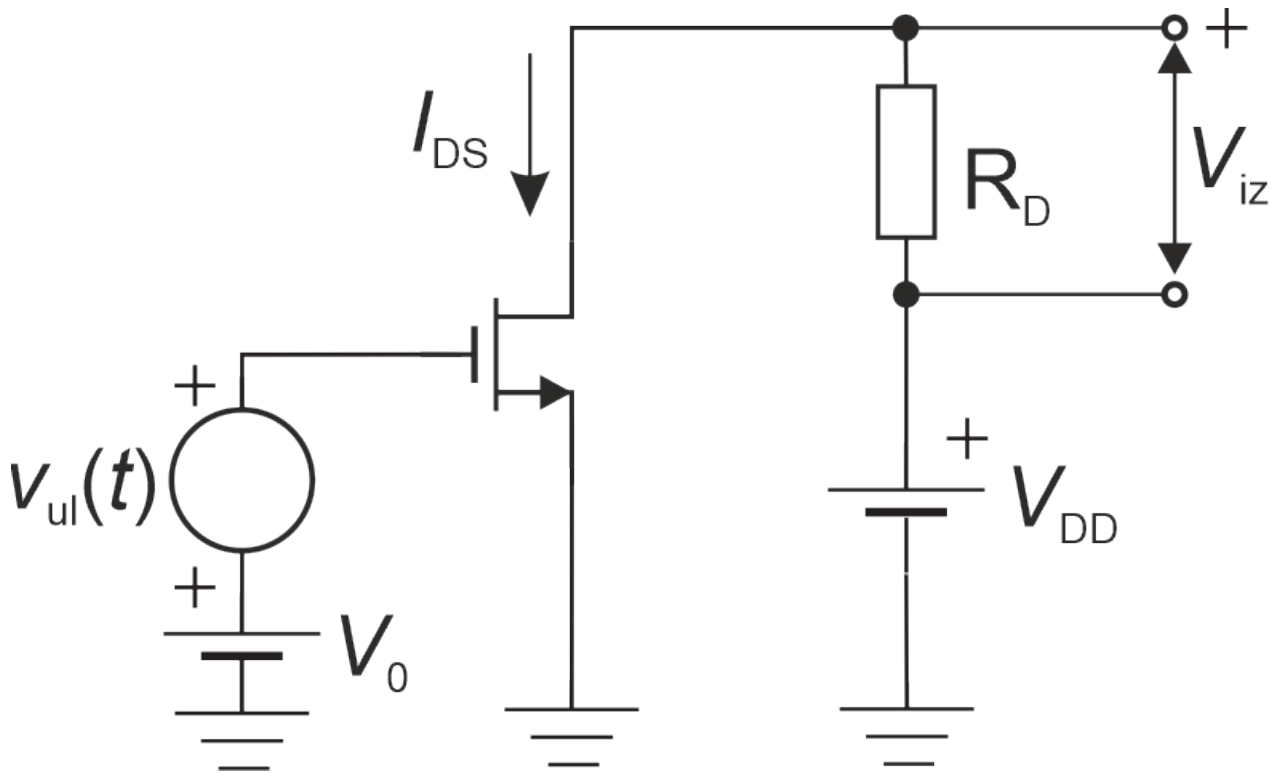
$$g_m = \frac{2I_{DSS}}{V_{TH}} \cdot \left(\frac{V_{GS}}{V_{TH}} - 1 \right), \quad r_o = \frac{1}{\lambda I_{DS0}}$$



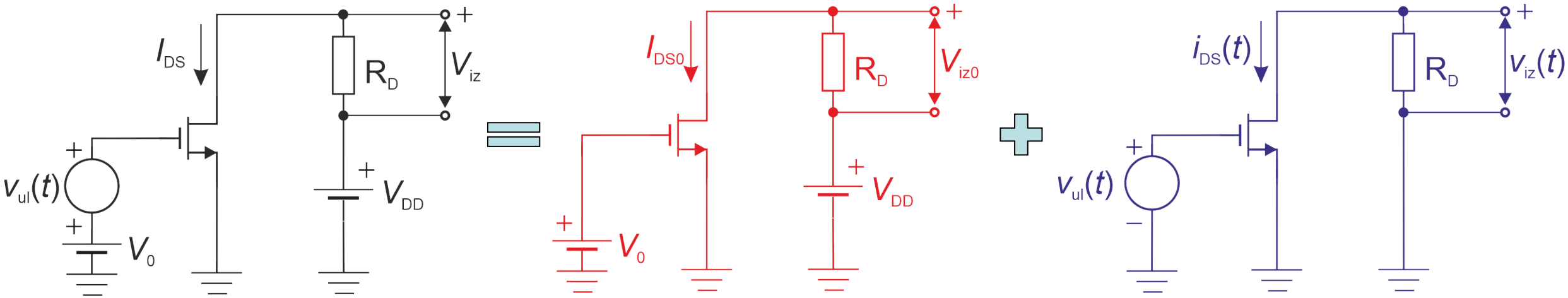
Pojačavač – analiza i sinteza

- 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)

Pojačavač sa zajedničkim sorsom



Superpozicija – kola za velike i male signale

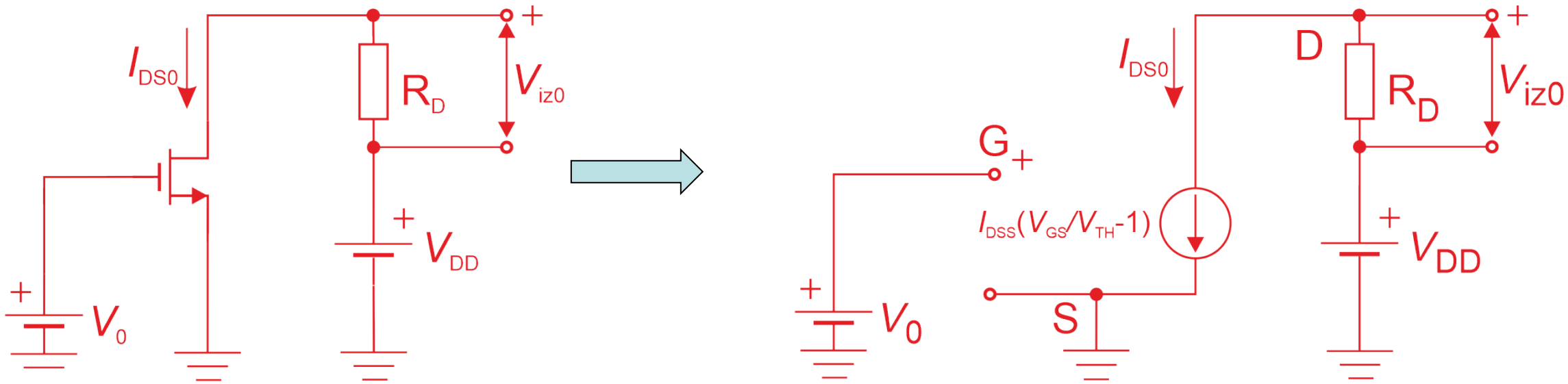


Veliki signali (polarizacija)

Signali malih amplituda

Jednosmerni režim (veliki signali)

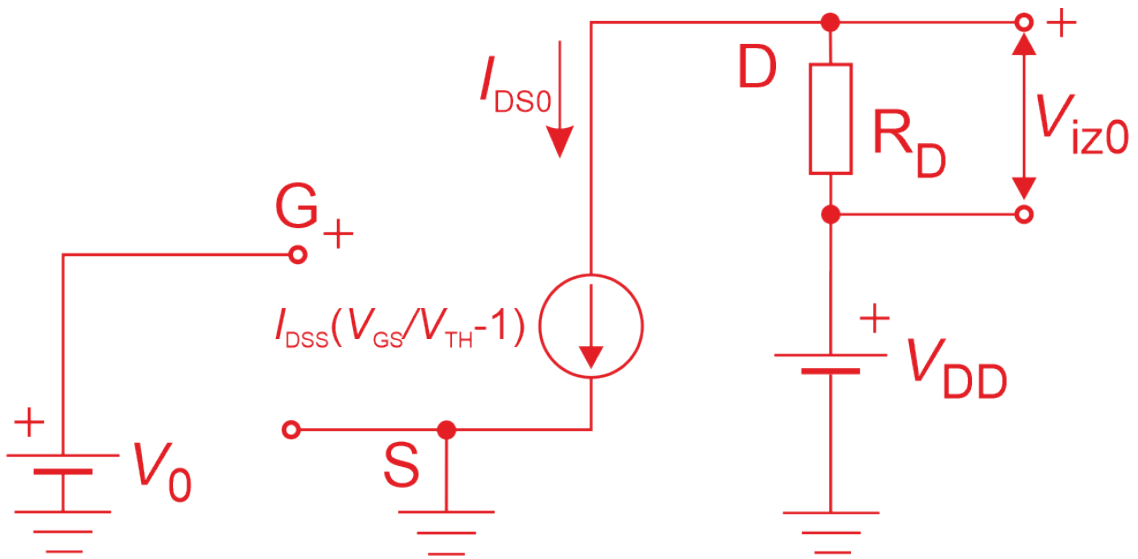
- Pronalazi se se I_{DS0}, izračunava g_m, r_o.



Jednosmerni režim (veliki signali)

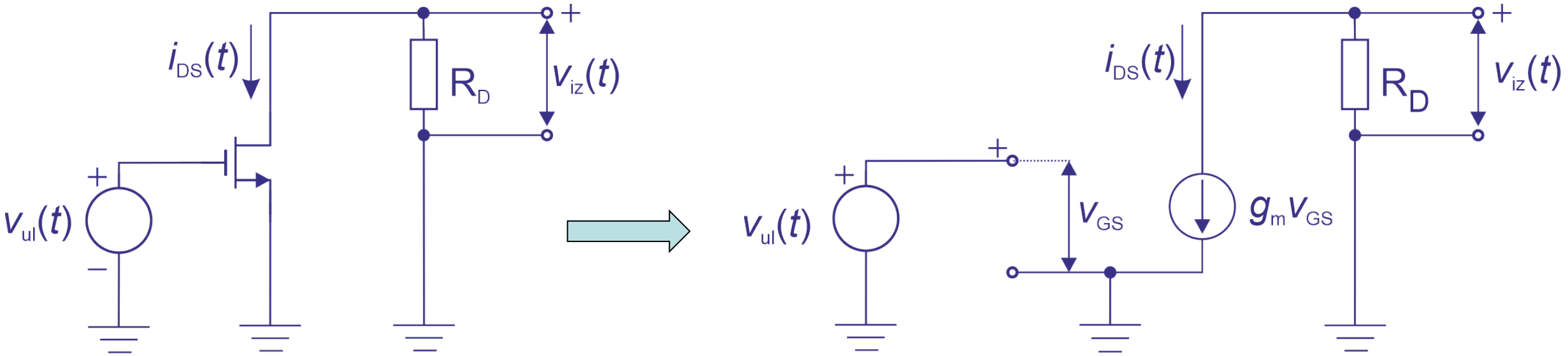
- V_{TH}, I_{DSS}, λ =0

$$I_{DS0} = I_{DSS} \cdot \left(\frac{V_0}{V_{TH}} - 1 \right)^2$$



Naizmenični režim (mali signali)

- g_m, $r_o=\infty$



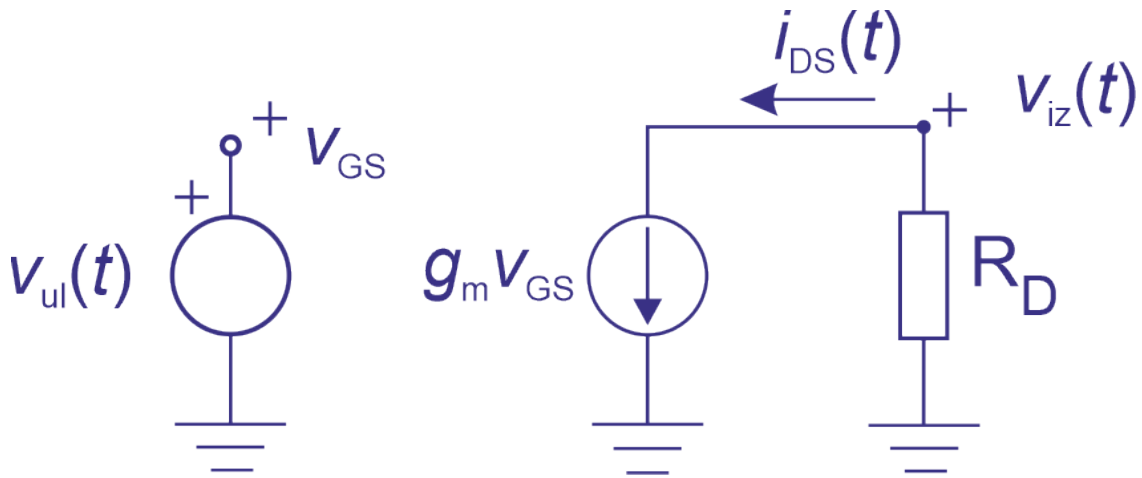
Naizmenični režim (mali signali)

$$v_{GS} = v_{ul}$$

$$v_{iz} = -i_{DS} \cdot R_D$$

$$v_{iz} = -g_m \cdot R_D \cdot v_{GS}$$

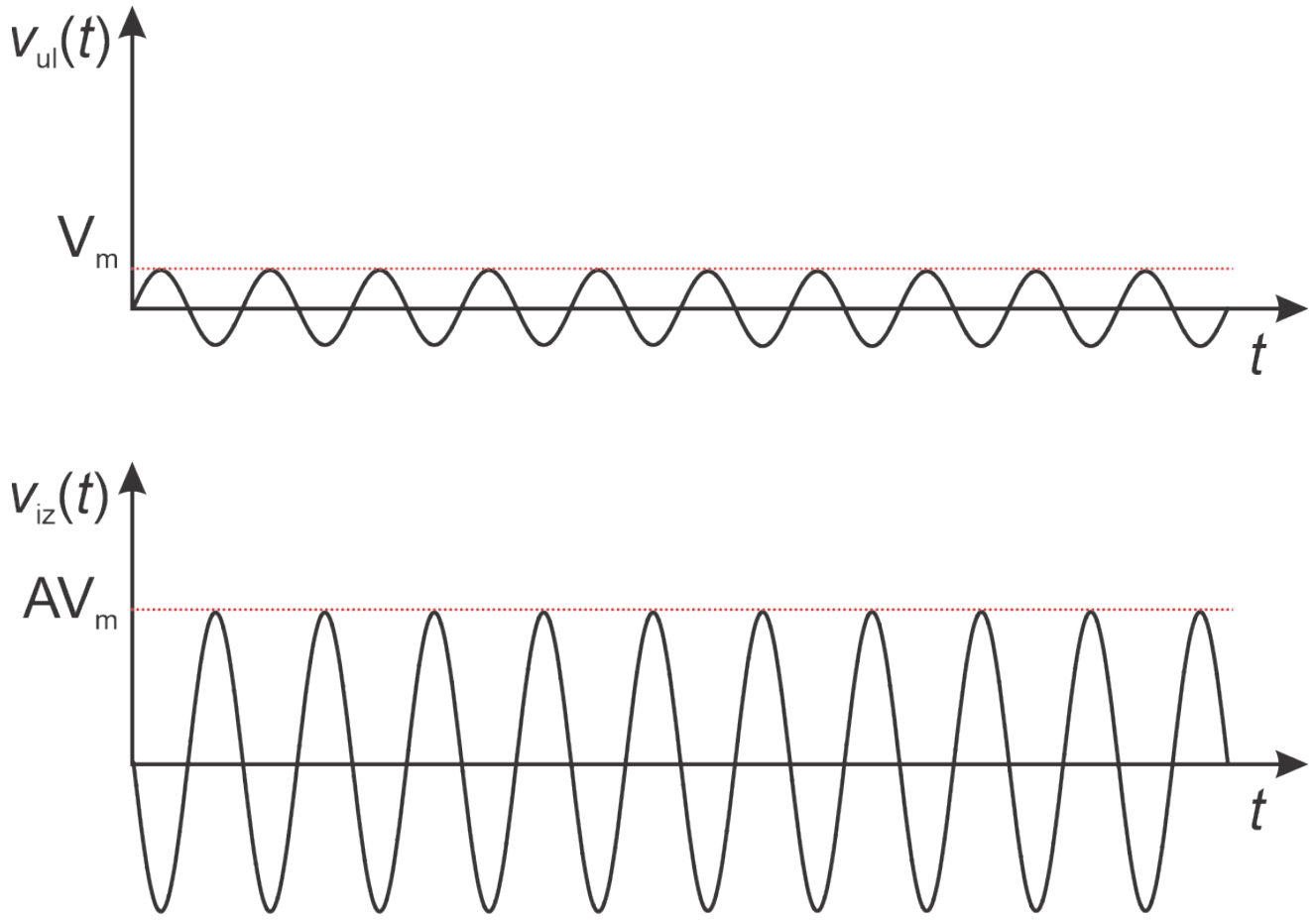
$$v_{iz} = -g_m \cdot R_D \cdot v_{ul}$$



Pojačanje pojačavača

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

$$A = -g_m \cdot R_D$$

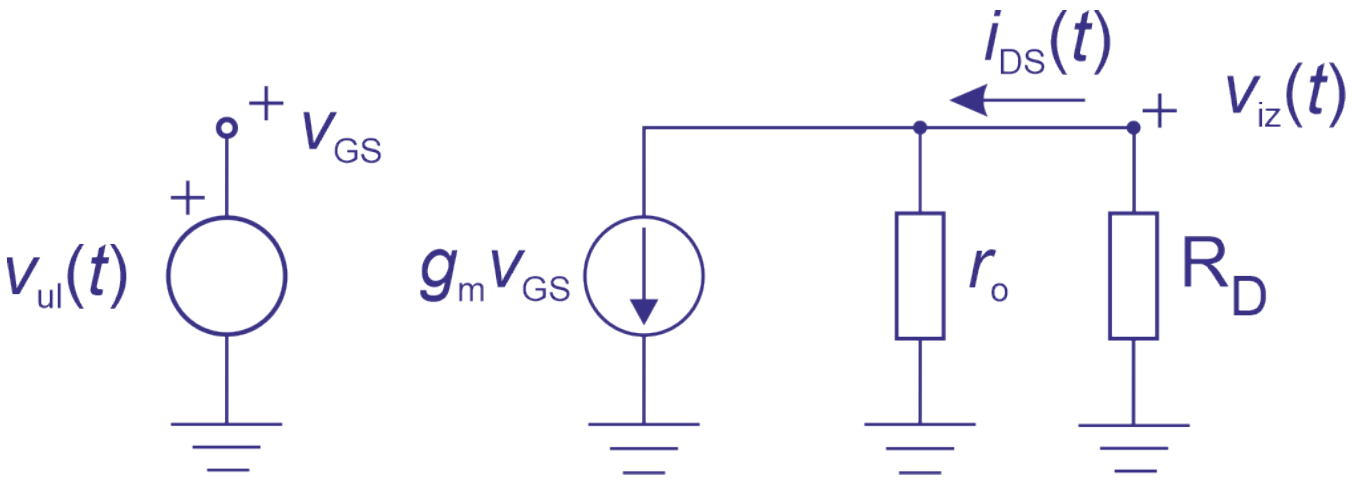


Uticaj modulacije dužine kanala na pojačanje

$$v_{GS} = v_{ul}$$

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

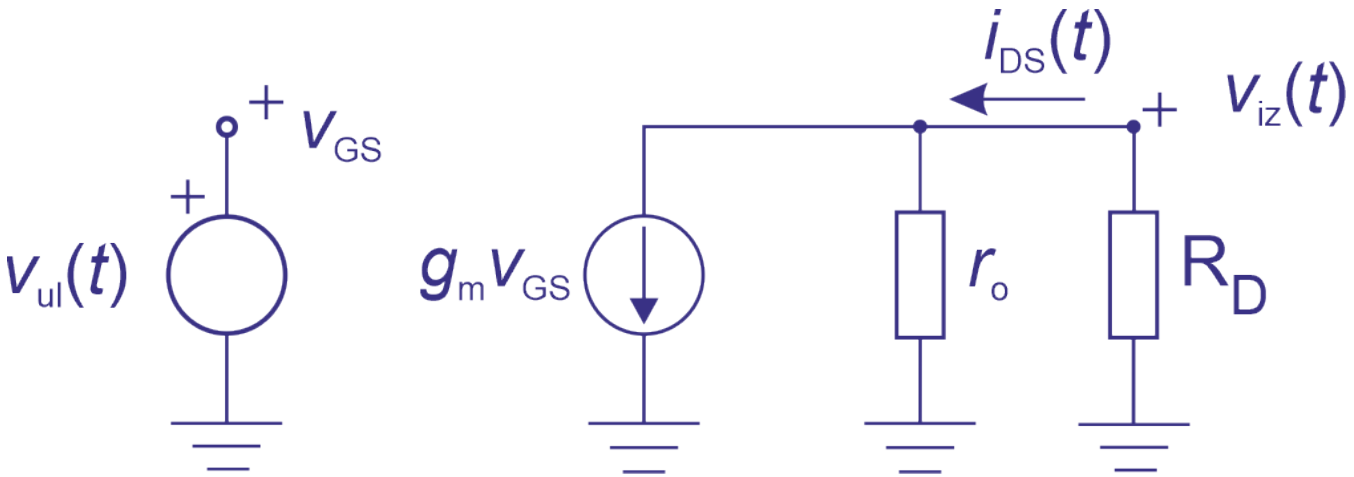
$$v_{iz} = -g_m \cdot \left(R_D \parallel r_o\right) \cdot v_{ul}$$



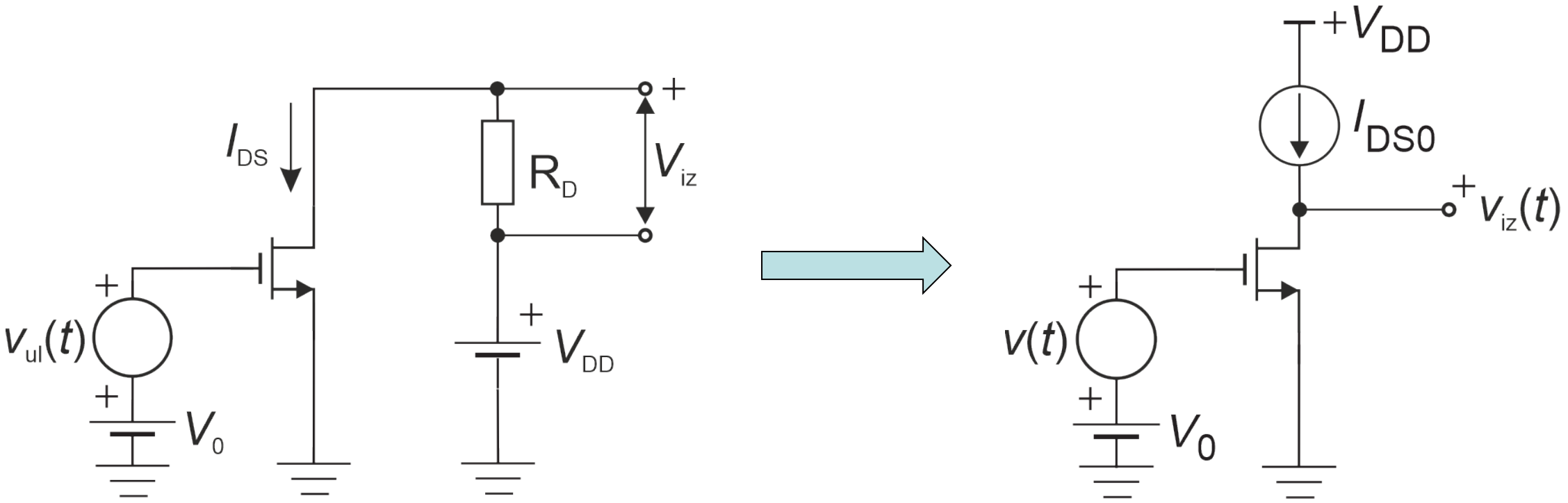
Uticaj modulacije dužine kanala na pojačanje

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

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



Maksimalno pojačanje pojačavača

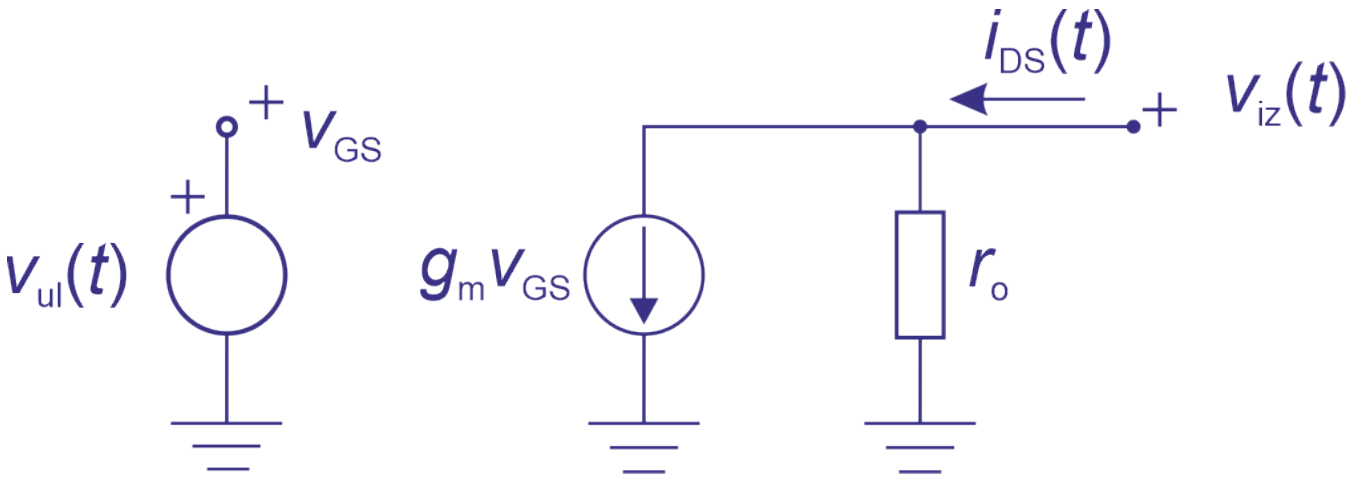


Maksimalno pojačanje pojačavača

$$v_{GS} = v_{ul}$$

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

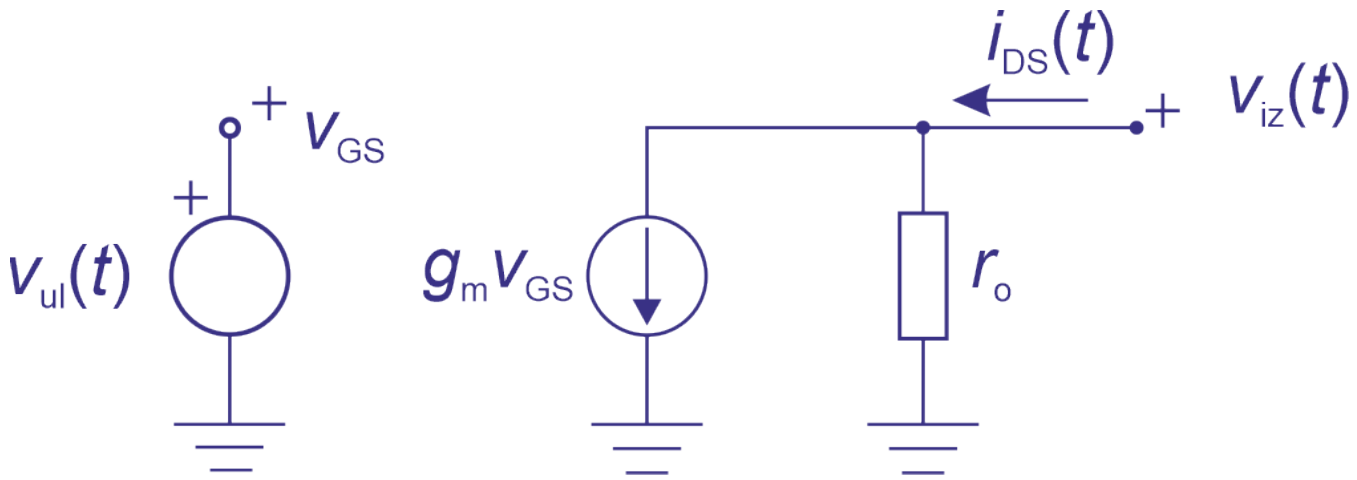
$$v_{iz} = -g_m \cdot r_o \cdot v_{ul}$$



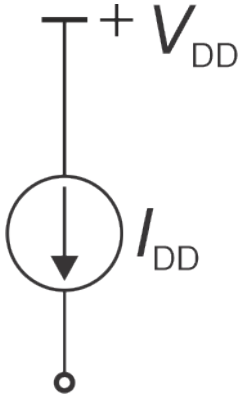
Maksimalno pojačanje pojačavača

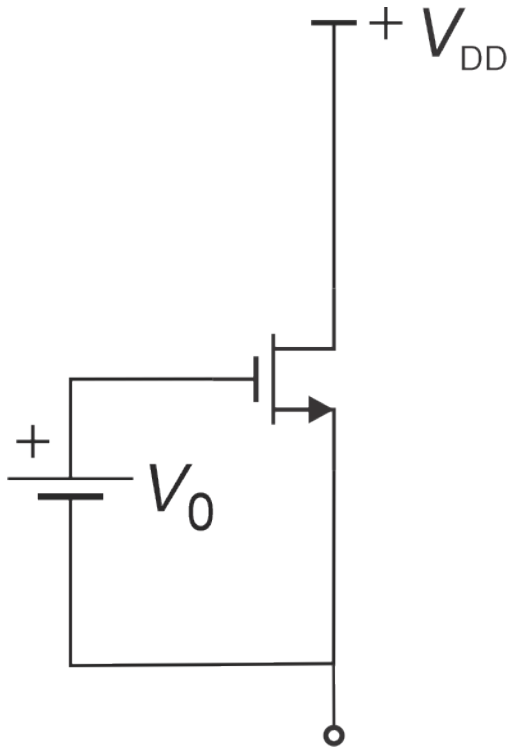
- Intrisično pojačanje pojačavača

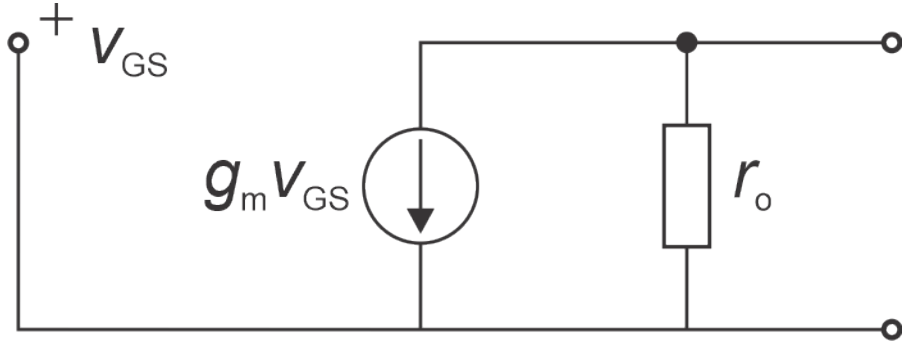
$$A = -g_{\mathrm{m}} \cdot r_{\mathrm{o}}$$



Izvori konstantne struje



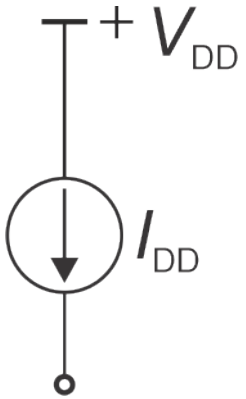


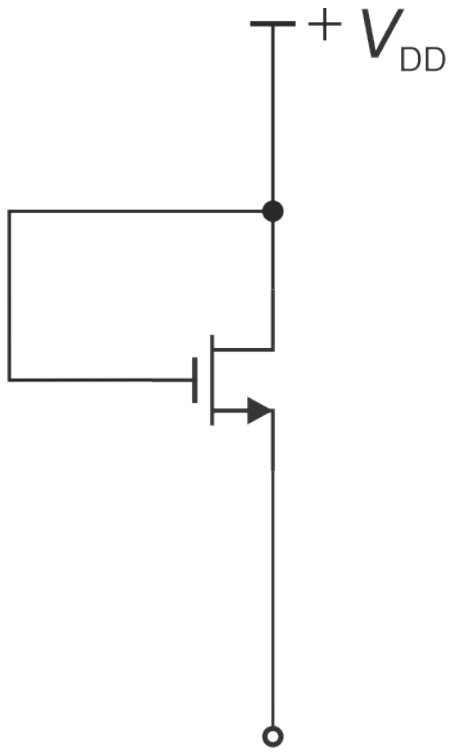


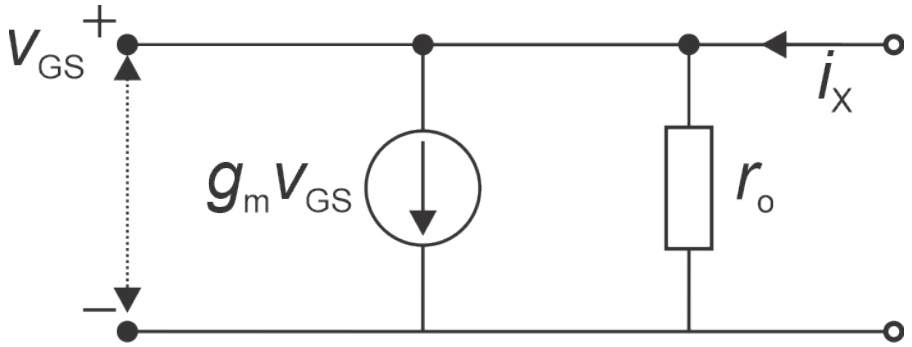
$$R_{DS} = r_o$$

$$I_{DD} = I_{DSS}\left(\frac{V_0}{V_{TH}} - 1\right)^2$$

Izvori konstantne struje







$$i_X = g_m v_{GS} + v_X / r_o \qquad i_X = g_m v_X + v_X / r_o$$

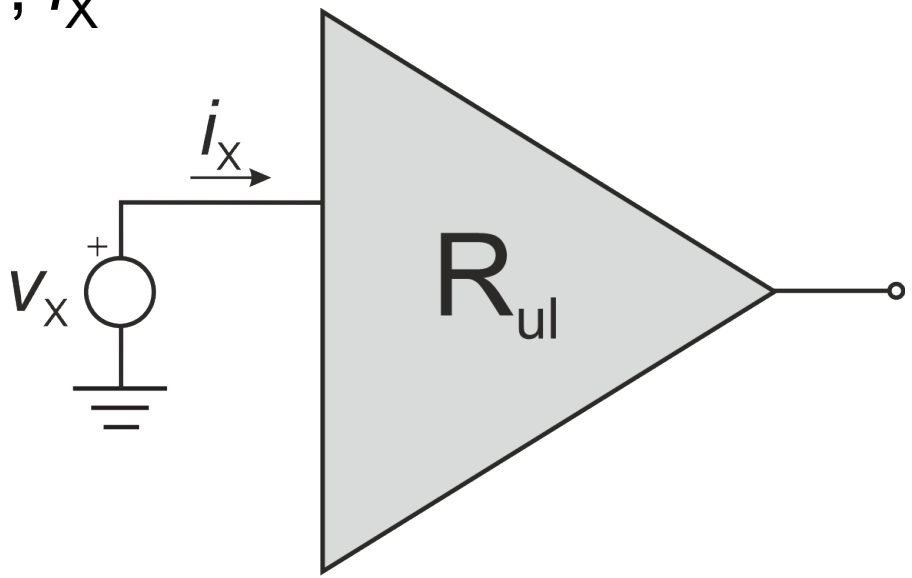
$$I_{DD} = I_{DSS}\left(\frac{V_0}{V_{TH}} - 1\right)^2$$

$$R_{DS} = \frac{1}{1/r_o + g_m} \qquad R_{DS} = r_o \,\|\, 1/g_m$$

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

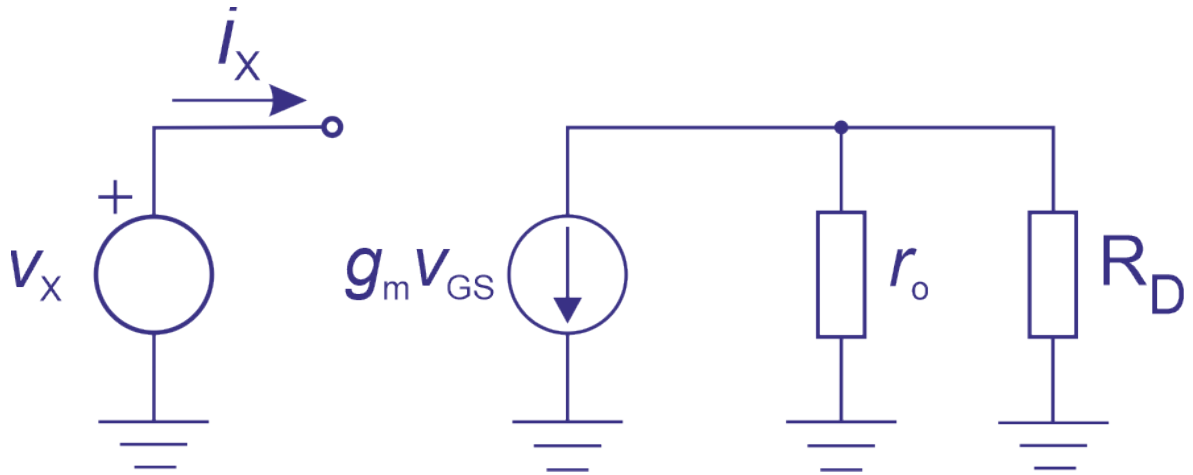
$$R_{ul} = \frac{v_X}{i_X}$$



Ulazna impedansa

$$i_X = 0$$

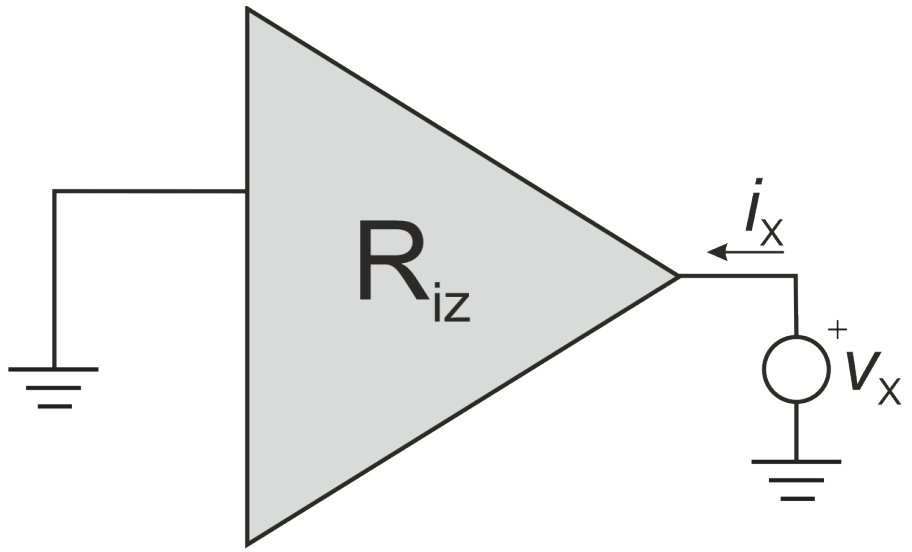
$$R_{ul} = \infty$$



Izlazna impedansa

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

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

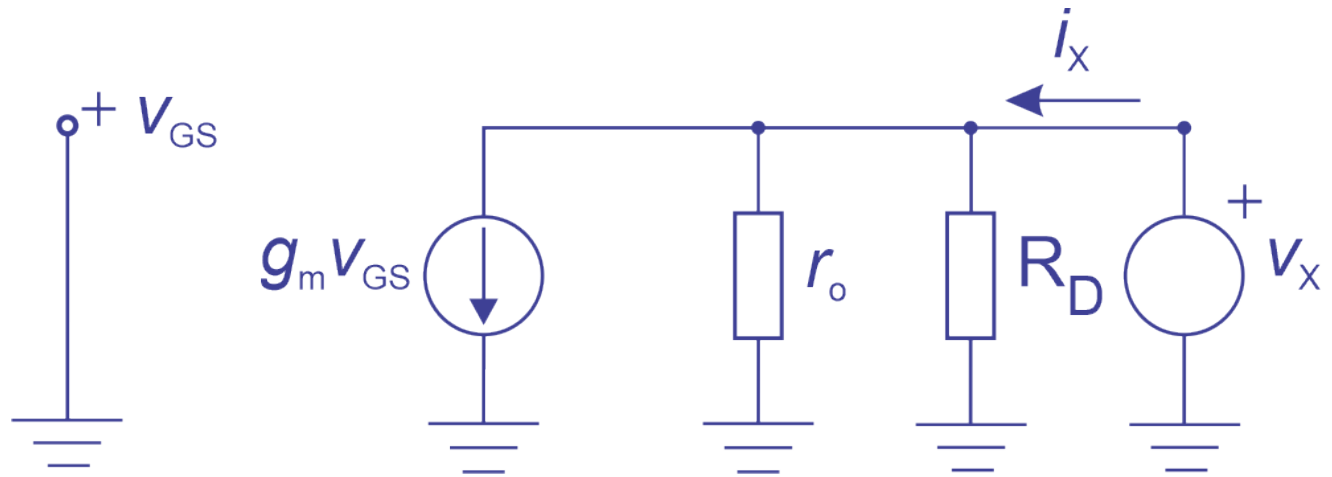


Izlazna impedansa

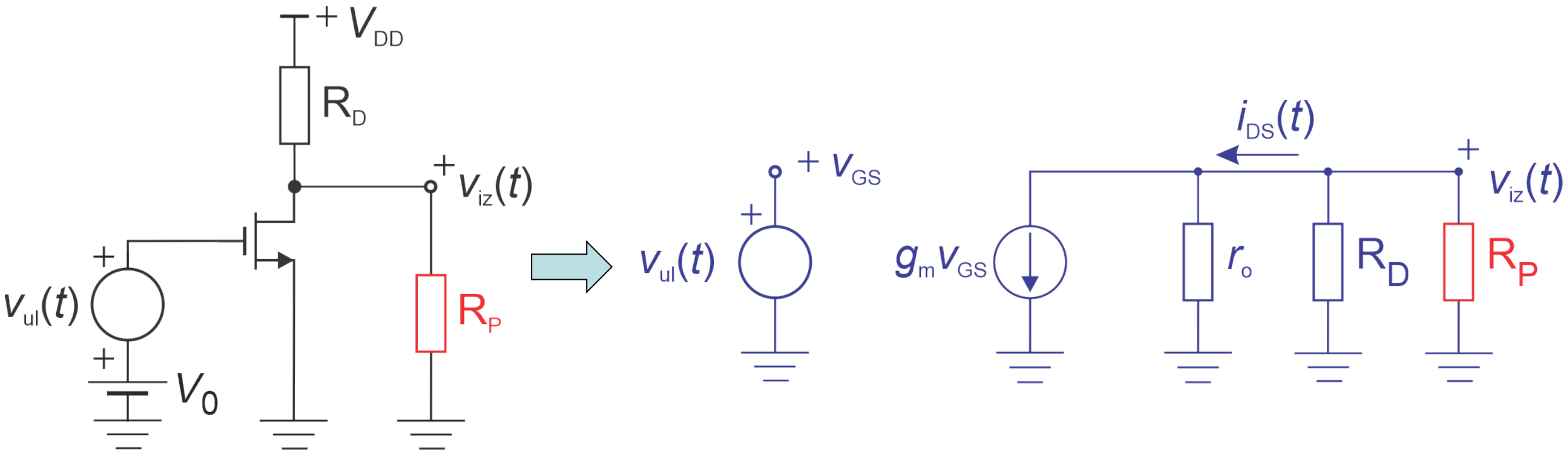
$$v_{GS} = 0$$

$$v_X = i_X \cdot \left(r_o \parallel R_D \right)$$

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



Uticaj otpornosti potrošača



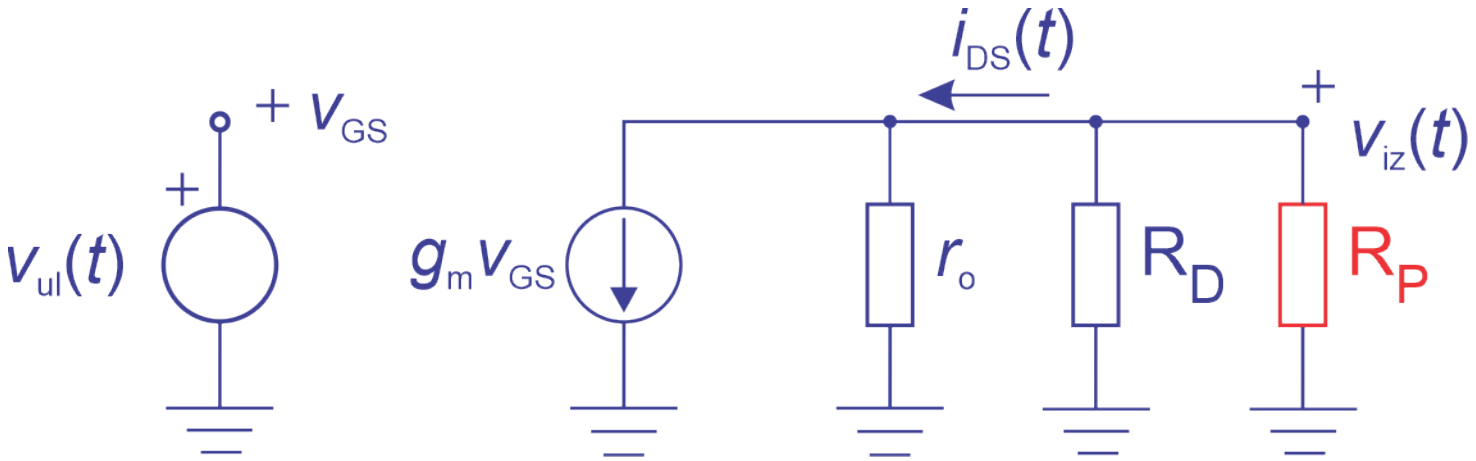
Uticaj otpornosti potrošača

$$v_{GS} = v_{ul}$$

$$v_{iz} = -g_m \cdot \left(R_D \parallel r_o \parallel R_P \right) \cdot v_{GS}$$

$$v_{iz} = -g_m \cdot \left(R_D \parallel r_o \parallel R_P \right) \cdot v_{ul}$$

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



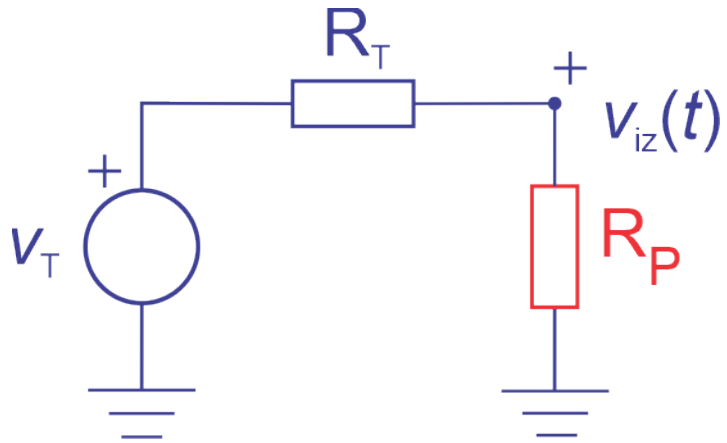
Uticaj otpornosti potrošača

$$v_T = -g_m \cdot \left(r_o \parallel R_D\right) \cdot v_{ul} \qquad R_T = R_{iz} = r_o \parallel R_D$$

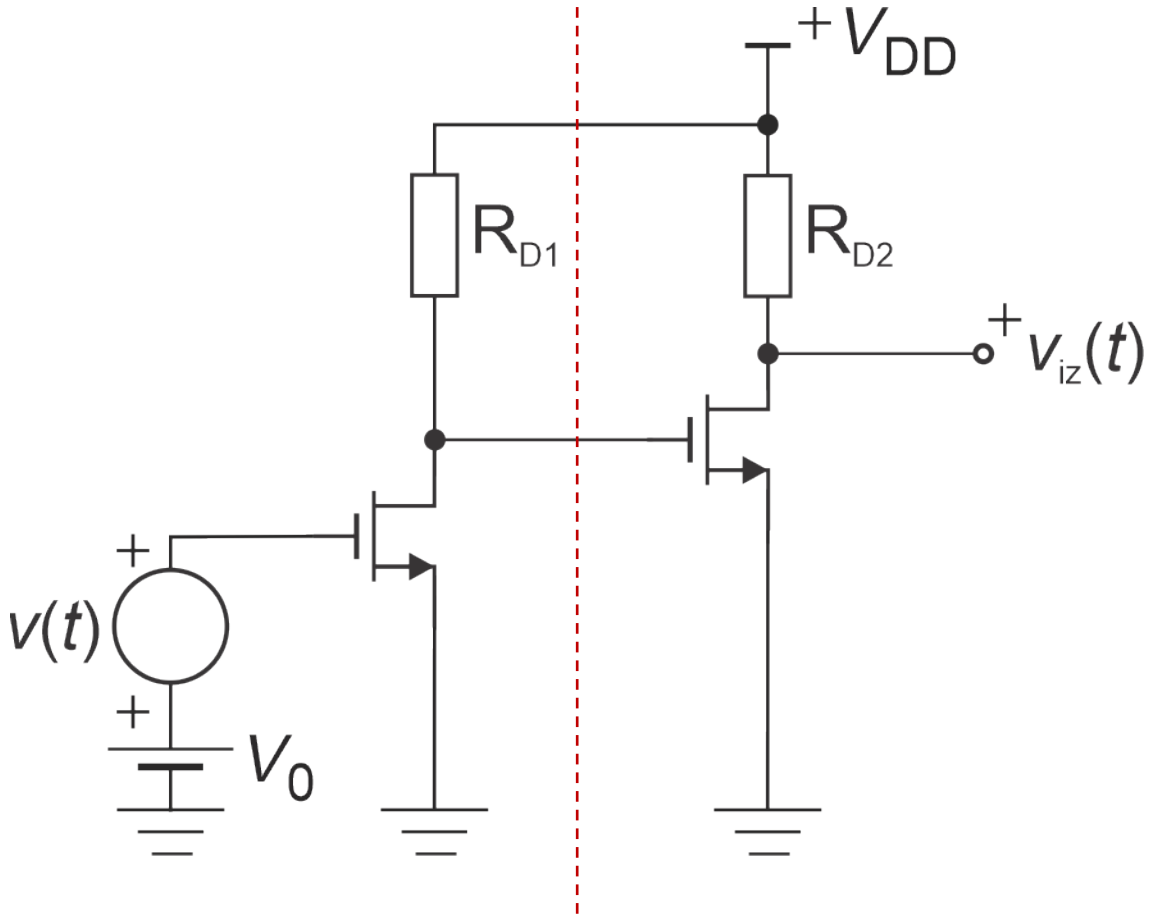
$$v_{iz} = \frac{R_P}{R_T + R_P} \cdot v_T$$

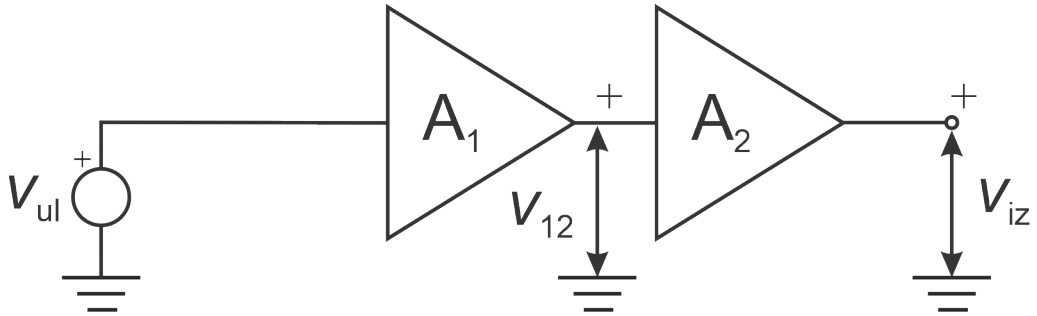
$$v_{iz} = -g_m \cdot \frac{R_P R_D r_o}{R_D r_o + R_D R_P + r_o R_P} \cdot v_{ul}$$

$$v_{iz} = -g_m \cdot \left(r_o \parallel R_D \parallel R_P\right) \cdot v_{ul}$$



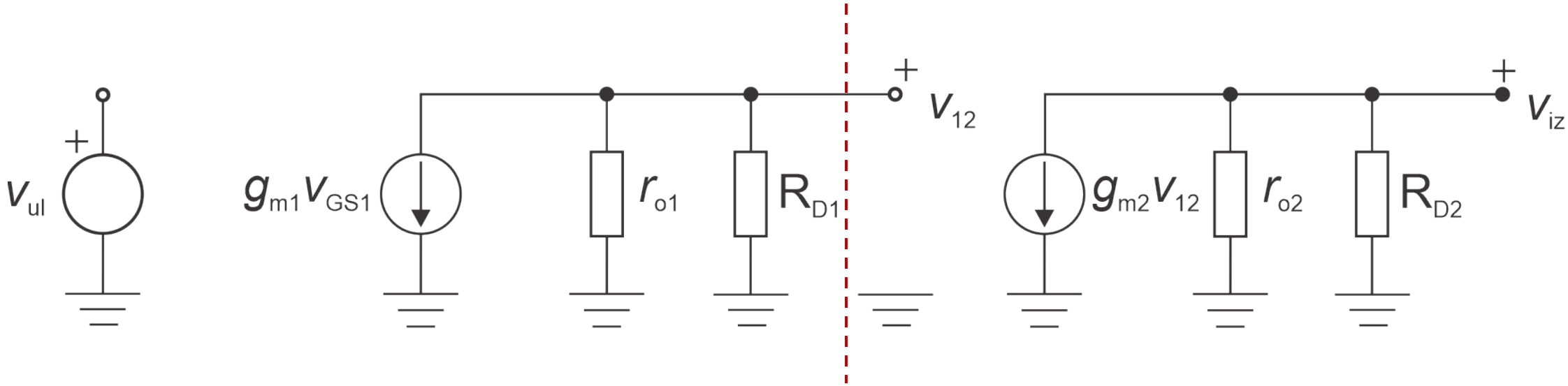
Kaskadna veza pojačavača





$A=A_1A_2$?

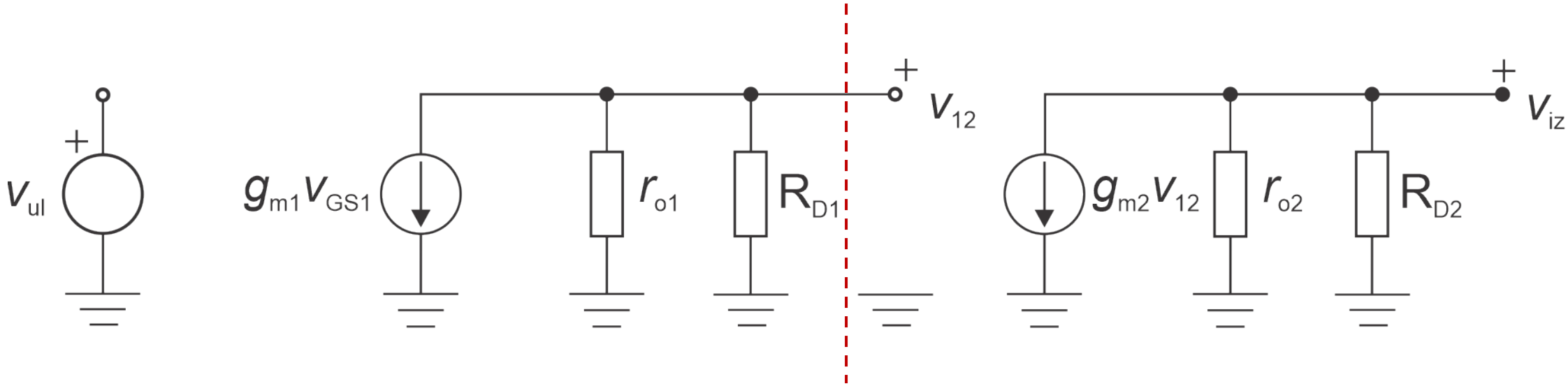
Kaskadna veza pojačavača



$$v_{12} = -g_{m1} \cdot \left(r_{o1} \parallel R_{D1} \right) \cdot v_{ul}$$

$$v_{iz} = -g_{m2} \cdot \left(r_{o2} \parallel R_{D2} \right) \cdot v_{12}$$

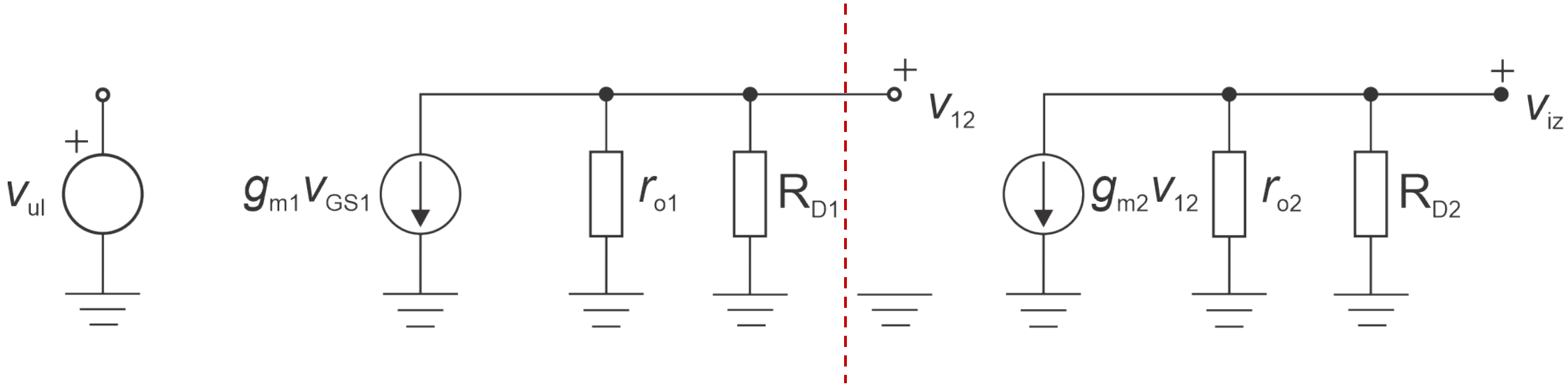
Kaskadna veza pojačavača



$$A_1 = -g_{m1} \cdot \left(r_{o1} \parallel R_{D1} \right)$$

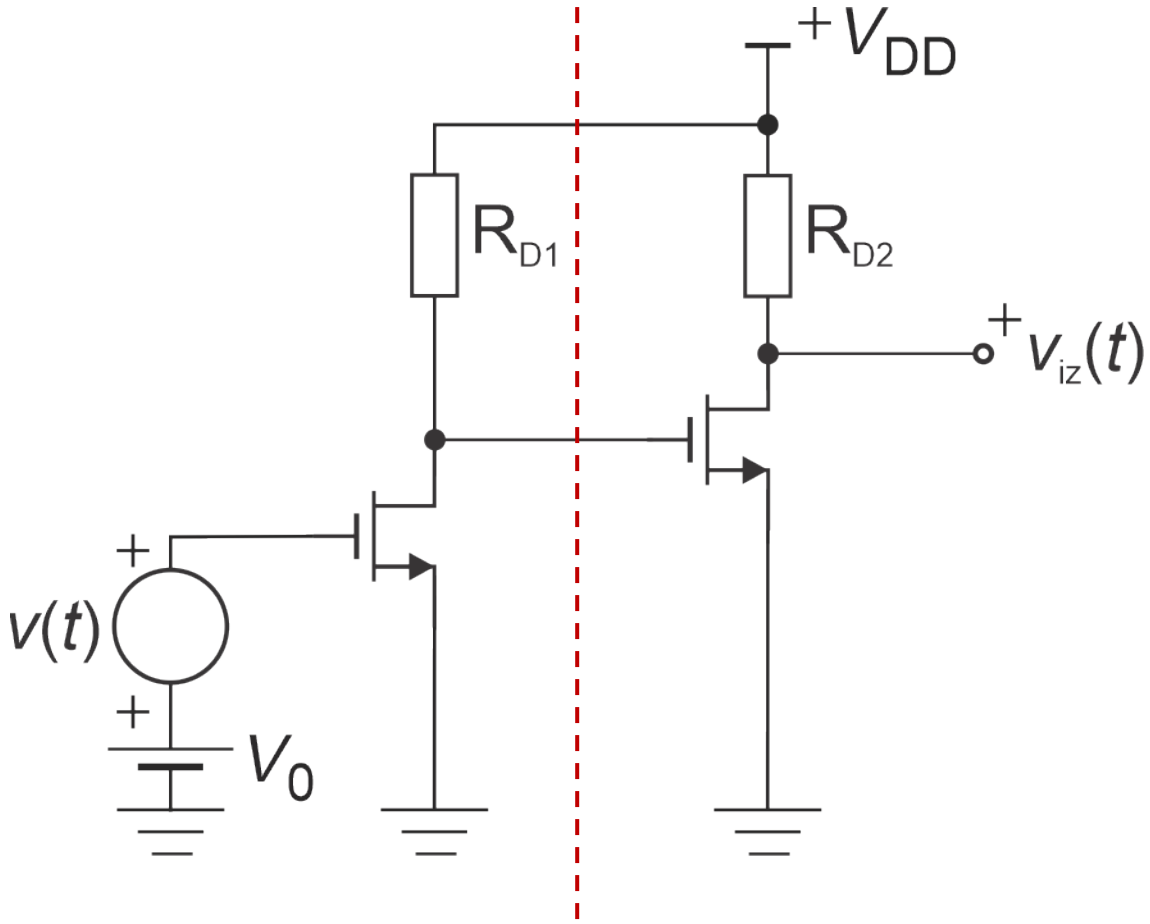
$$A_2 = -g_{m2} \cdot \left(r_{o2} \parallel R_{D2} \right)$$

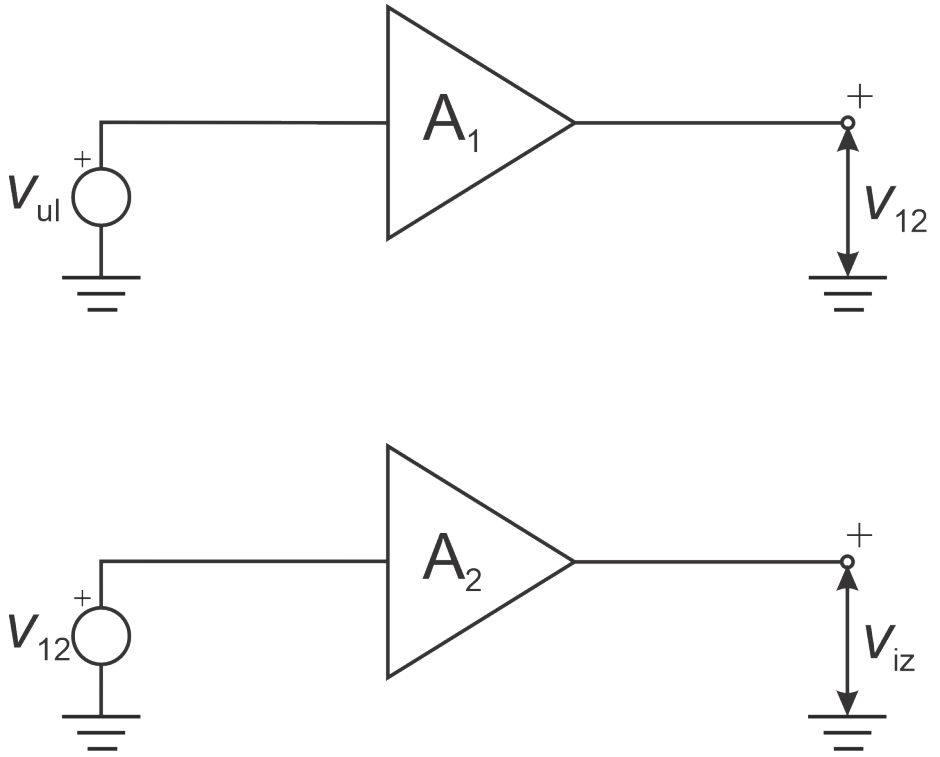
Kaskadna veza pojačavača



$$A = A_1 A_2 = g_{m1} \cdot g_{m2} \cdot \left(r_{o1} \parallel R_{D1}\right) \cdot \left(r_{o2} \parallel R_{D2}\right)$$

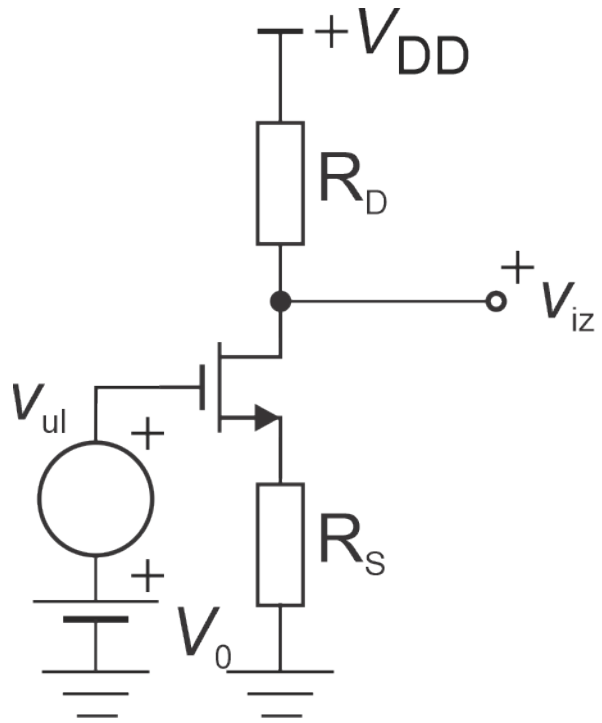
Kaskadna veza pojačavača





Degenerisani sors

- Otpornik u grani sorsa, polarizacija



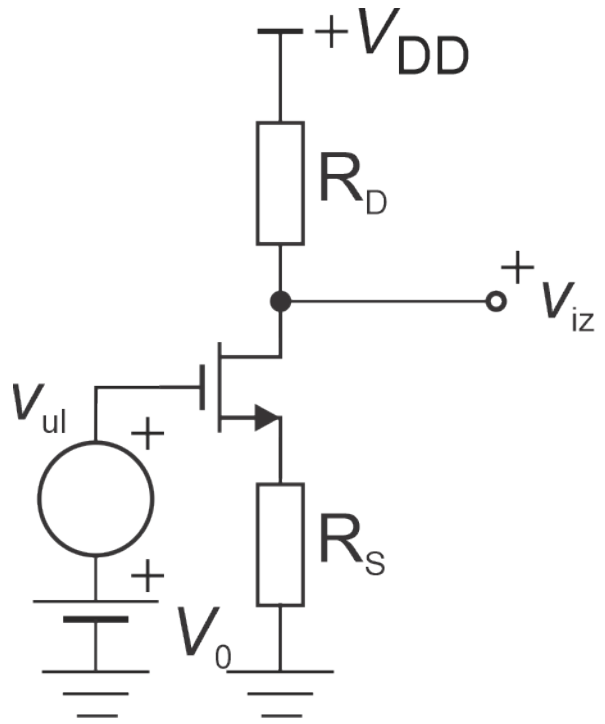
$$V_{DS} > V_{DS} - V_{TH}$$

$$V_{GS} = V_0 - I_{DS} R_S$$

$$I_{DS} = I_{DSS} \left(\frac{V_{GS}}{V_{TH}} - 1 \right)^2$$

$$I_{DS} = \frac{I_{DSS}}{V_{TH}^2} \left(V_0 - I_{DS} R_S - V_{TH} \right)^2$$

Degenerisani sors



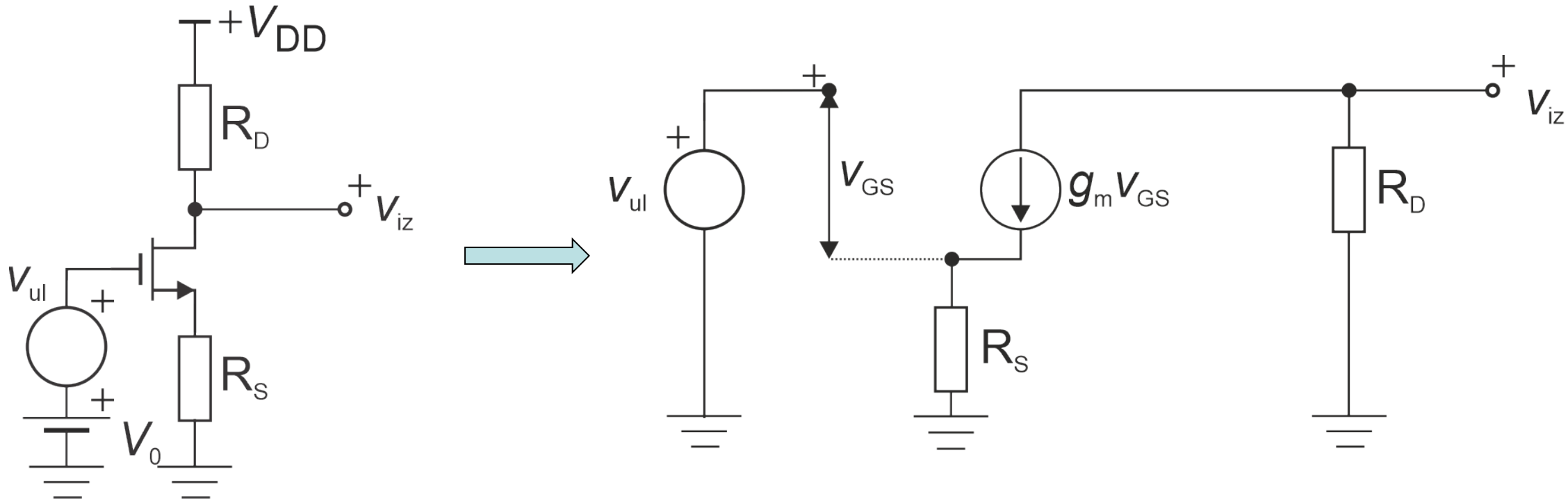
$$I_{DS}^2 R_S^2 - \left(2\left(V_0 - V_{TH}\right) R_S + \frac{V_{TH}^2}{I_{DSS}} \right) I_{DS} + \left(V_0 - V_{TH}\right)^2 = 0$$

$$I_{DS} = \ldots$$

- Ukoliko rešenja nisu realna, MOS tranzistor nije u zasićenju

Degenerisani sors

- Model za male signale ($r_o=\infty$)

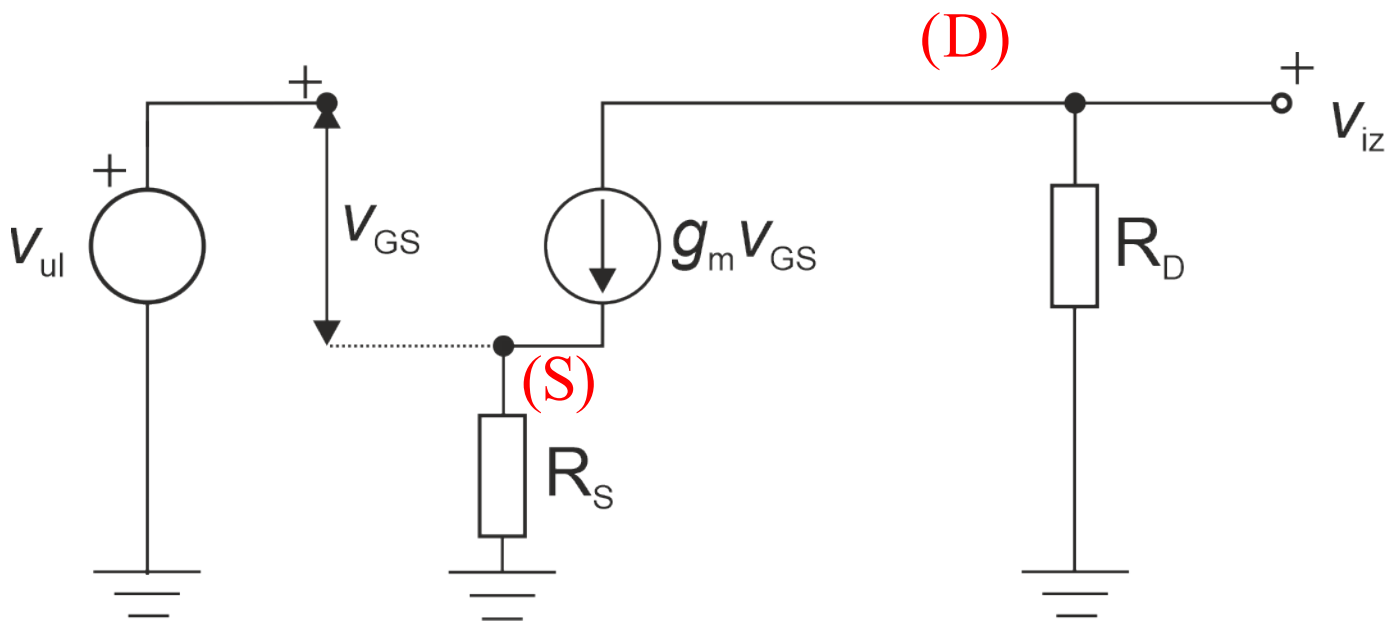


Degenerisani sors – pojačanje

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

$$v_{\text{iz}} = -g_{\text{m}} R_{\text{D}} v_{\text{GS}}$$

$$v_{\text{ul}} = v_{\text{GS}} + g_{\text{m}} v_{\text{GS}} R_{\text{S}} \quad \text{(S)}$$

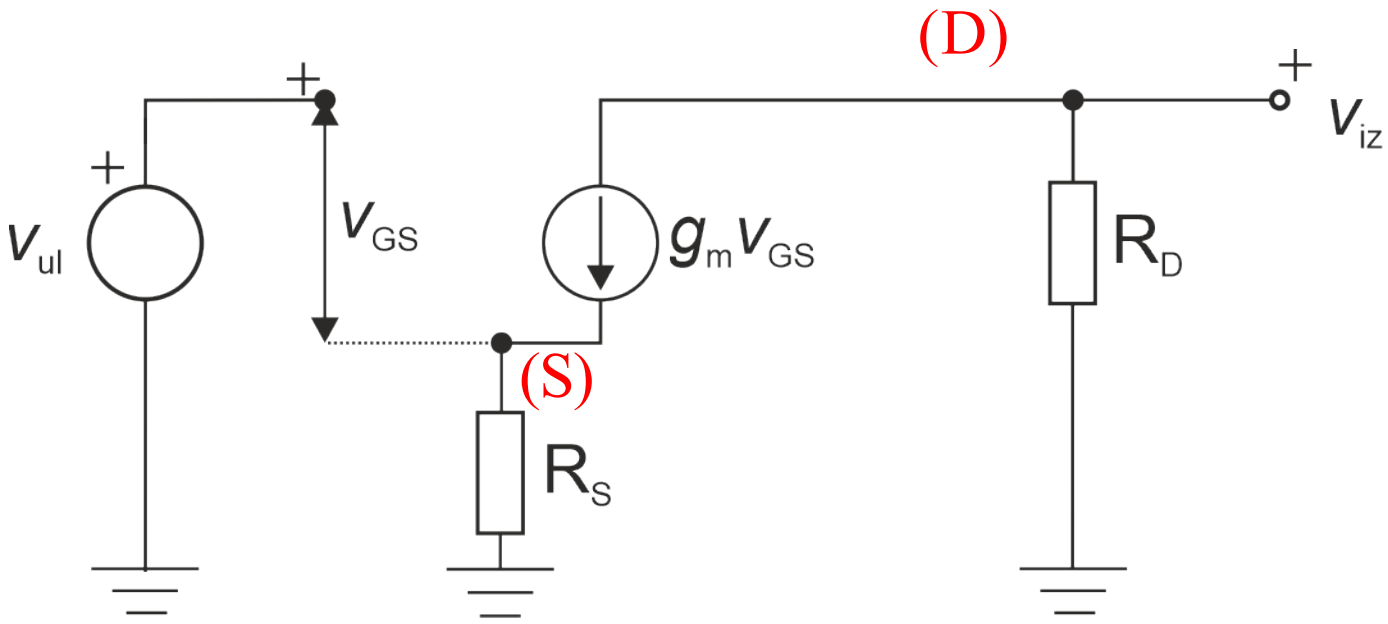


Degenerisani sors – pojačanje

$$v_{GS} = \frac{v_{ul}}{1 + g_m R_S}$$

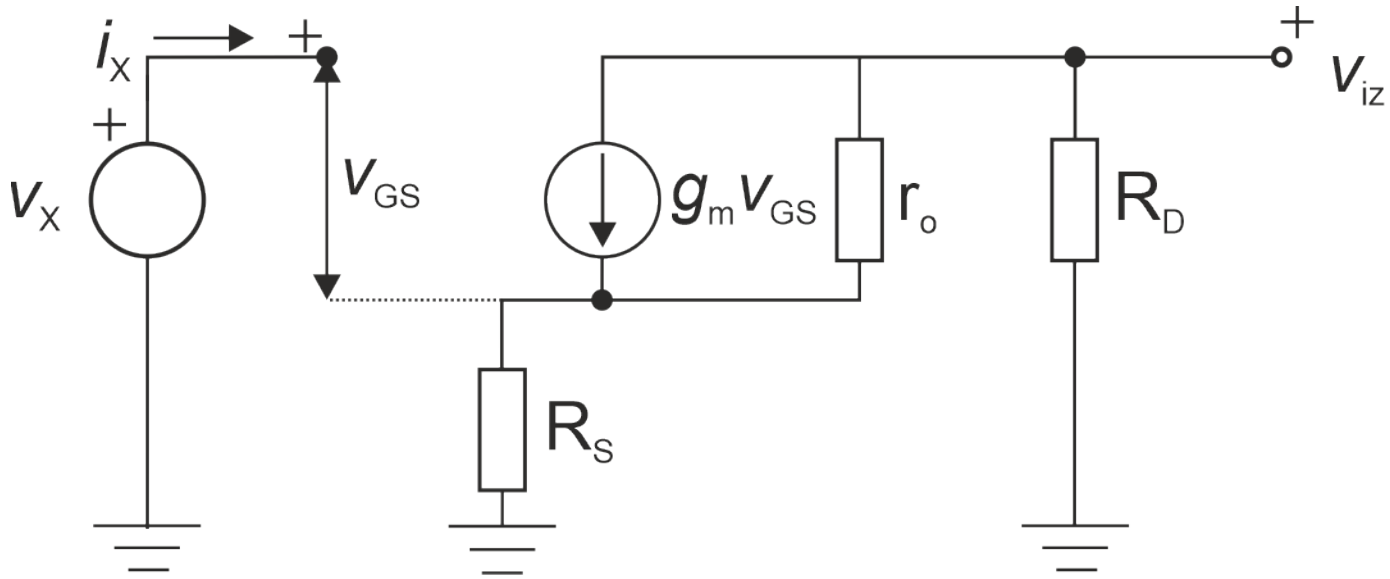
$$v_{iz} = -\frac{g_m R_D}{1 + g_m R_S} v_{ul}$$

$$A = -\frac{g_m R_D}{1 + g_m R_S}$$



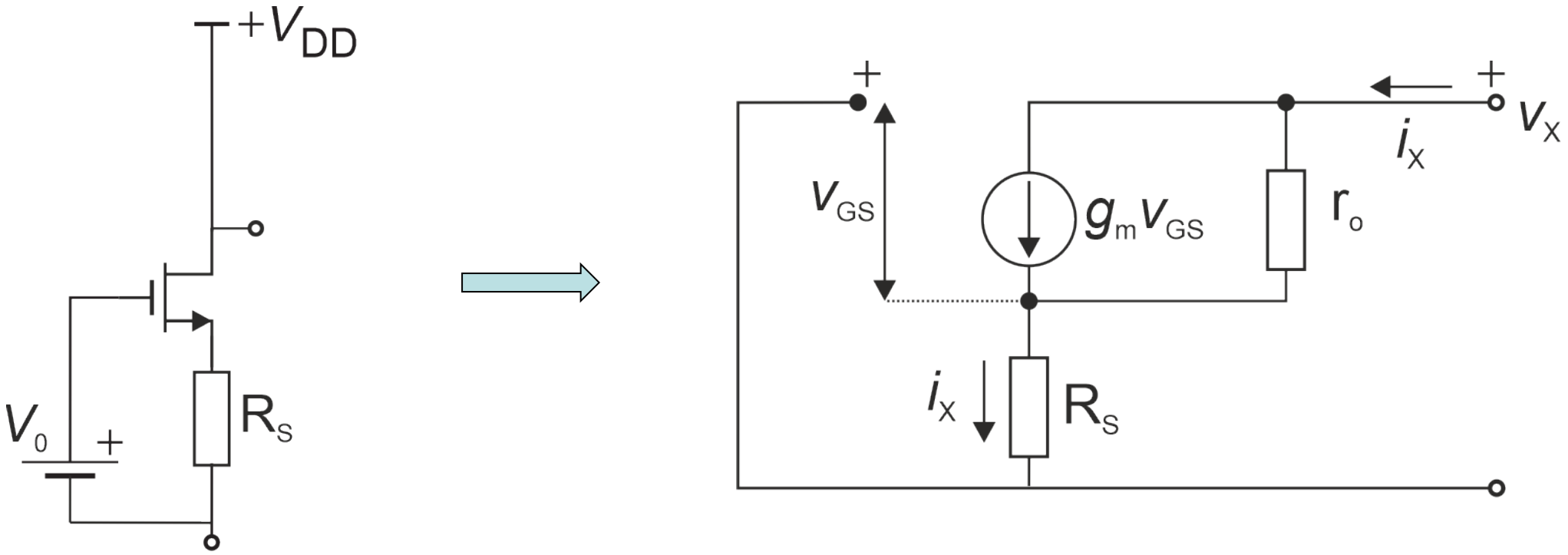
Degenerisani sors – ulazna impedansa

$$R_{ul} = \infty$$



Strujni izvor sa degenerisanim sorsom – impedansa

- Model za male signale (r_o)



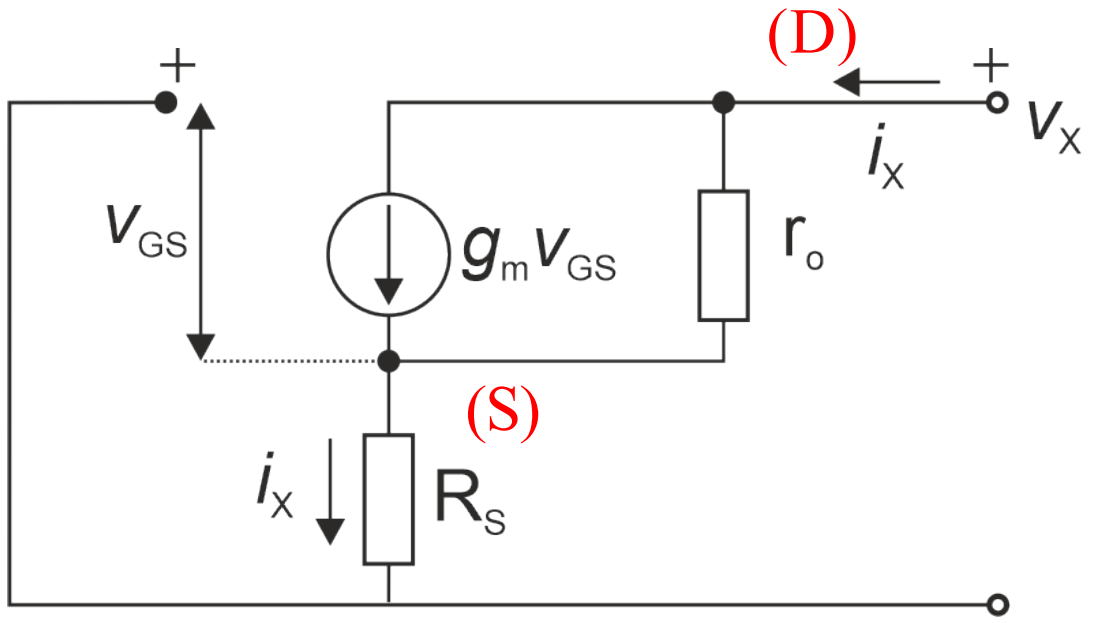
Strujni izvor sa degenerisanim sorsom – impedansa

$$v_{GS} = -i_X R_S \quad \text{(S)}$$

$$v_X = \left(i_X - g_m v_{GS}\right) r_o + i_X R_S$$

$$v_X = \left(i_X + i_X g_m R_S\right) r_o + i_X R_S$$

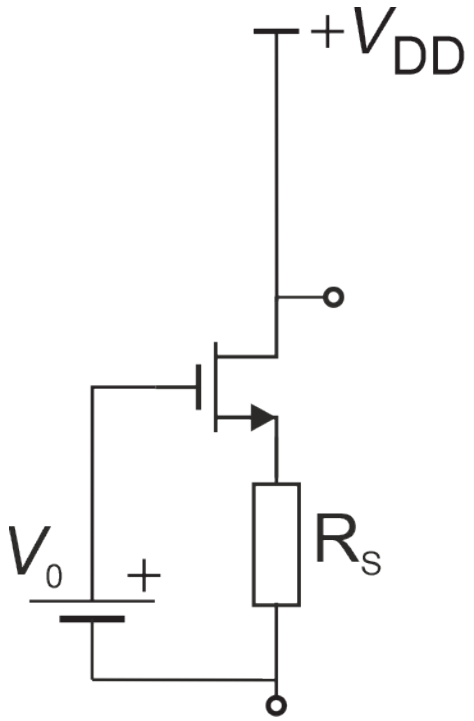
$$\frac{v_X}{i_X} = \left(1 + g_m R_S\right) r_o + R_S$$



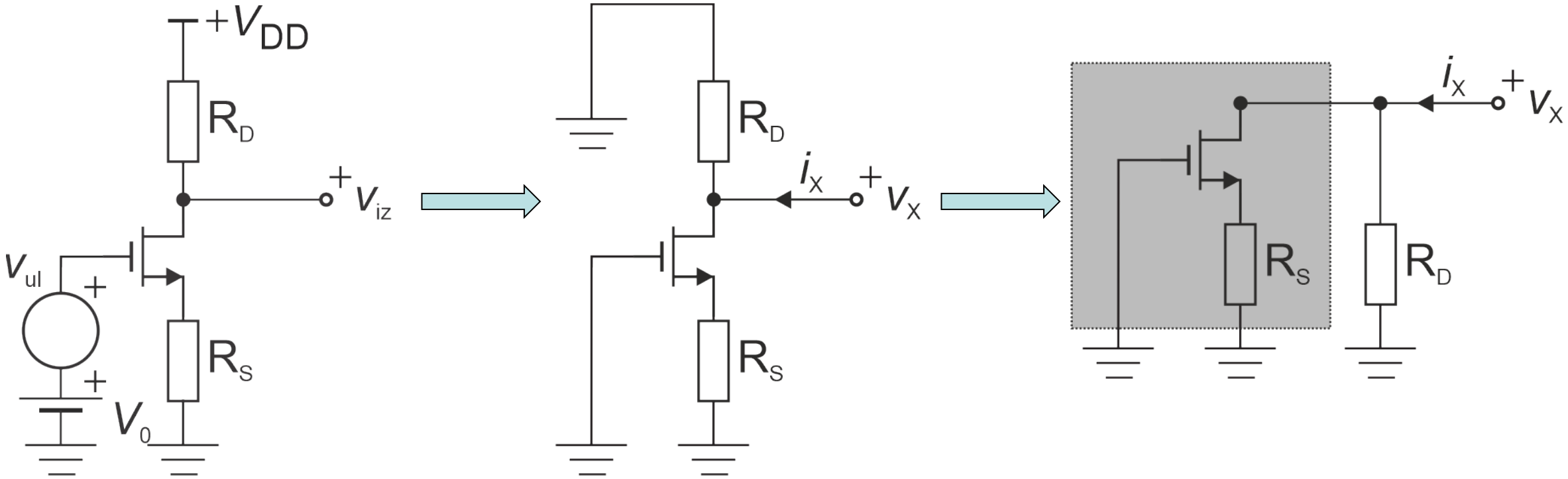
Strujni izvor sa degenerisanim sorsom – impedansa

$$R_{DS} = \left(1 + g_m R_S\right) r_o + R_S$$

$$R_{DS} = \left(1 + g_m r_o\right) R_S + r_o$$



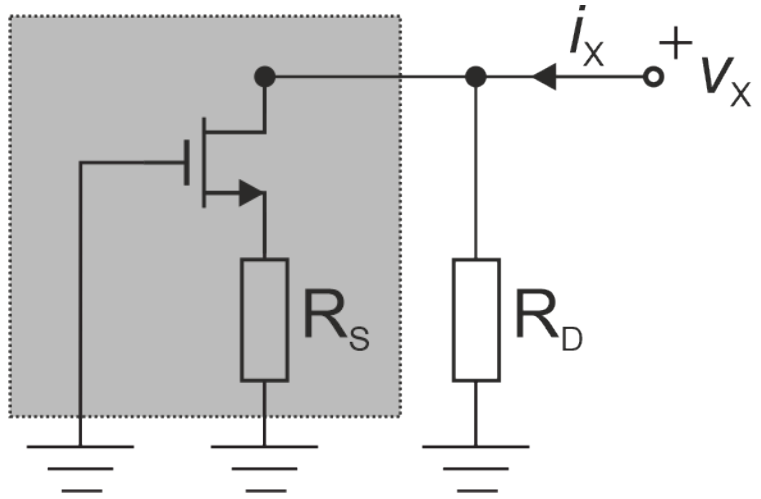
Degenerisani sors – izlazna impedansa



Degenerisani sors – izlazna impedansa

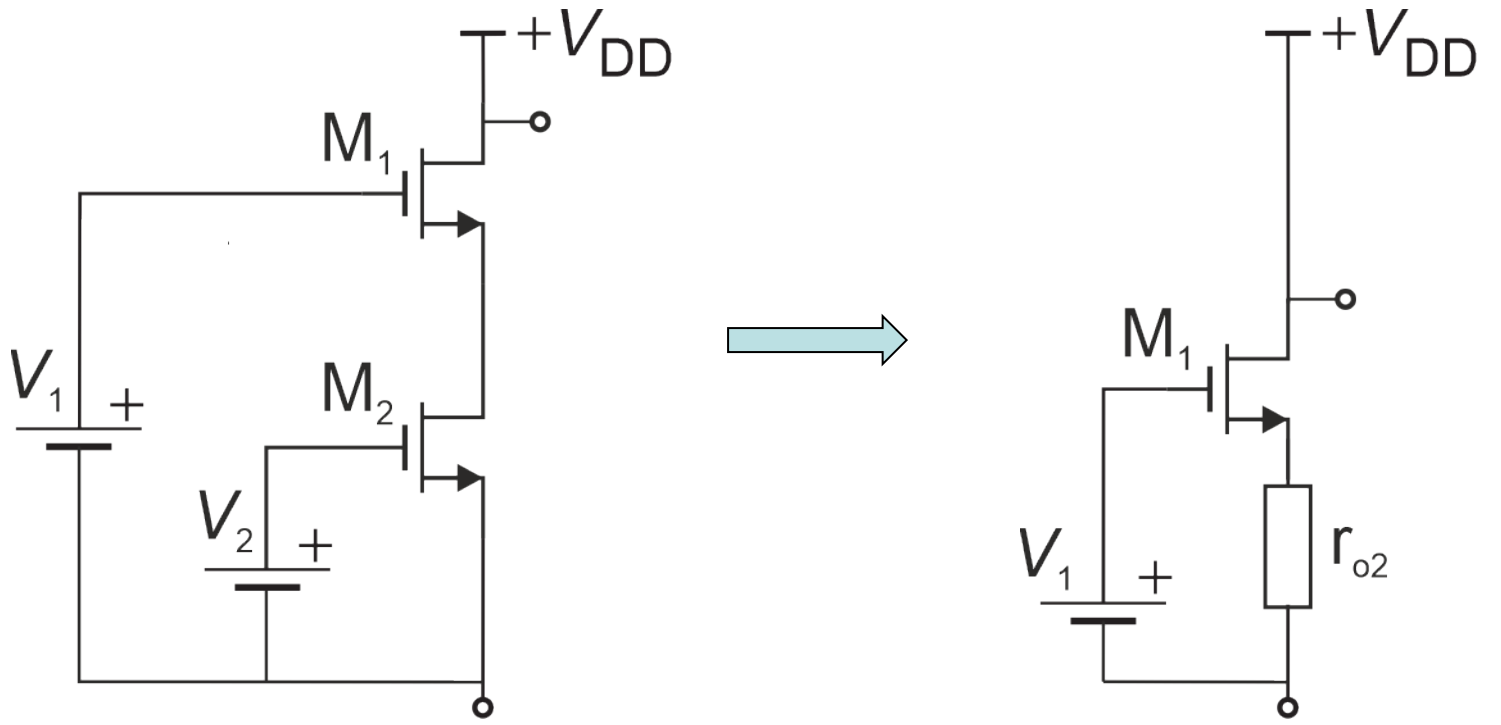
$$R_{iz} = R_D \parallel R_{DS}$$

$$R_{iz} = R_D \parallel \left(\left(1 + g_m r_o \right) R_S + r_o \right)$$



Kaskodna veza

- Otpornik R_S je zamenjen izvorom konstantne struje

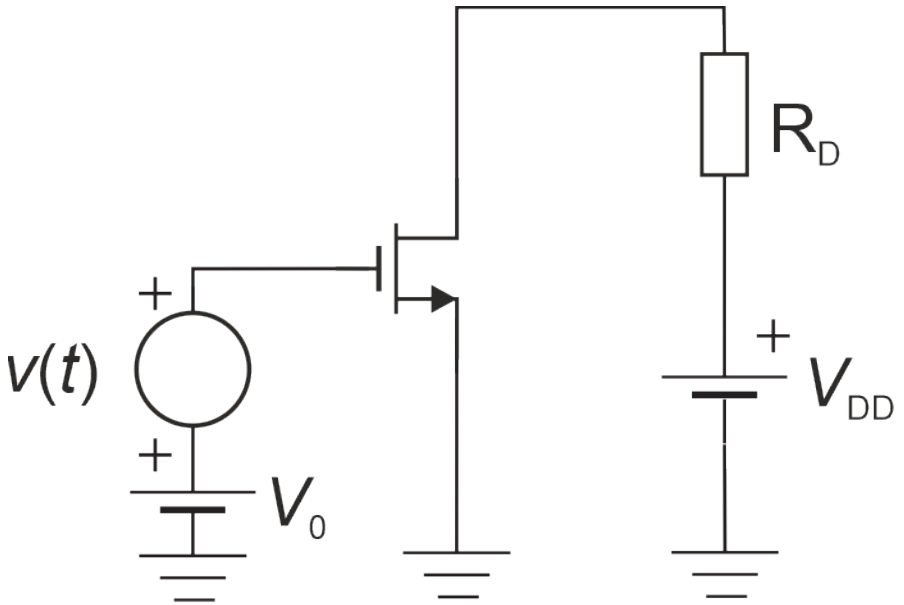


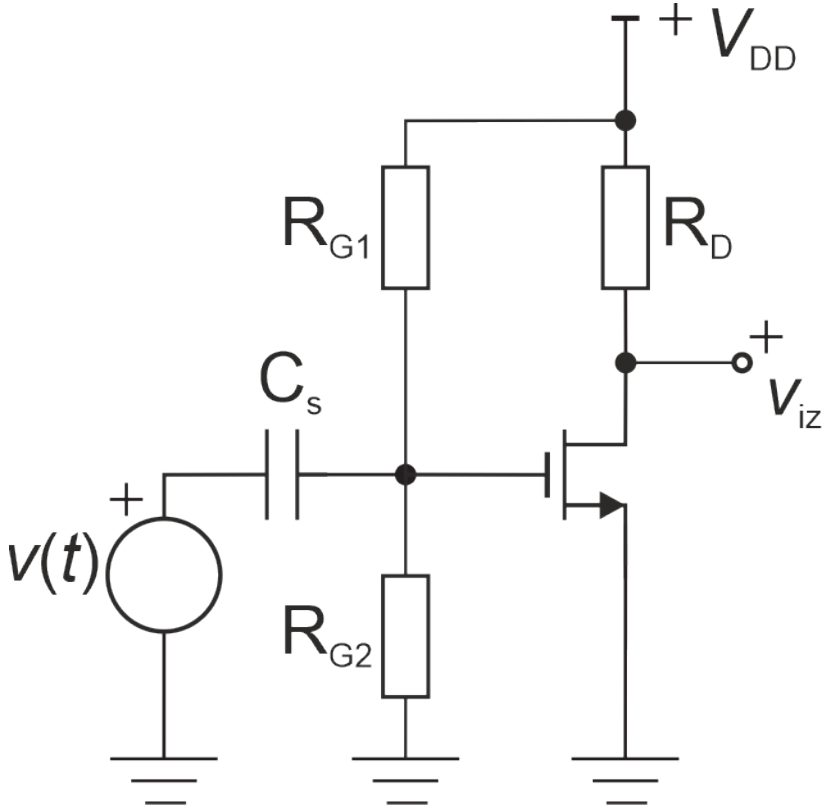
$$R_{DS} = \left(1 + g_{m1} r_{o2}\right) r_{o1} + r_{o2}$$

$$R_{DS} = \left(1 + g_{m1} r_{o1}\right) r_{o2} + r_{o1}$$

Kola za polarizaciju

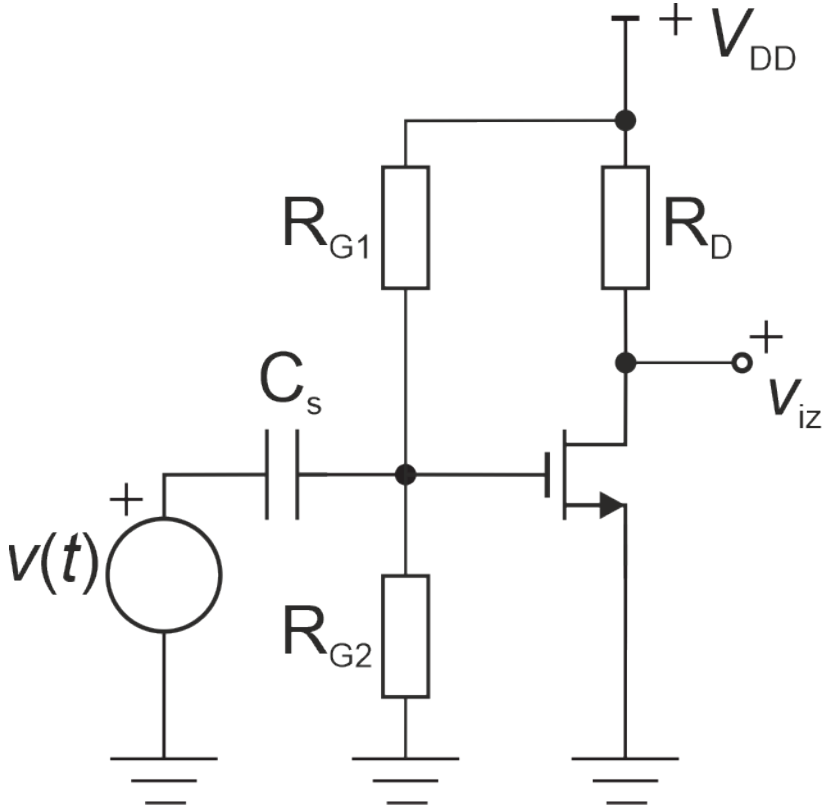
$$V_{GS} = \frac{R_{G1}}{R_{G1} + R_{G2}} V_{DD}$$





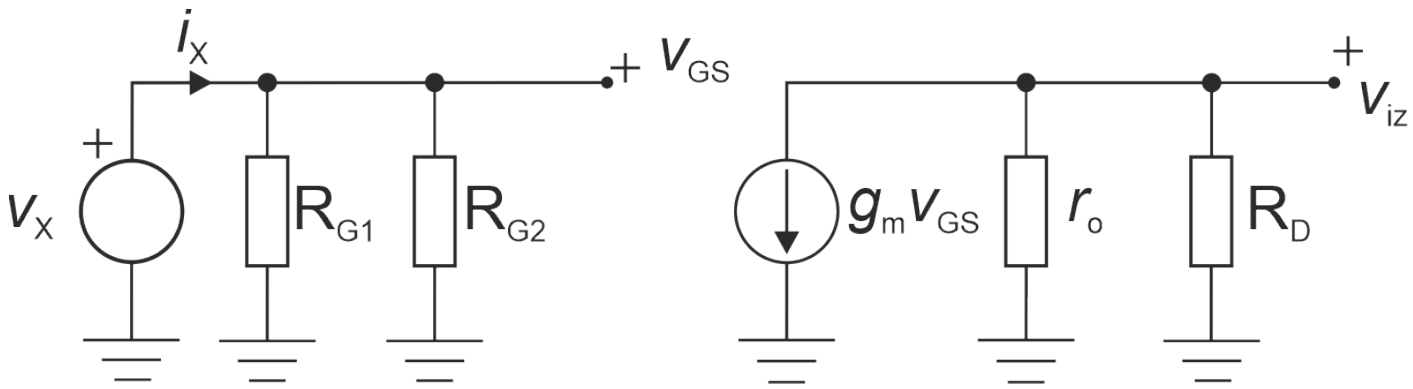
Kola za polarizaciju

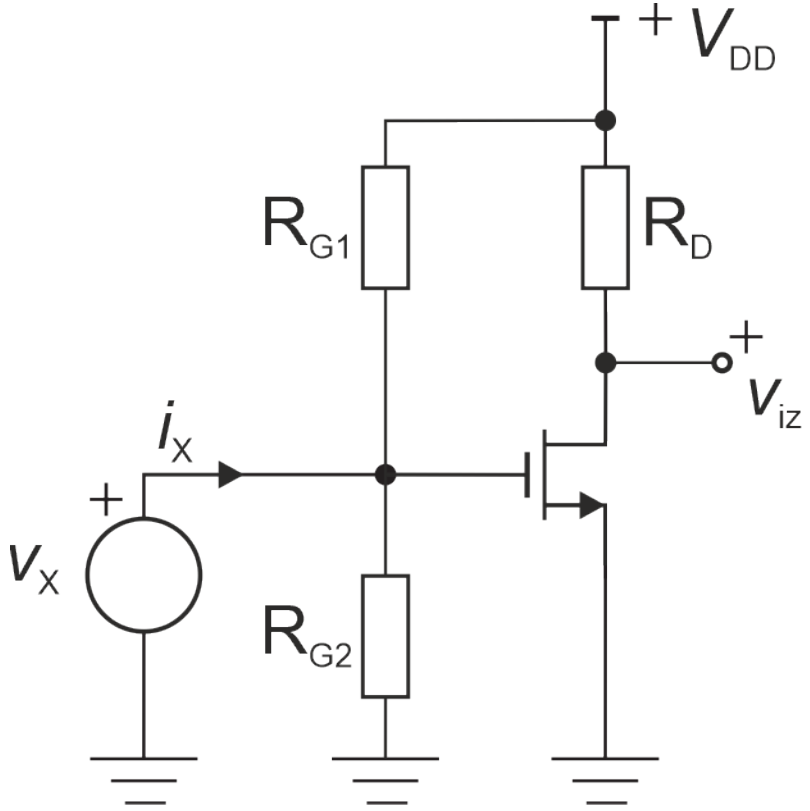
- Ukoliko je otpornost izvora signala mala, otpornik R_{G2} je kratkospojen, da bi se postigao odgovarajući jednosmerni napon na gejtu, postavlja se otpornik C_s, koji predstavlja prekid u jednosmernom režimu
- Kapacitivnost C_s je velika, tako da predstavlja kratak spoj za naizmeničan signal



Kola za polarizaciju – ulazna impedansa

$$R_{ul} = R_{G1} \parallel R_{G2}$$





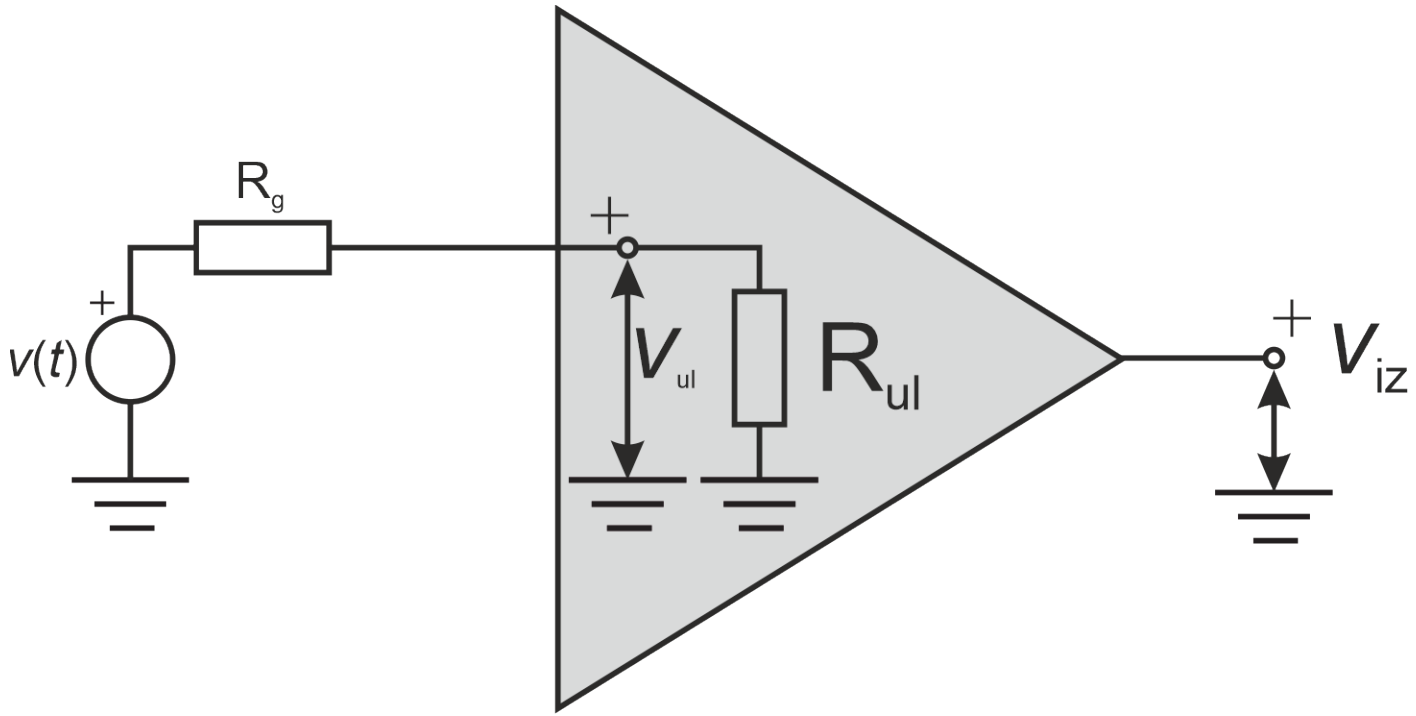
Kola za polarizaciju - pojačanje

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

$$v_{ul} = \frac{R_{ul}}{R_g + R_{ul}} v$$

$$\frac{v_{iz}}{v_{ul}} = -g_m R_D$$

$$A = -\frac{R_{G1} \parallel R_{G2}}{R_g + R_{G1} \parallel R_{G2}} g_m R_D$$



Kola za polarizaciju - pojačanje

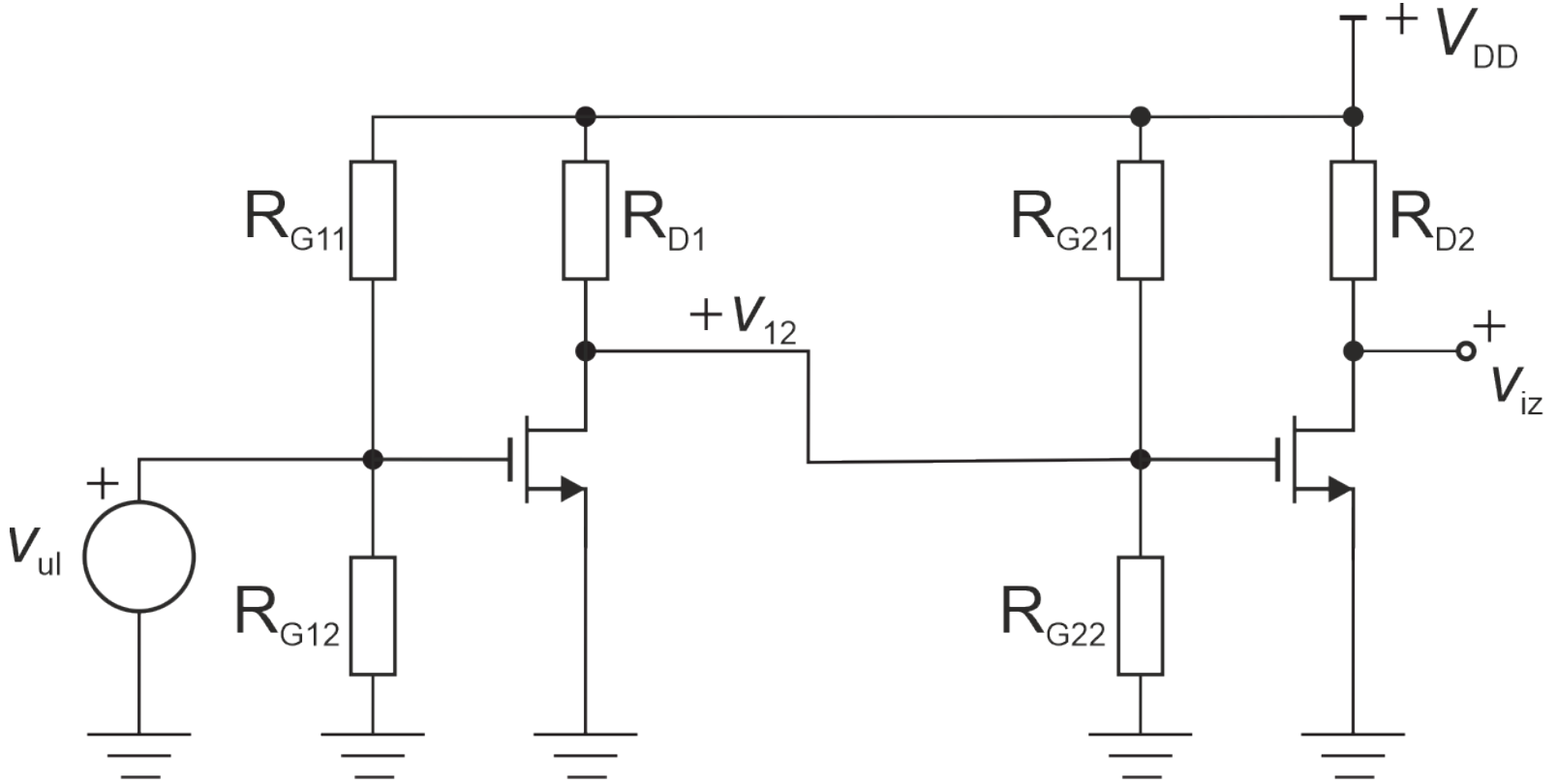
- Manje pojačanje zbog unutrašnje otpornosti izvora signala

$$A = -\frac{R_{G1} \parallel R_{G2}}{R_g + R_{G1} \parallel R_{G2}} g_m R_D$$

- Prilikom izbora otpornika, potrebno je:

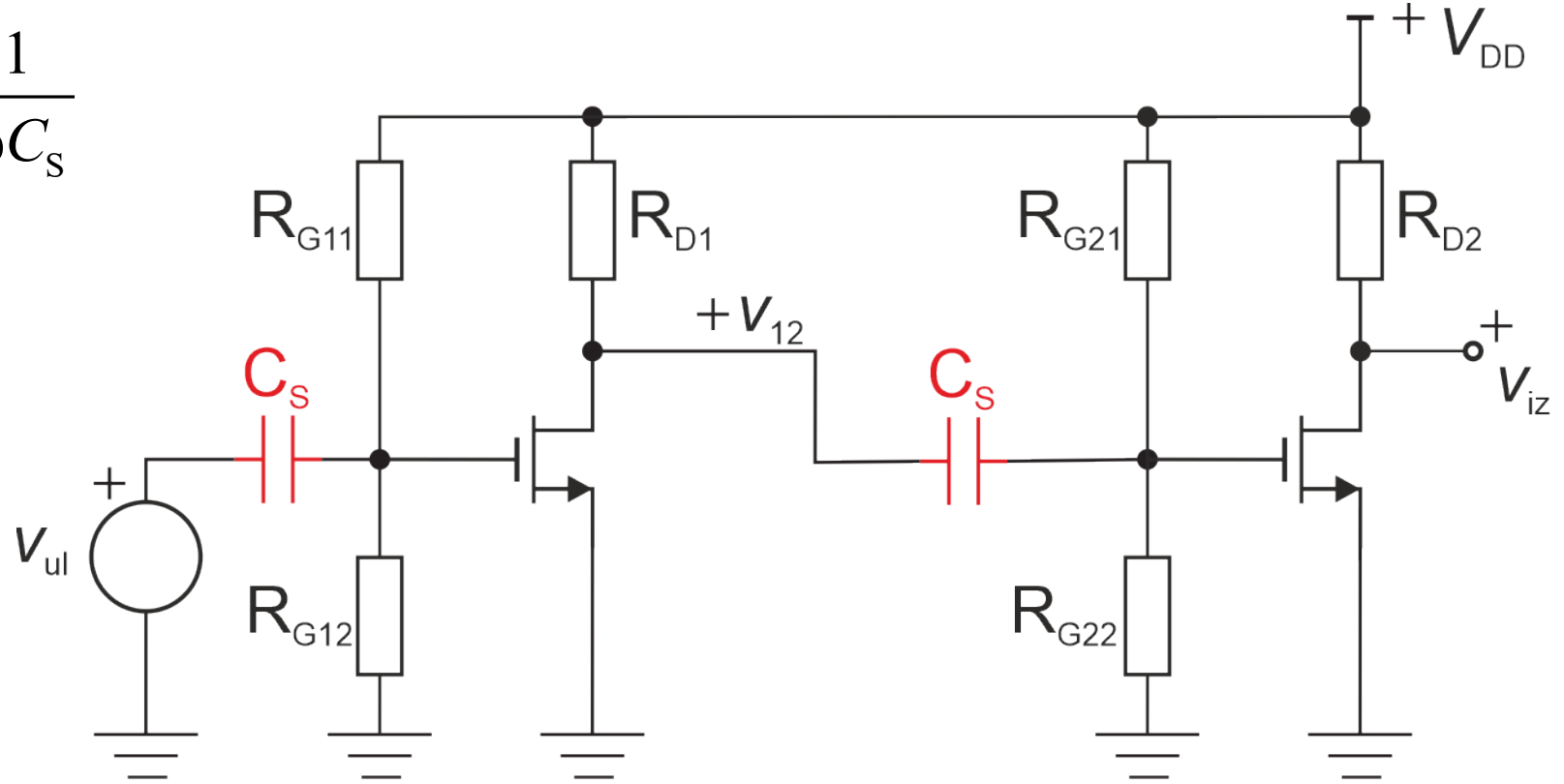
$$R_{G1} \parallel R_{G2} \gg R_g$$
$$R_{G1} \parallel R_{G2} \gg 1/\omega C_s$$

Kola za polarizaciju



Kola za polarizaciju

$$R_{ul1}, R_{ul2} \gg \frac{1}{\omega C_S}$$

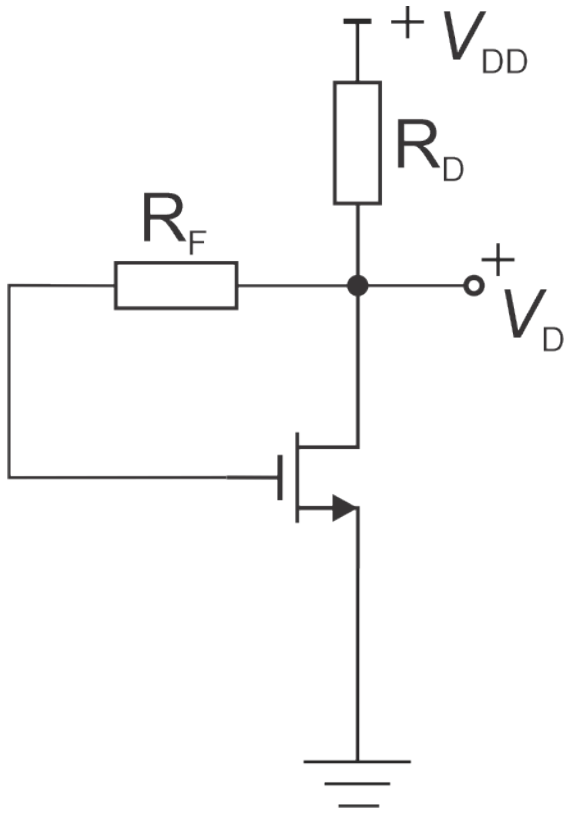


Kola za polarizaciju

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

$$V_{\mathrm{G}} = V_{\mathrm{D}} = V_{\mathrm{DD}} - I_{\mathrm{DS}} R_{\mathrm{D}}$$

$$V_{\mathrm{DS}} = V_{\mathrm{GS}} > V_{\mathrm{GS}} - V_{\mathrm{TH}}$$

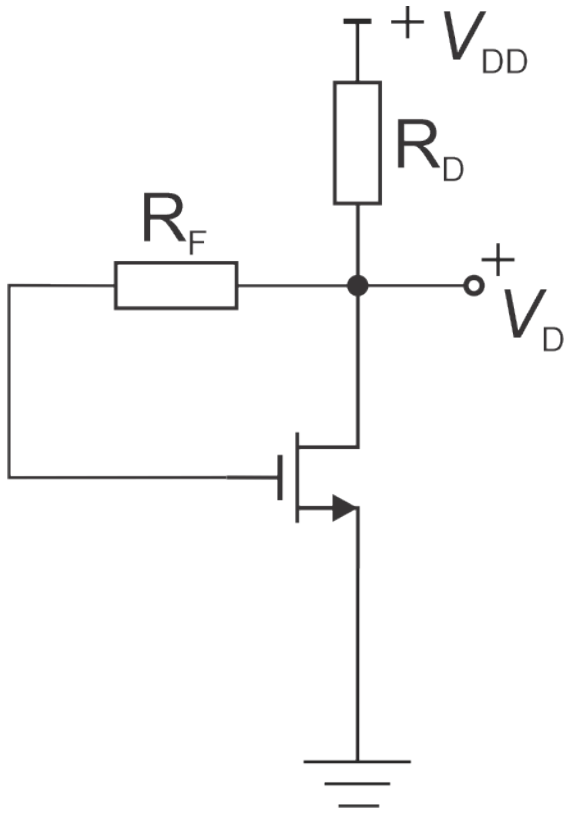


Kola za polarizaciju

$$I_{DS} = I_{DSS}\left(\frac{V_{GS}}{V_{TH}} - 1\right)^2$$

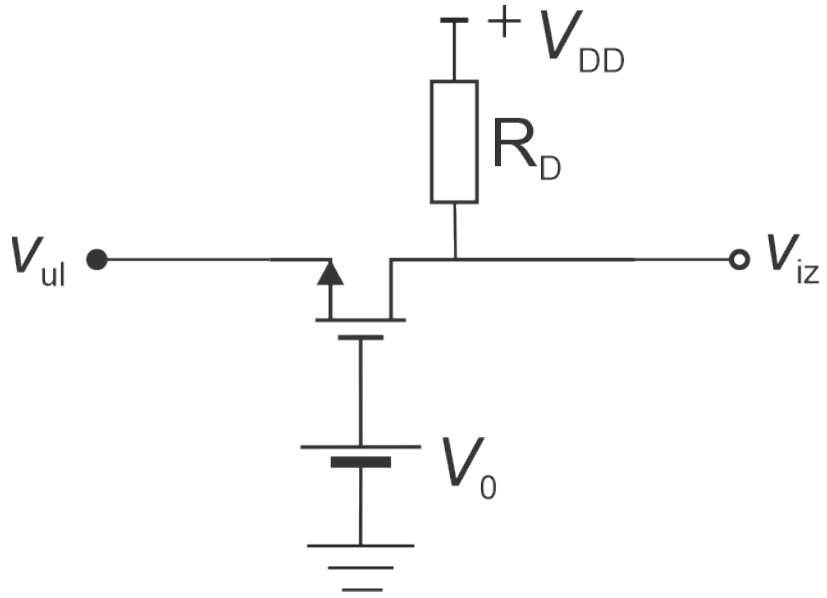
$$I_{DS} = I_{DSS}\left(\frac{V_{DD} - R_D I_{DS}}{V_{TH}} - 1\right)^2$$

$$I_{DS} = \ldots$$



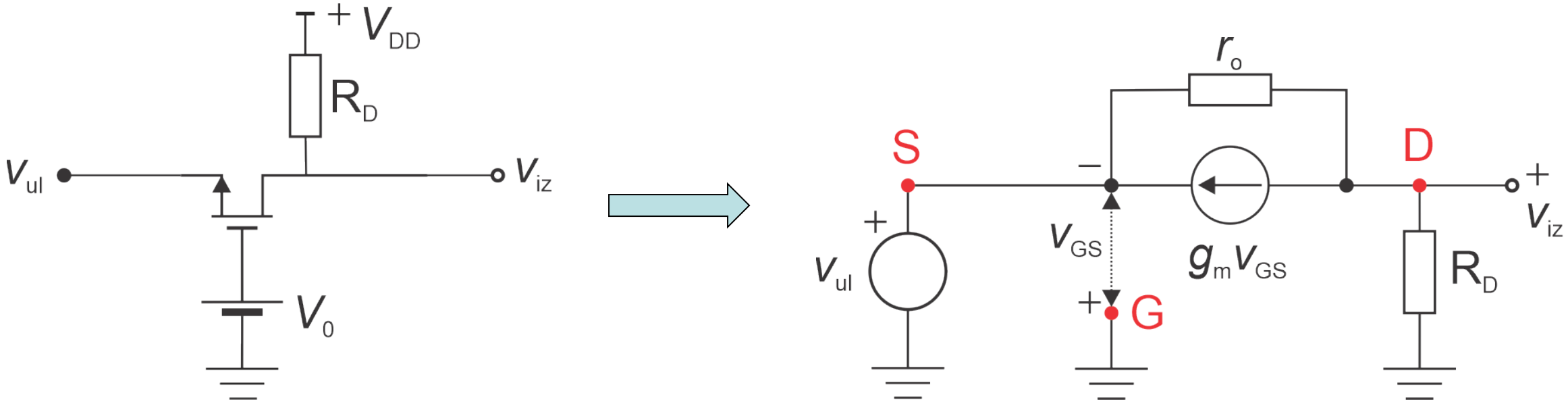
Pojačavač sa zajedničkim gejtom

- Pojačanje, ulazna i izlazna impedansa, polarizacija



Pojačavač sa zajedničkim gejtom

- Kolo za male signale



Pojačavač sa zajedničkim gejtom – pojačanje

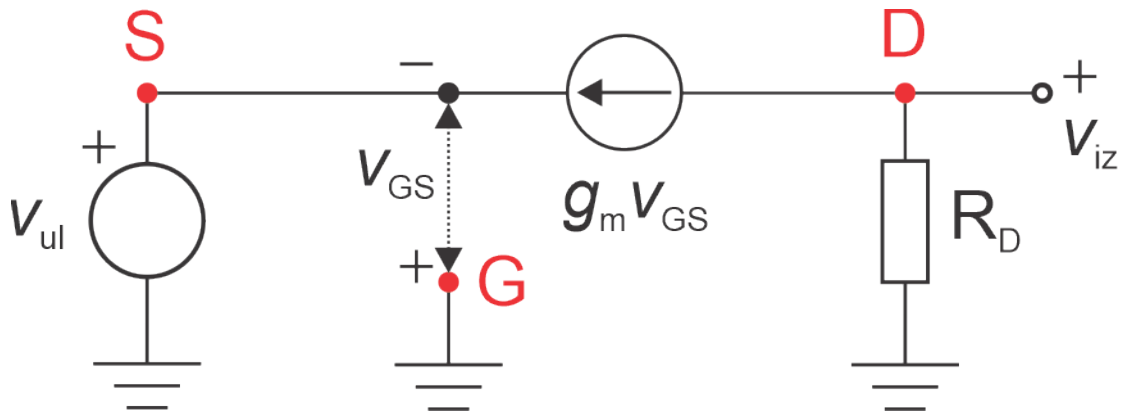
- Kolo za male signale, zanemarićemo modulaciju dužine ($r_o=\infty$)

$$v_{GS} = -v_{ul}$$

$$v_{iz} = -g_m v_{GS} R_D$$

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

$$A = g_m R_D$$



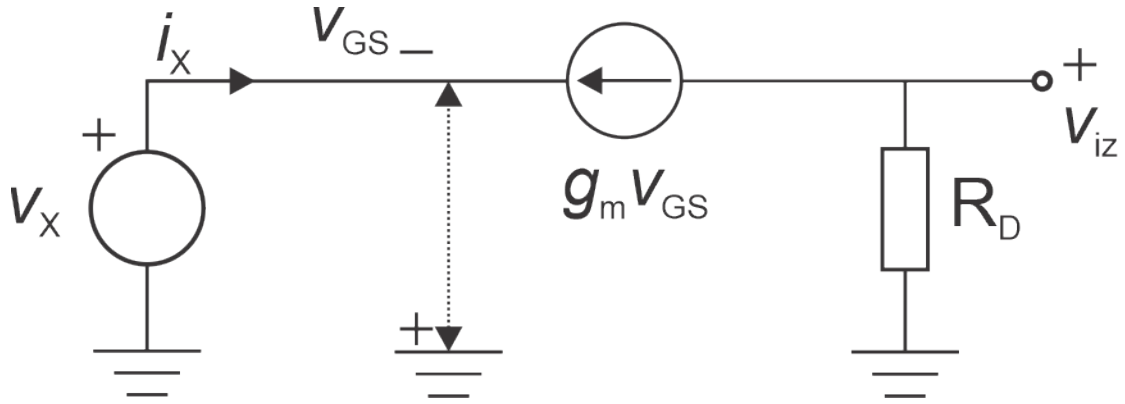
Pojačavač sa zajedničkim gejtom – ul. impedansa

- Kolo za male signale, zanemarićemo modulaciju dužine ($r_o=\infty$)

$$v_X = -v_{GS}$$

$$i_X = -g_m v_{GS}$$

$$R_{ul} = \frac{v_X}{i_X} = \frac{1}{g_m}$$



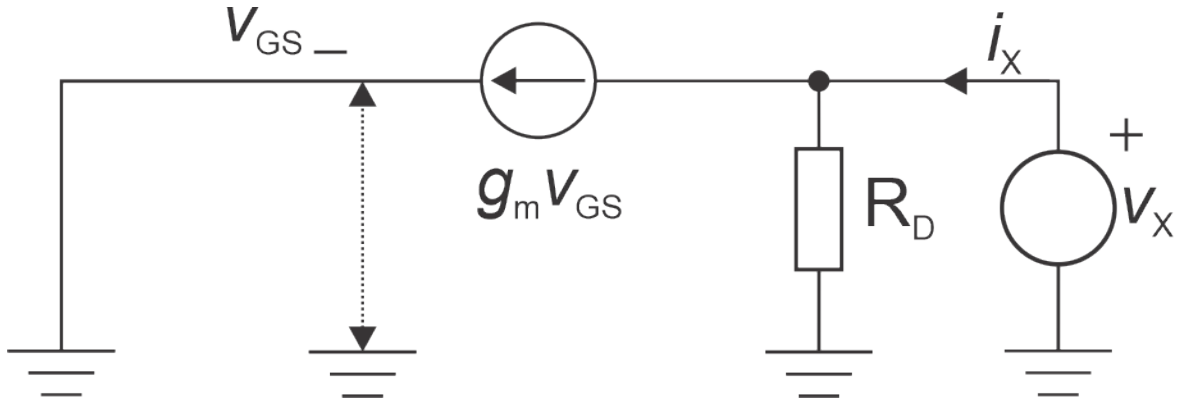
Pojačavač sa zajedničkim gejtom – iz. impedansa

- Kolo za male signale, zanemarićemo modulaciju dužine ($r_o=\infty$)

$$v_{GS} = 0$$

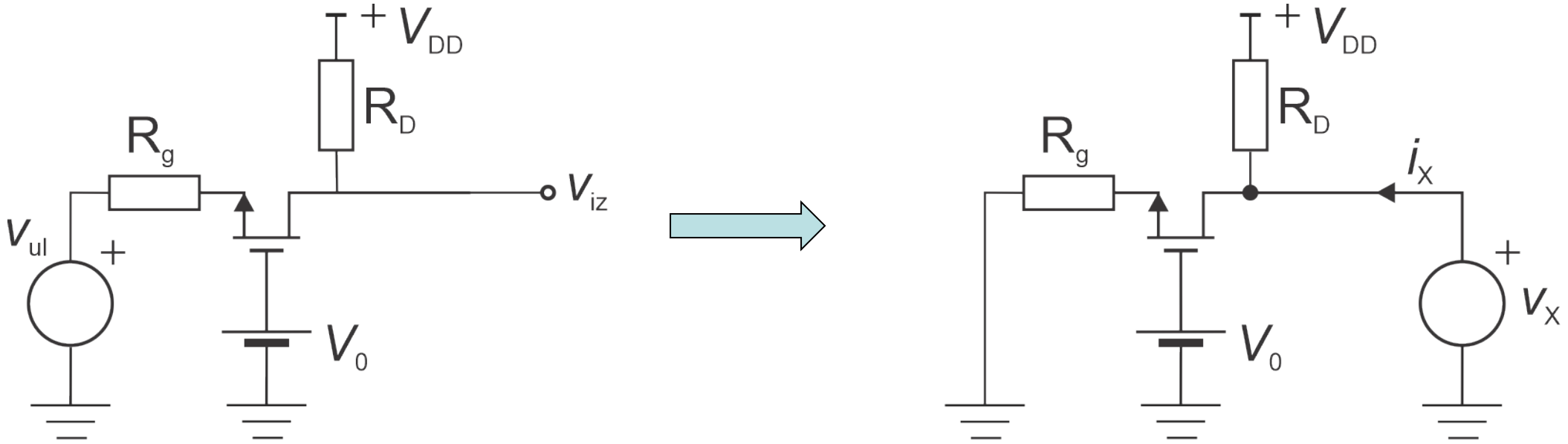
$$i_X = \frac{v_X}{R_D} + g_m v_{GS}$$

$$R_{iz} = R_D$$



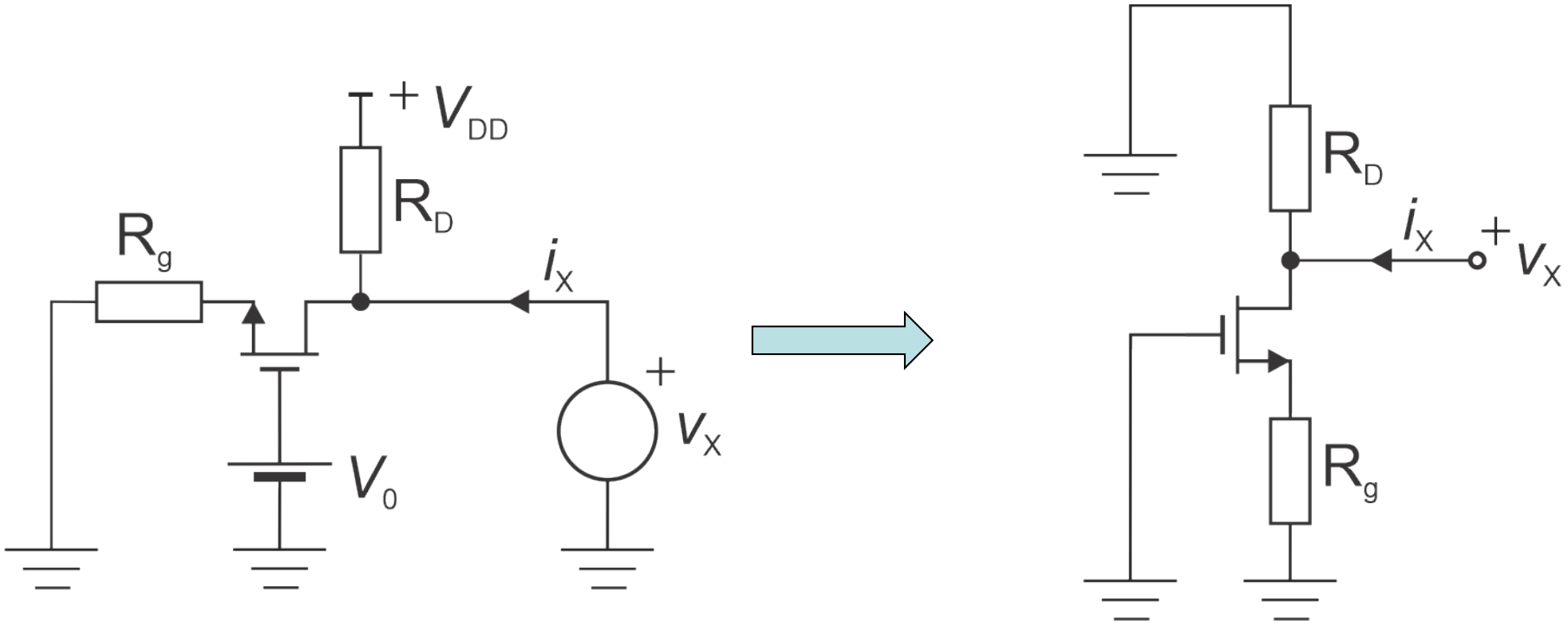
Pojačavač sa zajedničkim gejtom – iz. impedansa

- Uticaj otpornosti izvora signala R_g, na iz. impedansu



Pojačavač sa zajedničkim gejtom – iz. impedansa

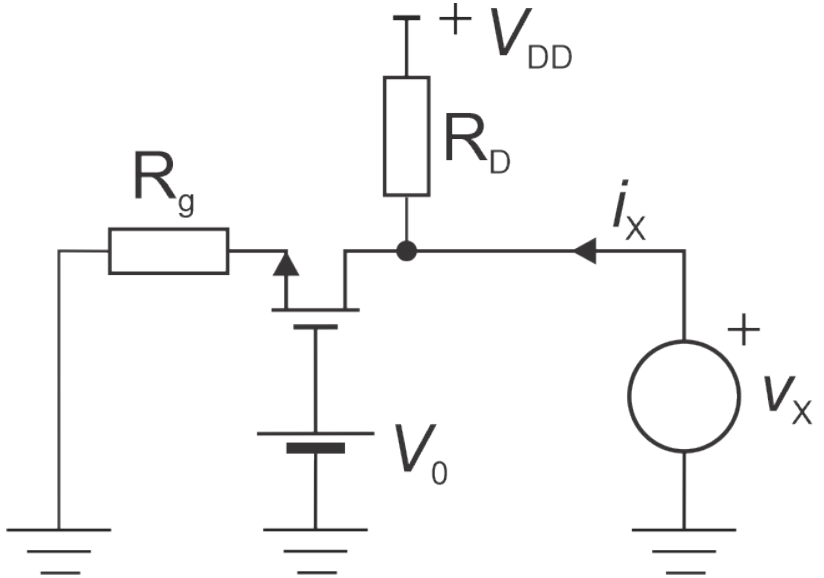
- Kolo je ekvivalentno degenerisanom sorsu



Pojačavač sa zajedničkim gejtom – iz. impedansa

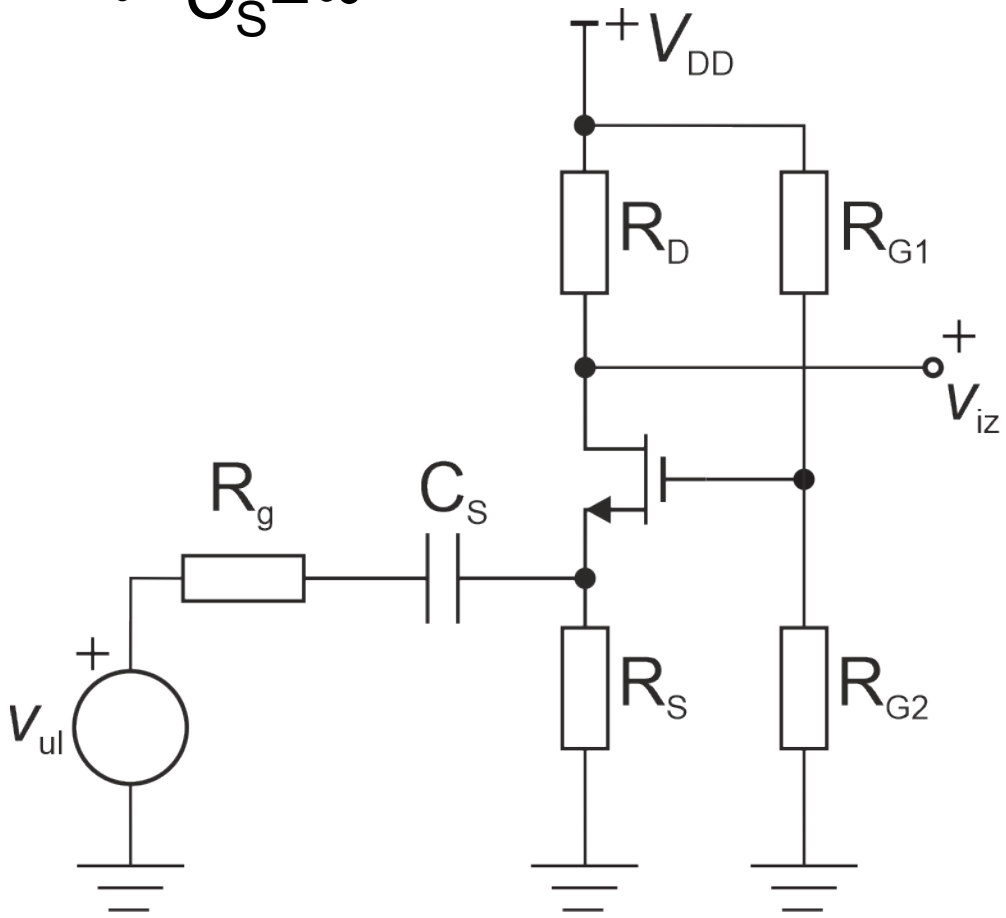
- Kolo je ekvivalentno degenerisanom sorsu

$$R_{iz} = R_D \parallel \left(\left(1 + g_m r_o \right) R_g + r_o \right)$$



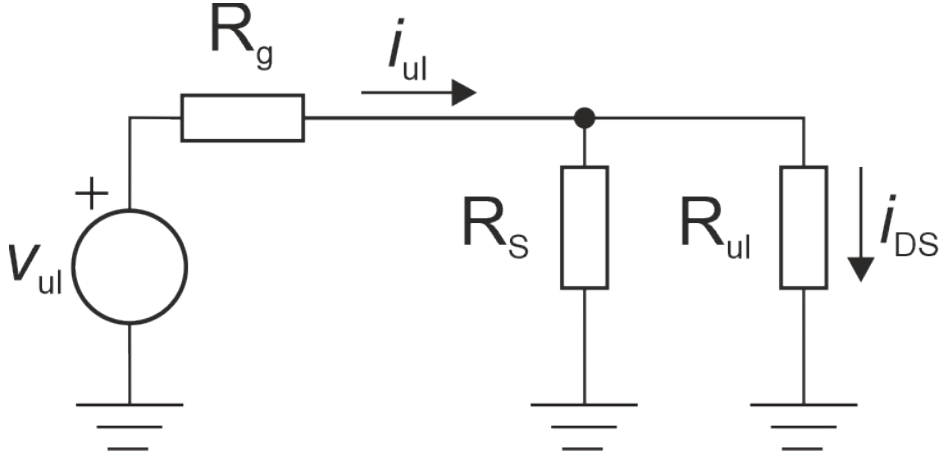
Pojačavač sa zajedničkim gejtom – polarizacija

- $C_S=\infty$



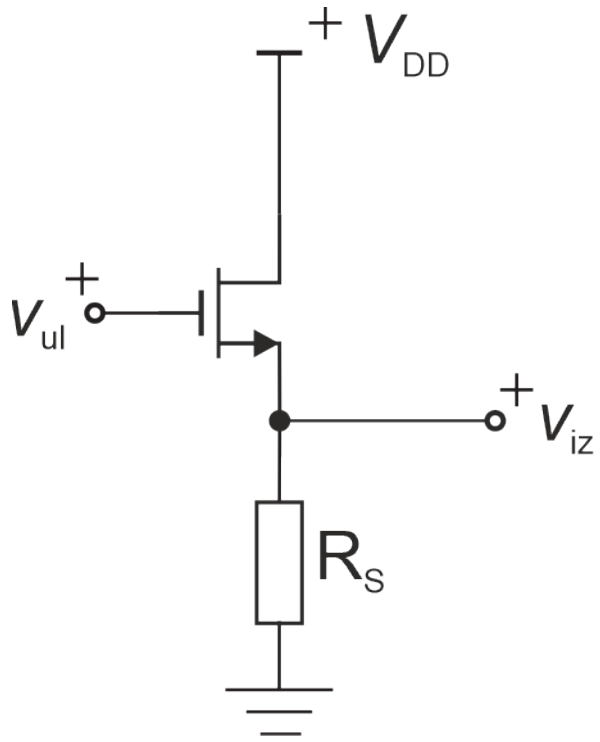
$$i_{DS} = \frac{R_S}{R_S + R_{ul}} i_{ul}$$

$$R_S \gg R_{ul}, \quad R_S \gg 1/g_m$$



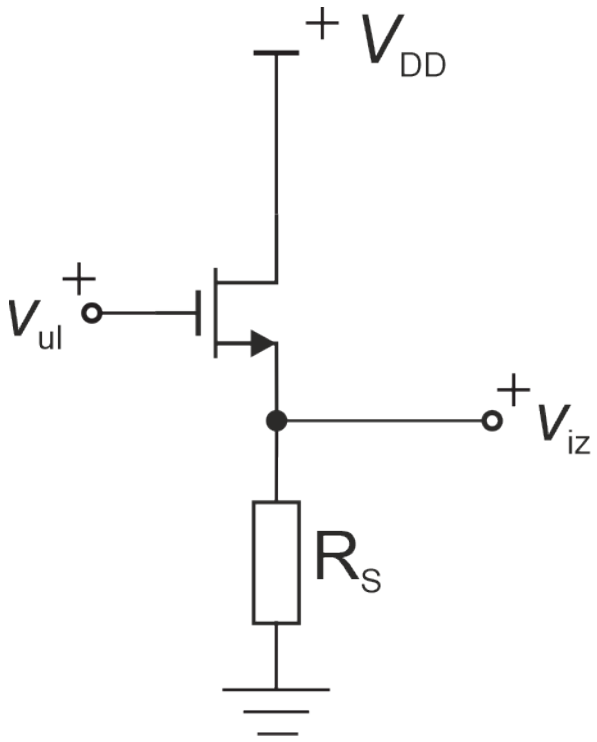
Pojačavač sa zajedničkim drejnom

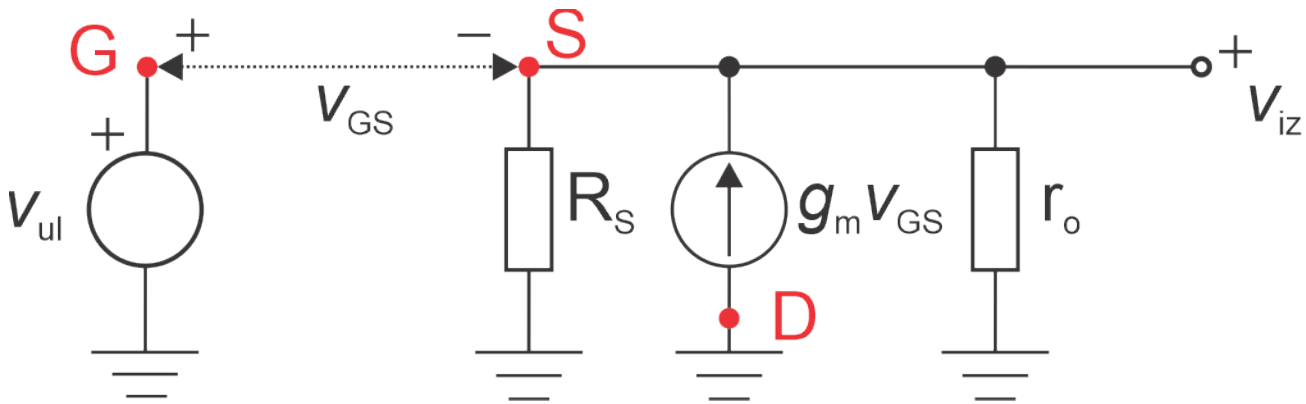
- Pojačanje, ulazna i izlazna impedansa, polarizacija



Pojačavač sa zajedničkim drejnom

- Kolo za male signale





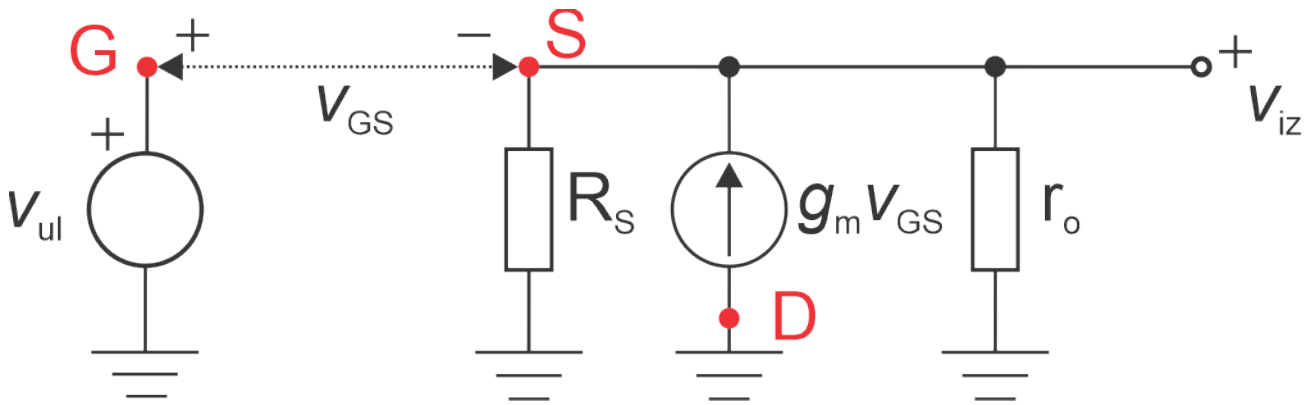
Pojačavač sa zajedničkim drejnom – pojačanje

$$v_{GS} = v_{ul} - v_{iz}$$

$$\frac{v_{iz}}{R_S} + \frac{v_{iz}}{r_o} = g_m v_{GS}$$

$$\frac{v_{iz}}{R_S} + \frac{v_{iz}}{r_o} = g_m v_{ul} - g_m v_{iz}$$

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



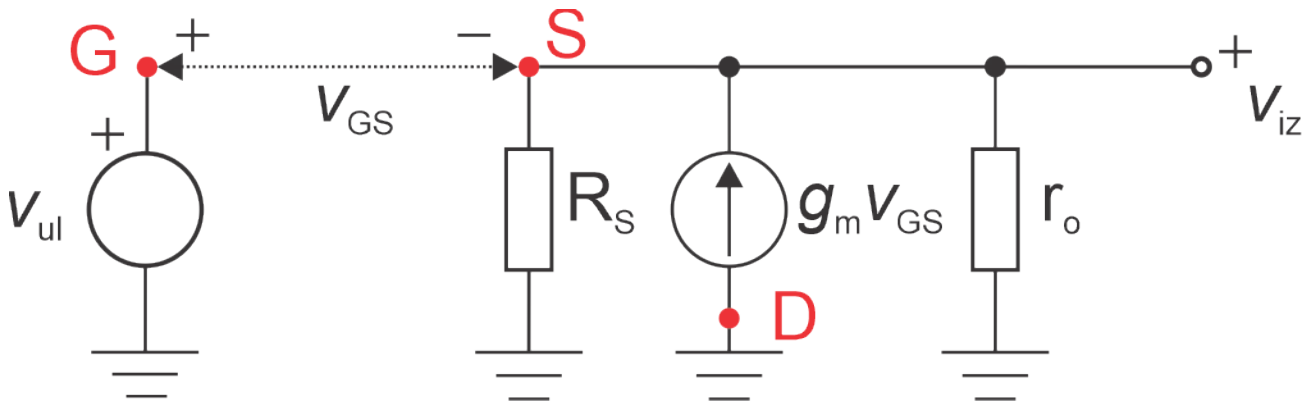
Pojačavač sa zajedničkim drejnom – pojačanje

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

$$A = \frac{g_m \left(R_S \parallel r_o \right)}{1 + g_m \left(R_S \parallel r_o \right)}$$

za $r_o \approx \infty$,

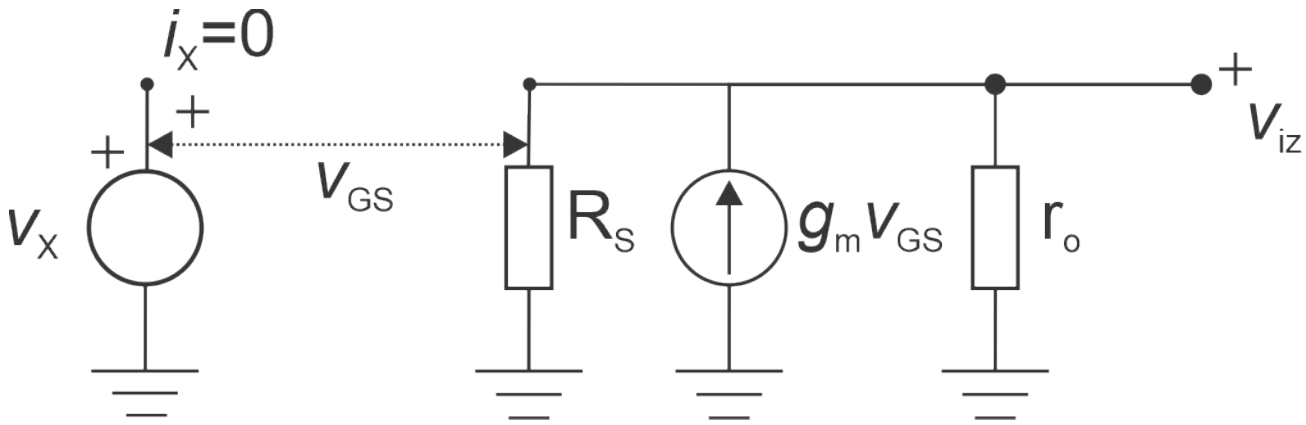
$$A \approx \frac{g_m R_S}{1 + g_m R_S} = \frac{R_S}{1/g_m + R_S} < 1$$



Pojačavač sa zajedničkim drejnom – ulazna imp.

$$i_X = 0$$

$$R_{ul} = \infty$$



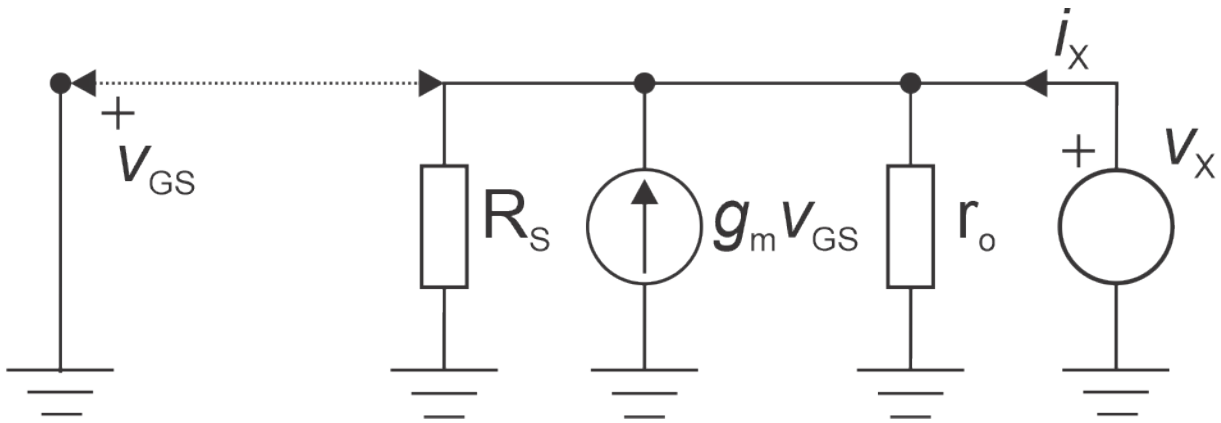
Pojačavač sa zajedničkim drejnom – izlazna imp.

$$v_{GS} = -v_X$$

$$i_X = \frac{v_X}{R_S} + \frac{v_X}{r_o} - g_m v_{GS}$$

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

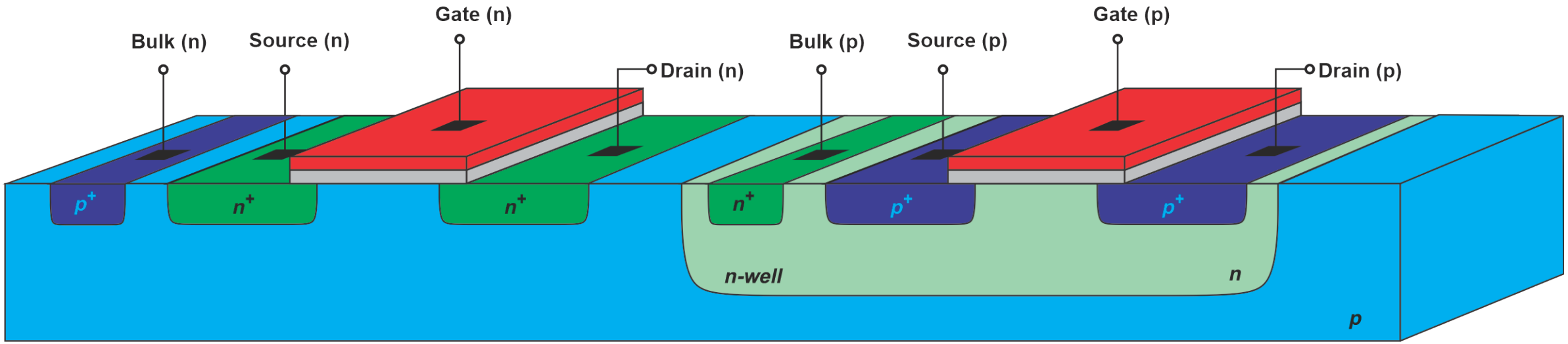
$$R_{iz} = \frac{v_X}{i_X} = R_S \parallel r_o \parallel 1/g_m$$



Poređenje topologija pojačavača sa MOSFET

Topologija	Naponsko pojačanje *A*	Fazni pomeraj	Ulazna impedansa R_{ul}	Izlazna impedansa R_{iz}
Zajednički sors	$-g_m \cdot (R_D \parallel r_o)$	π	∞	$r_o \parallel R_D$
Degenerisani sors	$-\frac{g_m R_D}{1+g_m R_S}$	π	∞	$(1+g_m r_o) R_S + r_o$
Zajednički sors sa naponskim razdelnikom	$-g_m \cdot (R_D \parallel r_o)$	π	$R_{G1} \parallel R_{G2}$	$r_o \parallel R_D$
Zajednički gejt	$g_m \cdot R_D$	0	$1/g_m$	R_D
Zajednički drejn	$\approx \frac{R_S \parallel r_o}{1/g_m + R_S \parallel r_o}$	0	∞	$R_S \parallel r_o \parallel 1/g_m$

Complementary Metal Oxide Semiconductor – CMOS

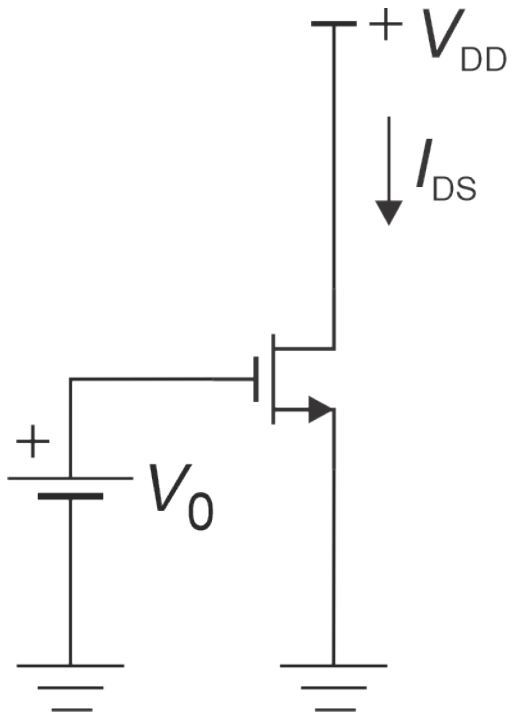


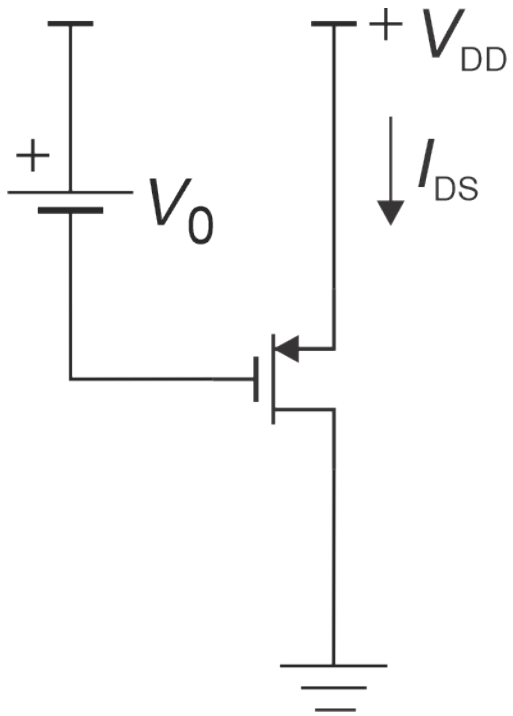
CMOS – polarizacija

- Polarizacija tranzistora, režim zasićenja:

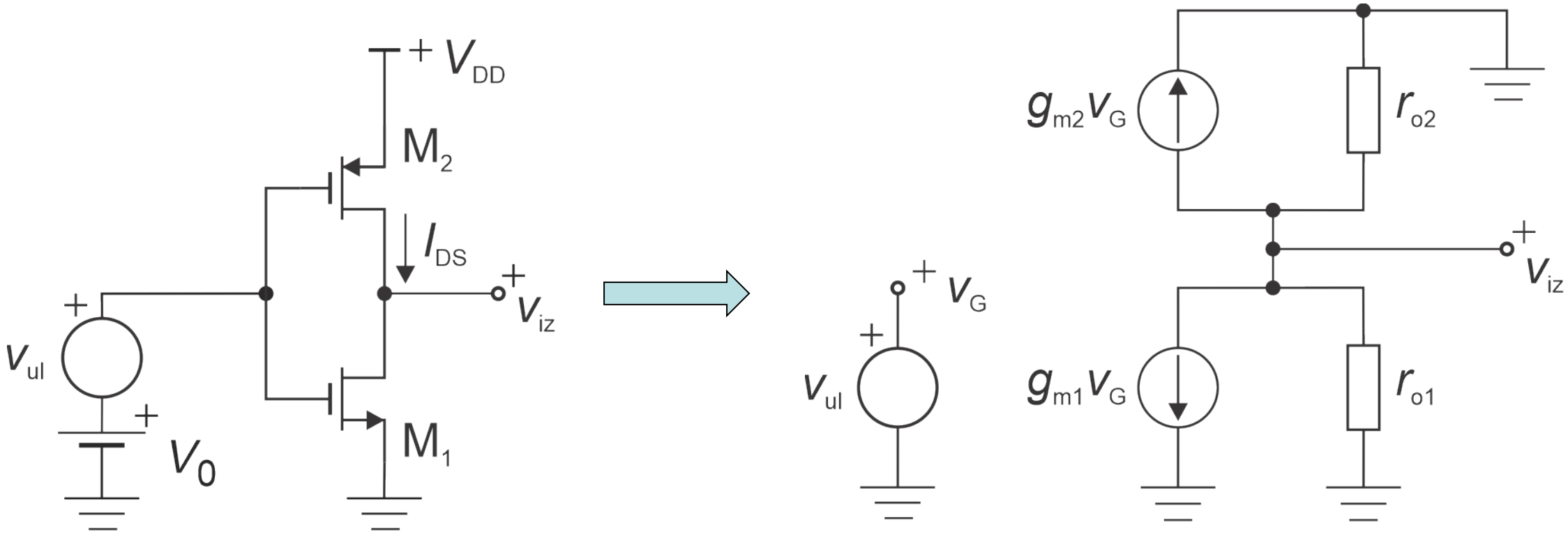
1. N-MOS: $V_{GS}>V_{TH}$, $V_{DS}>V_{GS}-V_{TH}$, V_{TH} je pozitivan, drejn je na višem potencijalu od sorsa ($V_D>V_S$)
2. P-MOS: $V_{GS}<V_{TH}$, $V_{DS}<V_{GS}-V_{TH}$, V_{TH} je negativan, drejn je na nižem potencijalu od sorsa ($V_D<V_S$)

CMOS – polarizacija





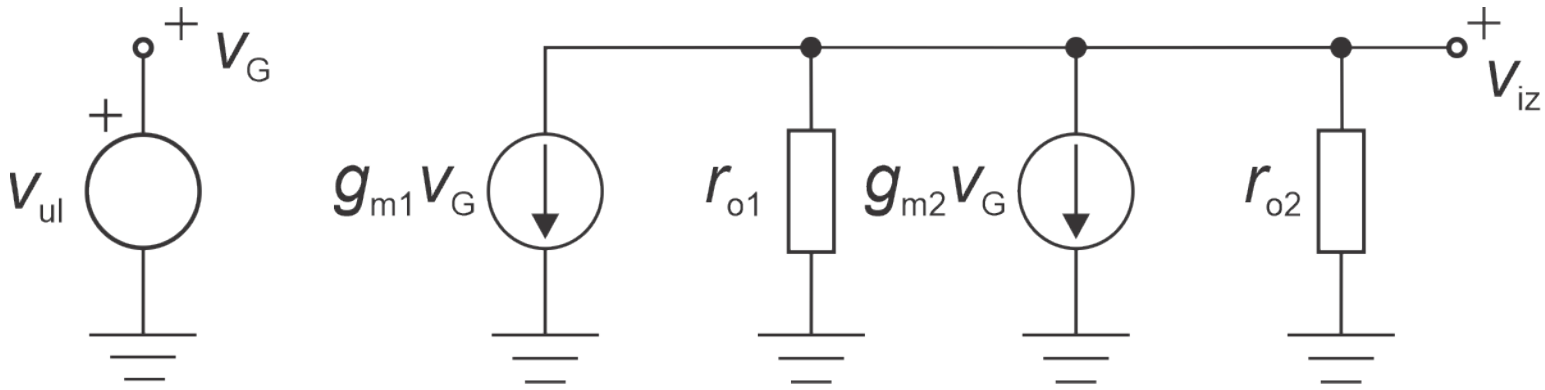
CMOS pojačavač



CMOS pojačavač

$$g_m = g_{m1} + g_{m2}$$

$$r_o = r_{o1} \parallel r_{o2}$$



CMOS pojačavač

$$A = -g_m r_o$$

$$A = -(g_{m1} + g_{m2})(r_{o1} \parallel r_{o2})$$

$$R_{ul} = \infty$$

$$R_{iz} = r_{o1} \parallel r_{o2}$$