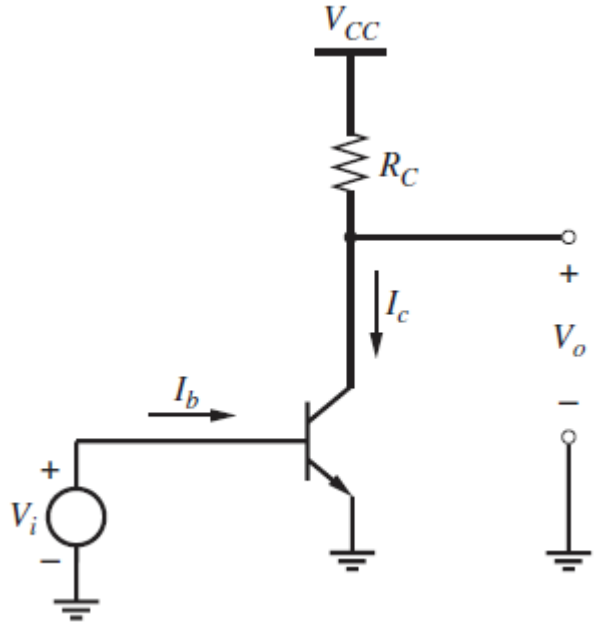
Osnove elektronike
III semestar

AKTIVNO OPTEREĆENJE

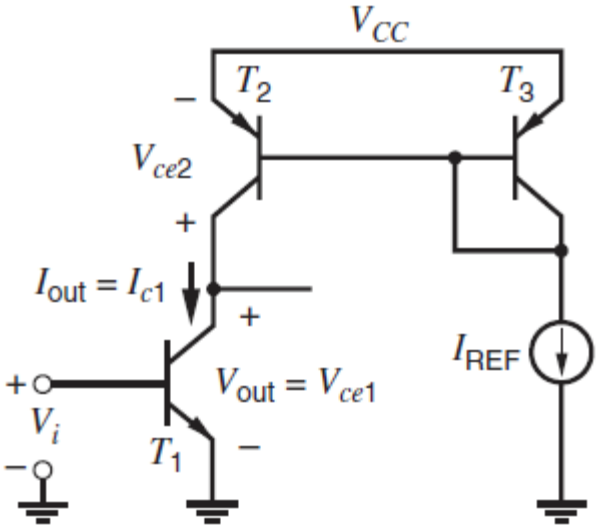
Ograničenje pojačanja pojačavača sa otpornim opterećenjem

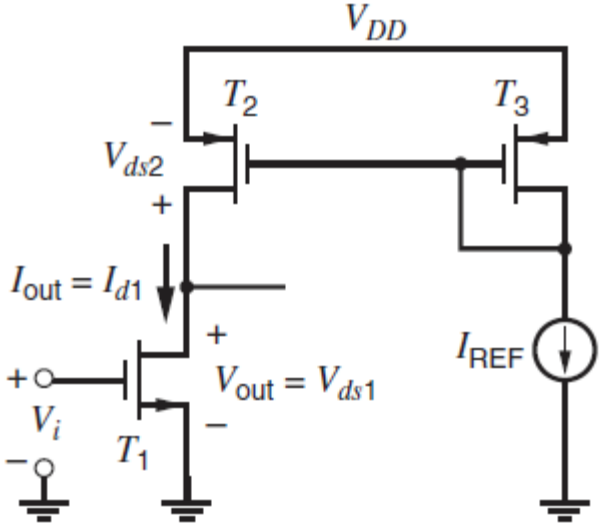


$$A_n = -g_m R_C = -\frac{I_C R_C}{V_T} \approx -\frac{V_{CC}}{2V_T}$$

Naponsko pojačanje pojačavača sa otpornim opterećenjem je ograničeno naponom napajanja.

Aktivno opterećenje sa bipolarnim i MOS trazistorima





$$i_{C1} = i_{C2}$$

$$v_{BE1} = v_i$$

$$v_{CE1} = v_{out}$$

$$v_{EC2} = V_{CC} - v_{CE1}$$

$$i_{C3} = I_{REF}$$

$$v_{EB2} = v_{EB3}$$

$$v_{EC3} = v_{EB3}$$

$$I_{S2} = I_{S3}$$

Prenosna karakteristika pojačavača sa aktivnim opterećenjem

$$i_{C1} = I_{S1}\left(e^{\frac{v_{BE1}}{V_T}} - 1\right)\left(1 + \frac{v_{CE1}}{V_{AN}}\right) = I_{S1}\left(e^{\frac{v_i}{V_T}} - 1\right)\left(1 + \frac{v_{out}}{V_{AN}}\right)$$

$$i_{C2} = I_{S2}\left(e^{\frac{v_{EB2}}{V_T}} - 1\right)\left(1 + \frac{v_{EC2}}{V_{AP}}\right) = I_{S2}\left(e^{\frac{V_{EB3}}{V_T}} - 1\right)\left(1 + \frac{V_{CC} - v_{out}}{V_{AP}}\right)$$

$$i_{C3} = I_{S3}\left(e^{\frac{v_{EB3}}{V_T}} - 1\right)\left(1 + \frac{v_{EC3}}{V_{AP}}\right) = I_{S3}\left(e^{\frac{V_{EB3}}{V_T}} - 1\right)\left(1 + \frac{V_{EB3}}{V_{AP}}\right)$$

$$I_{S1}\left(e^{\frac{v_i}{V_T}} - 1\right)\left(1 + \frac{v_{out}}{V_{AN}}\right) = I_{S2}\left(e^{\frac{V_{EB3}}{V_T}} - 1\right)\left(1 + \frac{V_{CC} - v_{out}}{V_{AP}}\right)$$

$$I_{REF} = I_{S3}\left(e^{\frac{V_{EB3}}{V_T}} - 1\right)\left(1 + \frac{V_{EB3}}{V_{AP}}\right) = I_{S2}\left(e^{\frac{V_{EB3}}{V_T}} - 1\right)\left(1 + \frac{V_{EB3}}{V_{AP}}\right)$$

$$I_{S2}\left(e^{\frac{V_{EB3}}{V_T}} - 1\right) = \frac{I_{REF}}{1 + \frac{V_{EB3}}{V_{AP}}}$$

Prenosna karakteristika pojačavača sa aktivnim opterećenjem

$$I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)\left(1+\frac{v_{out}}{V_{AN}}\right)=\frac{I_{REF}}{1+\frac{V_{EB3}}{V_{AP}}}\left(1+\frac{V_{CC}-v_{out}}{V_{AP}}\right)$$

$$I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)=I_{REF}\frac{1+\frac{V_{CC}-v_{out}}{V_{AP}}}{\left(1+\frac{V_{EB3}}{V_{AP}}\right)\left(1+\frac{v_{out}}{V_{AN}}\right)}$$

$$\frac{V_{EB3}}{V_{AP}}\ll 1 \qquad \frac{v_{out}}{V_{AN}}\ll 1$$

$$I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)\approx I_{REF}\left(1+\frac{V_{CC}-v_{out}}{V_{AP}}\right)\left(1-\frac{V_{EB3}}{V_{AP}}\right)\left(1-\frac{v_{out}}{V_{AN}}\right)$$

$$I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)\approx I_{REF}\left(1+\frac{V_{CC}-v_{out}}{V_{AP}}-\frac{V_{EB3}}{V_{AP}}-\frac{v_{out}}{V_{AN}}\right)$$

$$I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)\approx I_{REF}\left[1+\frac{V_{CC}-V_{EB3}}{V_{AP}}-v_{out}\left(\frac{1}{V_{AP}}+\frac{1}{V_{AN}}\right)\right]$$

Prenosna karakteristika pojačavača sa aktivnim opterećenjem

$$\frac{I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)}{I_{REF}} \approx 1+\frac{V_{CC}-V_{EB3}}{V_{AP}}-v_{out}\left(\frac{1}{V_{AP}}+\frac{1}{V_{AN}}\right)$$

$$v_{out}\left(\frac{1}{V_{AP}}+\frac{1}{V_{AN}}\right) \approx 1+\frac{V_{CC}-V_{EB3}}{V_{AP}}-\frac{I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)}{I_{REF}}$$

$$v_{out} \approx \frac{\frac{V_{CC}-V_{EB3}}{V_{AP}}+1-\frac{I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)}{I_{REF}}}{\frac{1}{V_{AP}}+\frac{1}{V_{AN}}}$$

$$v_{out} \approx \frac{\frac{V_{CC}-V_{EB3}}{V_{AP}}+1-\frac{I_{S1}\left(e^{\frac{v_i}{V_T}}-1\right)}{I_{REF}}}{\frac{V_{AP}+V_{AN}}{V_{AP}V_{AN}}}$$

Naponsko pojačanje pojačavača sa aktivnim opterećenjem

$$v_{out} \approx (V_{CC} - V_{EB3}) \frac{V_{AN}}{V_{AP} + V_{AN}} + \frac{V_{AN} V_{AP}}{V_{AP} + V_{AN}} \left[1 - \frac{I_{S1} \left(e^{\frac{v_i}{V_T}} - 1 \right)}{I_{REF}} \right]$$

$$A_n = \frac{dv_{out}}{dv_i} \approx - \frac{V_{AN} V_{AP}}{V_{AP} + V_{AN}} \frac{I_{S1} e^{\frac{v_i}{V_T}}}{I_{REF}} \frac{1}{V_T}$$

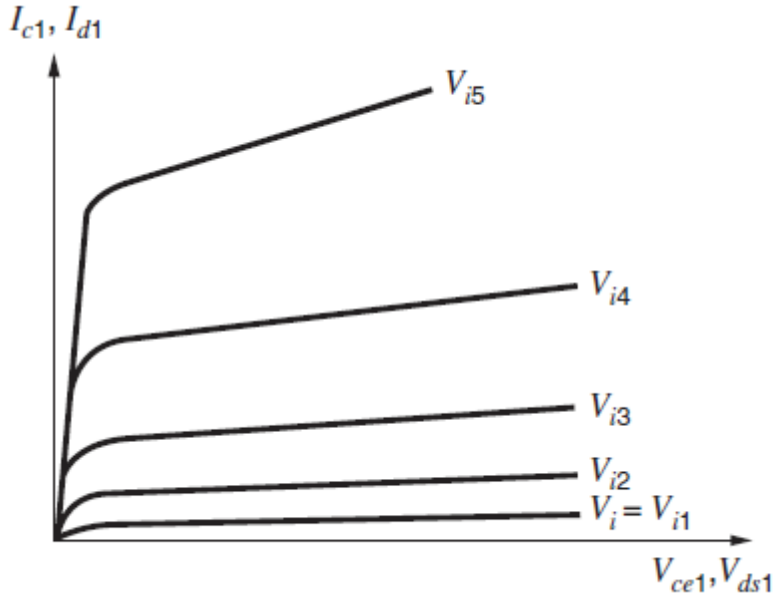
$$\frac{I_{S1} e^{\frac{v_i}{V_T}}}{I_{REF}} = 1$$

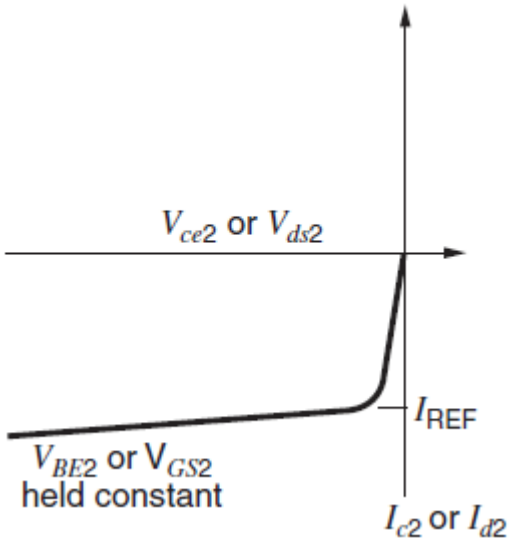
$$A_n = \frac{dv_{out}}{dv_i} \approx - \frac{V_{AN} V_{AP}}{V_{AP} + V_{AN}} \frac{1}{V_T}$$

$$A_n = \frac{dv_{out}}{dv_i} \approx - \frac{1}{\frac{V_T}{V_{AP}} + \frac{V_T}{V_{AN}}}$$

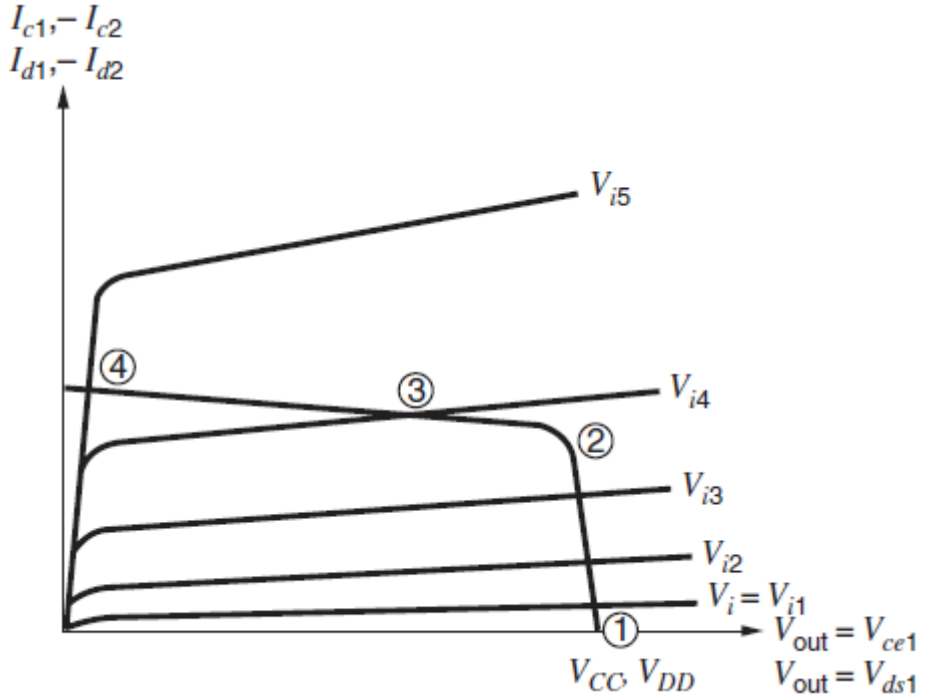
Naponsko pojačanje pojačavača sa aktivnim opterećenjem je nezavisno od napona napajanja.

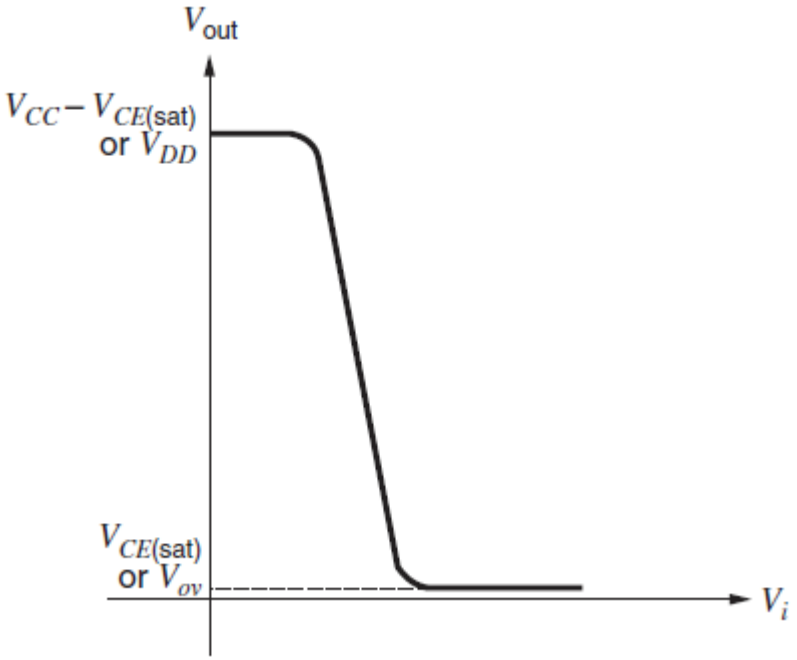
Strujno-naponska karakteristika ulaznog tranzistora i aktivnog opterećenja



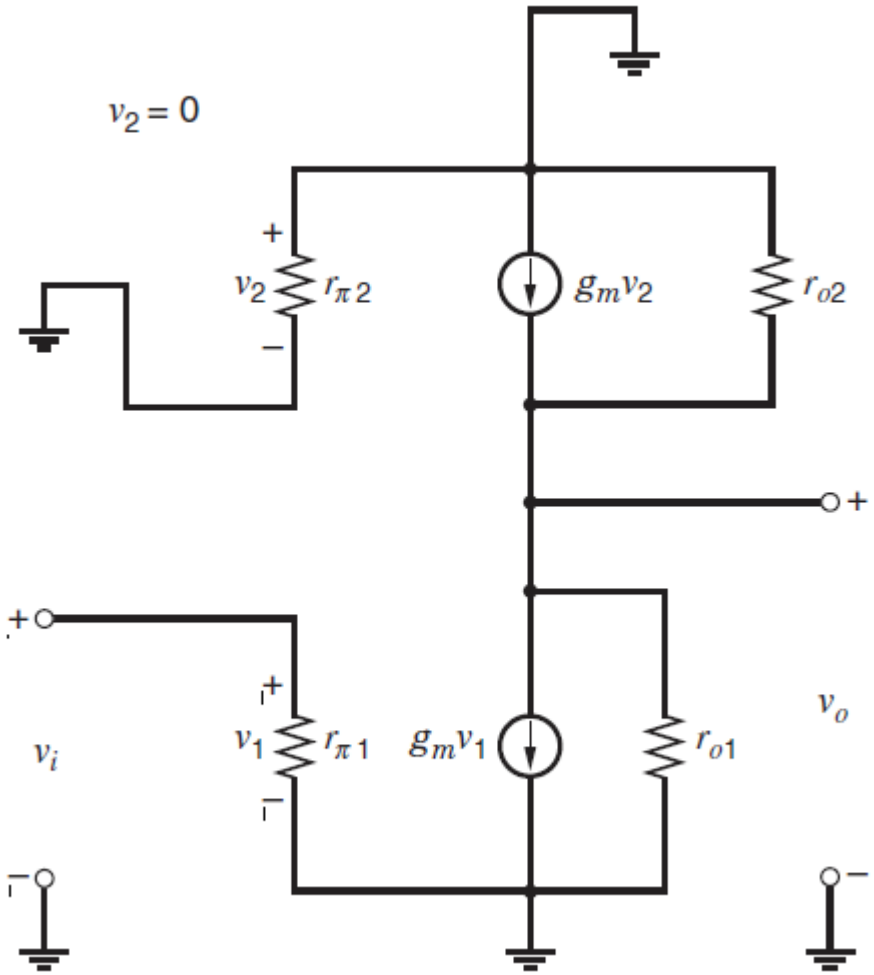


Superponirane strujno-naponske karakteristike ulaznog tranzistora i aktivnog opterećenja, kao i prenosna karakteristika





Šema za male signale pojačavača sa aktivnim opterećenjem



$$R_o = r_{o1} || r_{o2}$$

$$A_v = -g_{m1}(r_{o1} || r_{o2})$$

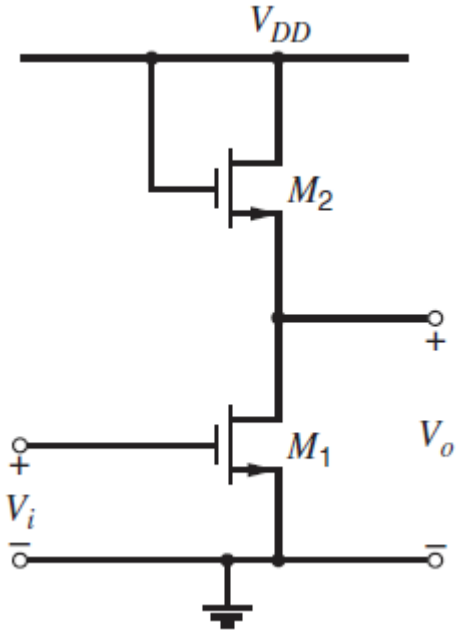
$$A_v = -\frac{1}{\frac{V_T}{V_{A1}} + \frac{V_T}{V_{A2}}}$$

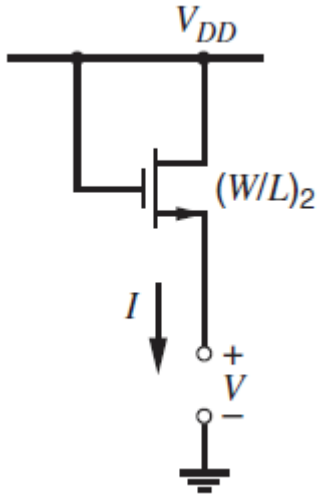
Ista šema važi za MOSFET ako se izbace ulazne otpornosti:

$$r_{\pi 1} \to \infty$$

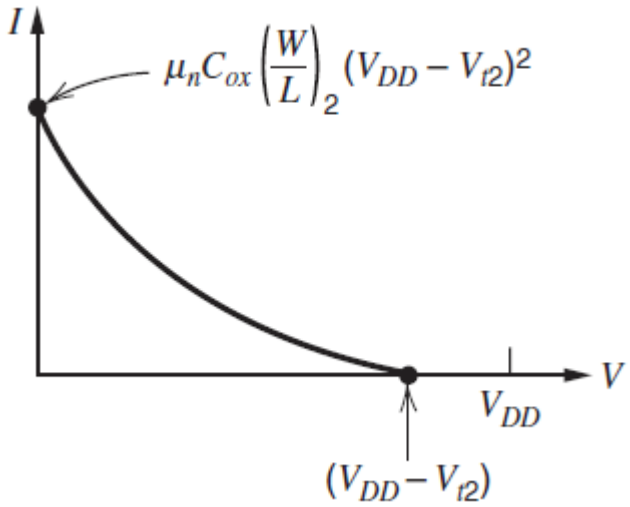
$$r_{\pi 2} \to \infty$$

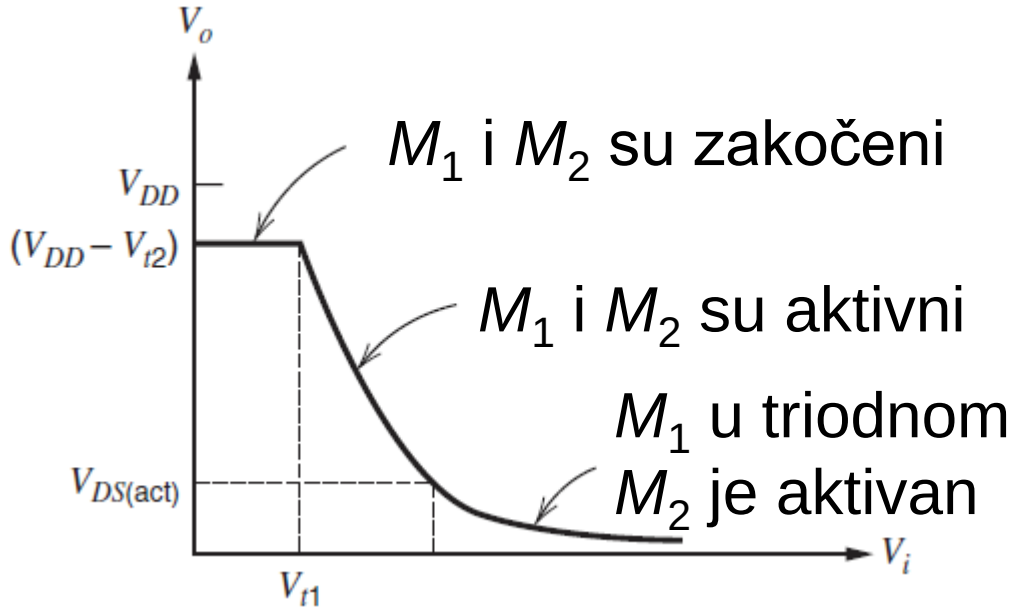
Pojačavač sa MOSFET-om i kolo za određivanje struje





Struja i prenosna karakteristika pojačavača sa MOSFET-om





Izlazni napon pojačavača sa MOSFET-om

$$i_{D1} = \frac{B_1}{2}(v_{GS1} - V_{T1})^2 \qquad B_1 = \frac{\mu_n C_{ox} W_1}{L_1} \qquad v_{GS1} = V_{T1} + \sqrt{\frac{2i_{D1}}{B_1}}$$

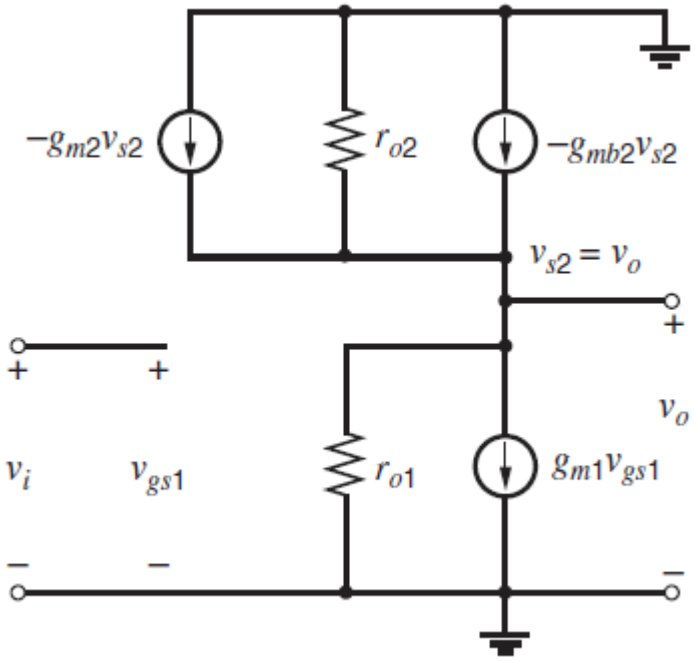
$$i_{D2} = \frac{B_2}{2}(v_{GS2} - V_{T2})^2 \qquad B_2 = \frac{\mu_p C_{ox} W_2}{L_2} \qquad v_{GS2} = V_{T2} + \sqrt{\frac{2i_{D2}}{B_2}}$$

$$v_o = V_{DD} - v_{GS2} \qquad v_o = V_{DD} - V_{T2} - \sqrt{\frac{2i_{D2}}{B_2}} \qquad i_{D2} = i_{D1}$$

$$v_o = V_{DD} - V_{T2} - \sqrt{\frac{2i_{D1}}{B_2}} \qquad \sqrt{\frac{2i_{D1}}{B_1}} = v_{GS1} - V_{T1} \qquad v_{GS1} = v_i$$

$$v_o = V_{DD} - V_{T2} - \sqrt{\frac{B_1}{B_2}}(v_{GS1} - V_{T1}) \qquad v_o = V_{DD} - V_{T2} - \sqrt{\frac{(W/L)_1}{(W/L)_2}}(v_i - V_{T1})$$

Šema za male signale pojačavača sa MOSFET-om



Pojačanje za male signale pojačavača sa MOSFET-om

$$g_{m1}v_i + \frac{v_o}{r_{o1}} + \frac{v_o}{r_{o2}} + g_{m2}v_o + g_{mb2}v_o = 0$$

$$\frac{v_o}{v_i} = -g_{m1}\left(\frac{1}{g_{m2}} || \frac{1}{g_{mb2}} || r_{o1} || r_{o2}\right) = -\frac{g_{m1}}{g_{m2}}\left(\frac{1}{1 + \frac{g_{mb2}}{g_{m2}} + \frac{1}{g_{m2}r_{o1}} + \frac{1}{g_{m2}r_{o2}}}\right)$$

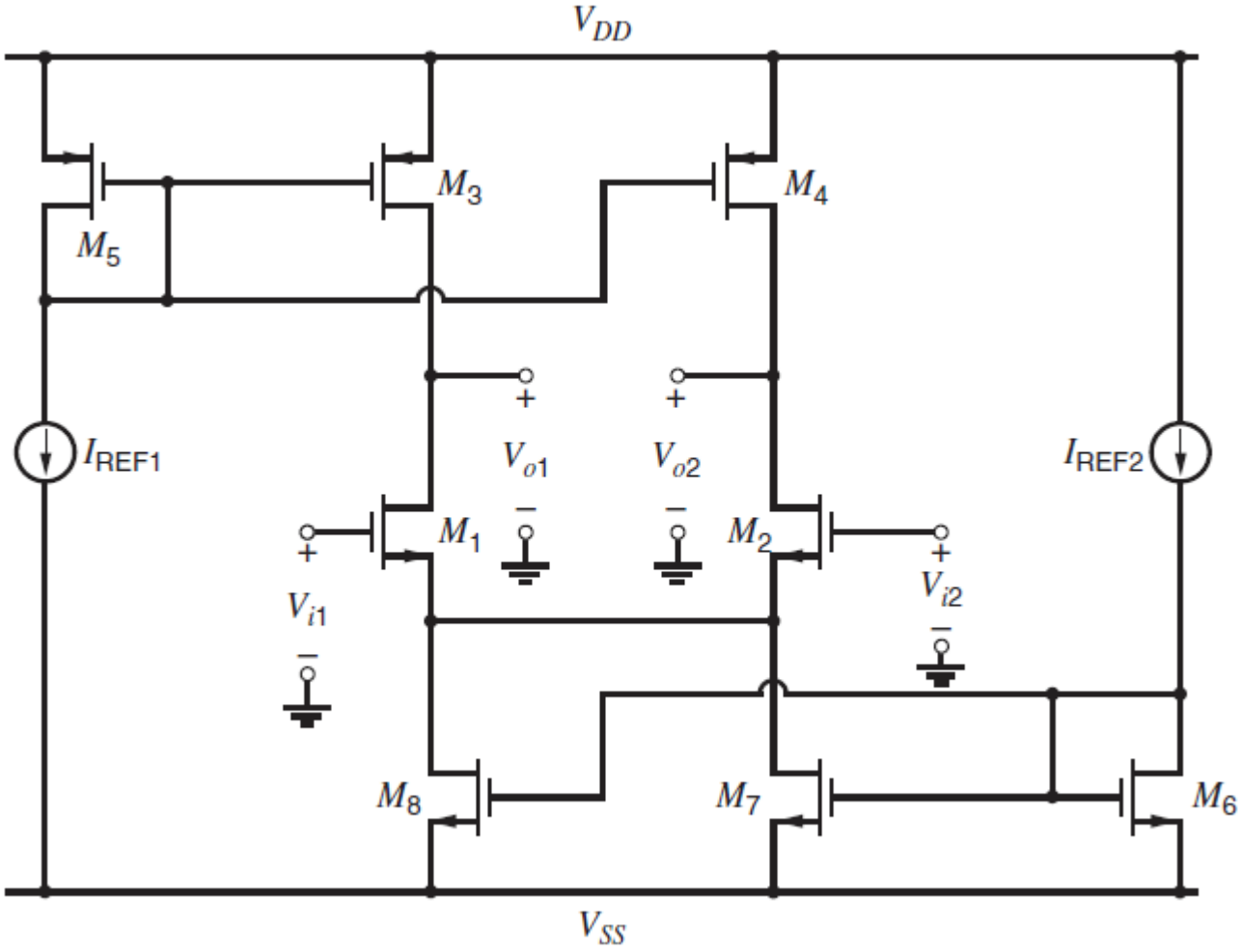
$$g_{m2}/g_{mb2} \gg 1$$

$$g_{m2}r_{o1} \gg 1$$

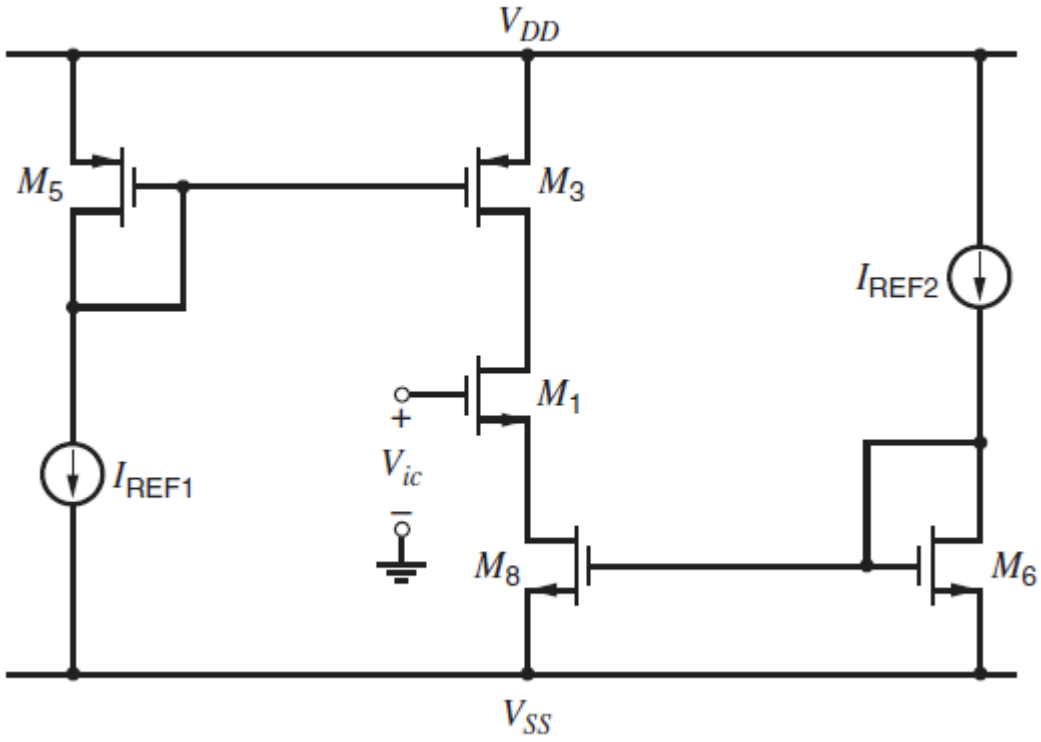
$$g_{m2}r_{o2} \gg 1$$

$$\frac{v_o}{v_i} \simeq -\frac{g_{m1}}{g_{m2}} = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}$$

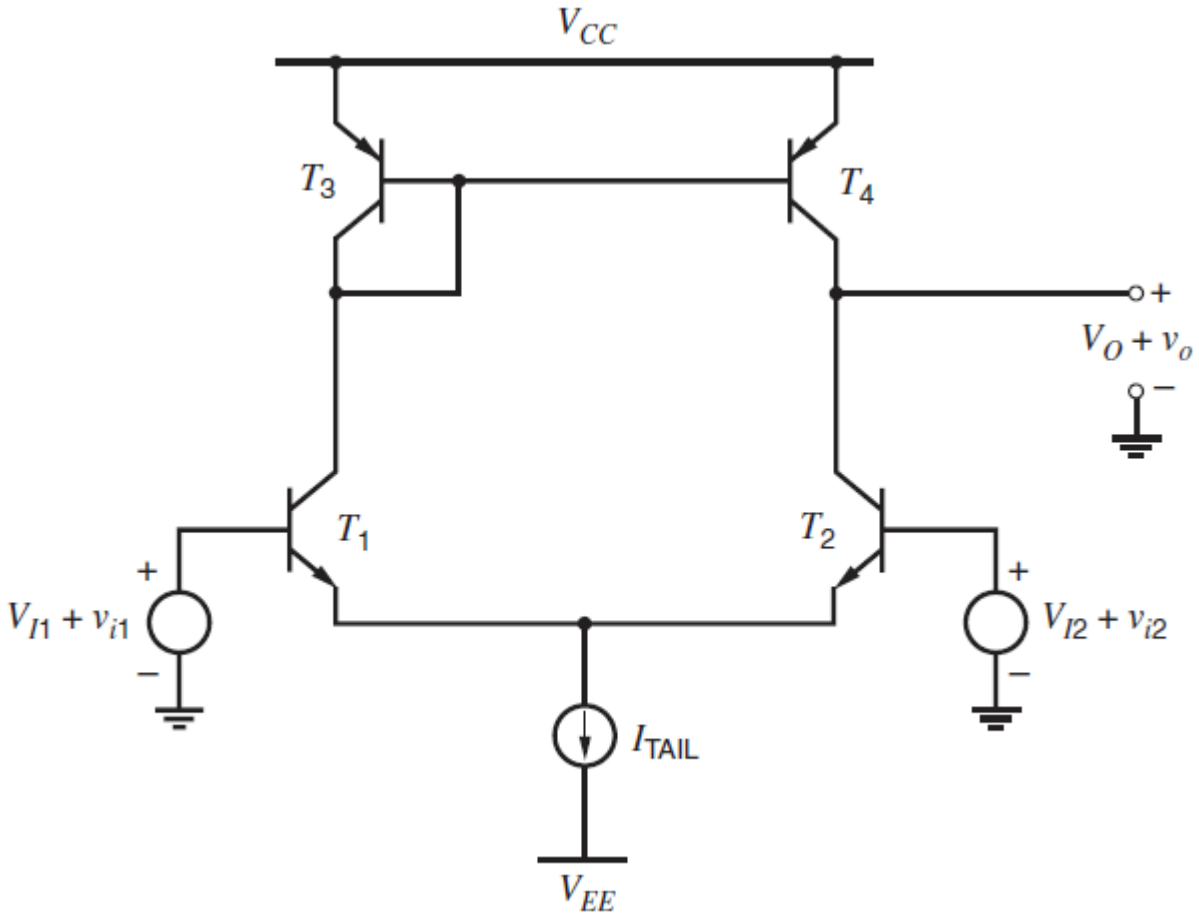
Diferencijalni par sa aktivnim opterećenjem



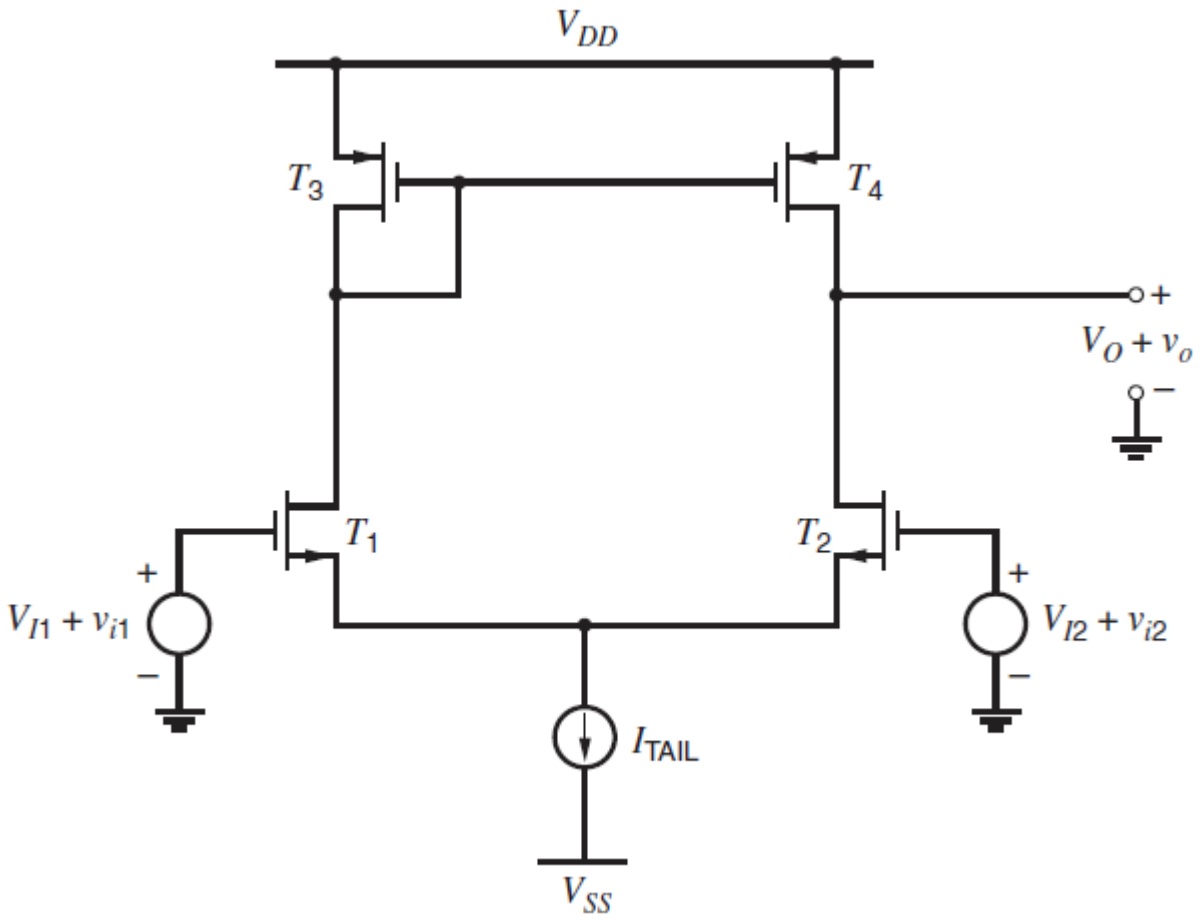
Polovina diferencijalnog para sa aktivnim opterećenjem



Diferencijalni par sa aktivnim opterećenjem za svođenje na jednostruki izlaz



Diferencijalni par sa aktivnim opterećenjem za svođenje na jednostruki izlaz



Šema za male signale diferencijalnog para sa aktivnim opterećenjem i jednostrukim izlazom

$$v_{id} = v_{i1} - v_{i2}$$

$$g_{m(dp)} = g_{m1} = g_{m2}$$

$$r_{\pi(dp)} = r_{\pi 1} = r_{\pi 2}$$

$$r_{o(dp)} = r_{o1} = r_{o2}$$

$$v_{i1} = v_{ic} + v_{id}/2$$

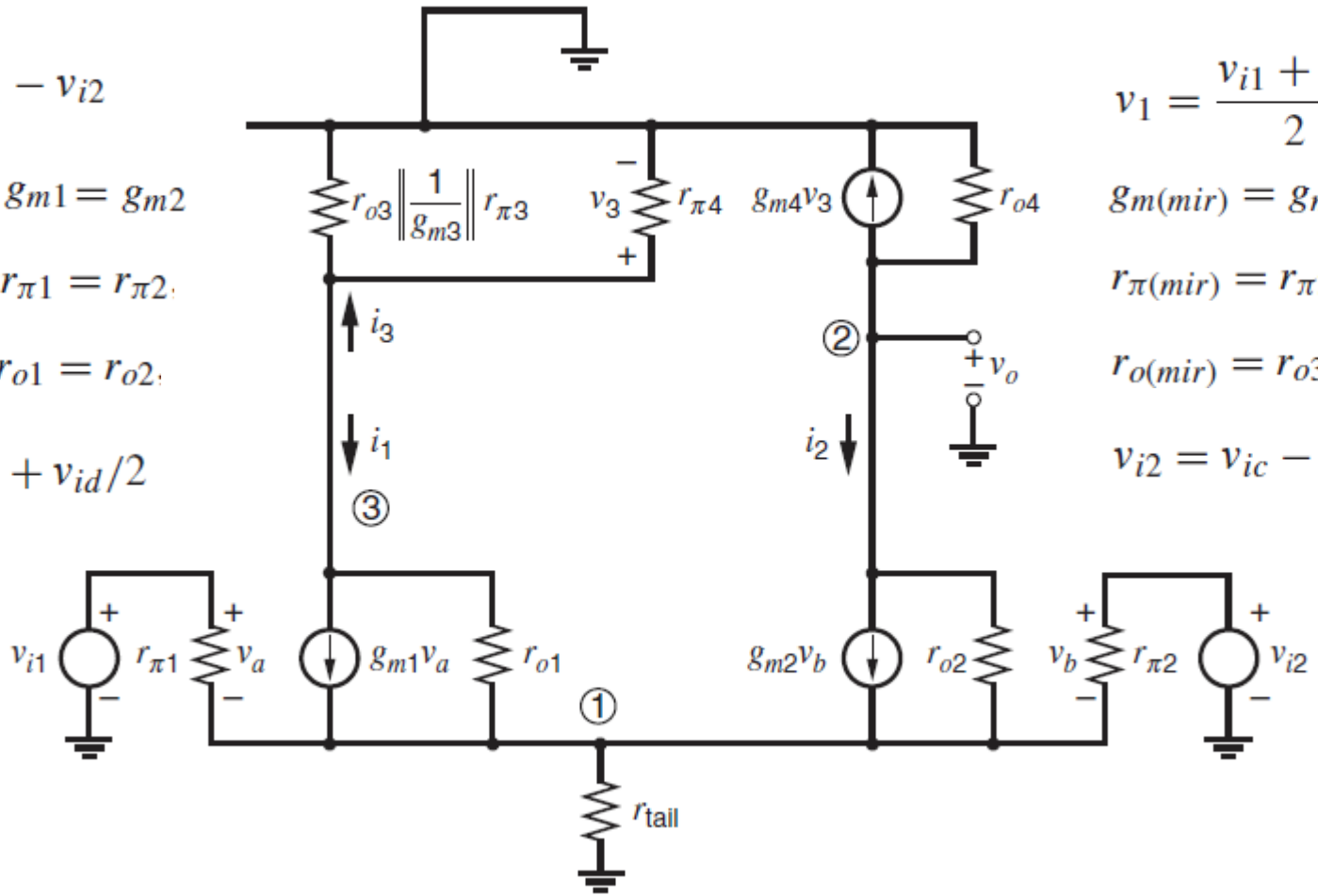
$$v_1 = \frac{v_{i1} + v_{i2}}{2} = v_{ic}$$

$$g_{m(mir)} = g_{m3} = g_{m4}$$

$$r_{\pi(mir)} = r_{\pi 3} = r_{\pi 4}$$

$$r_{o(mir)} = r_{o3} = r_{o4}$$

$$v_{i2} = v_{ic} - v_{id}/2$$



Šema za male signale diferencijalnog para sa aktivnim opterećenjem i jednostrukim izlazom

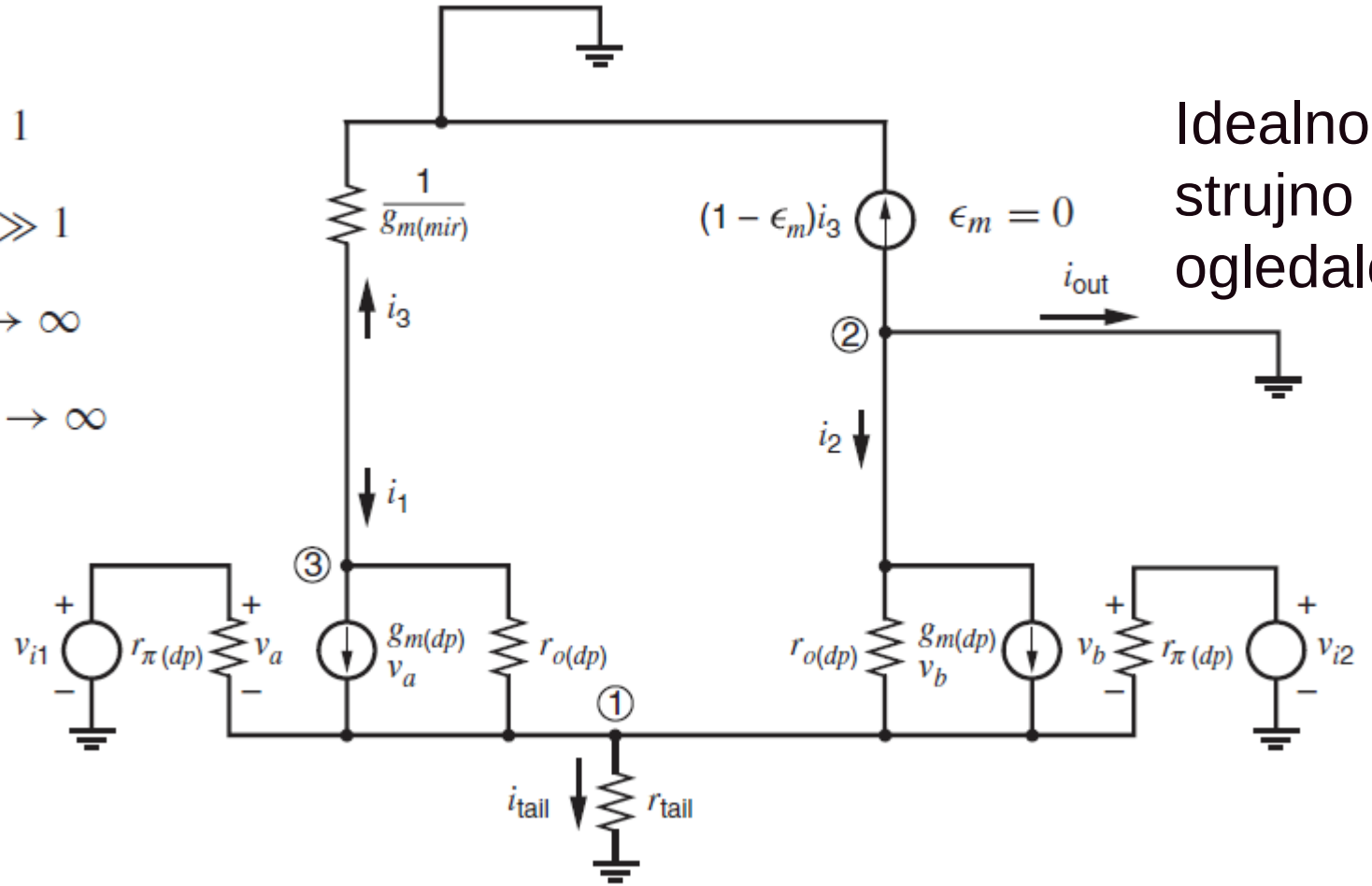
$\beta_0 \gg 1$

$g_m r_o \gg 1$

$r_{\text{tail}} \to \infty$

$r_{o(dp)} \to \infty$

Idealno strujno ogledalo



Pojačanje za male signale diferencijalnog para sa aktivnim opterećenjem i jednostrukim izlazom

$$v_3 = i_3 r_3 \simeq \frac{i_3}{g_{m3}}$$

$$(v_{i1} - v_1 + v_{i2} - v_1)\left(\frac{1}{r_{\pi(dp)}} + g_{m(dp)}\right) + \frac{v_3 - v_1}{r_{o(dp)}} - \frac{v_1}{r_{o(dp)} || r_{\text{tail}}} = 0$$

$$i_1 = g_{m(dp)}(v_{i1} - v_1) = \frac{g_{m(dp)} v_{id}}{2}$$

$$i_2 = g_{m(dp)}(v_{i2} - v_1) = -\frac{g_{m(dp)} v_{id}}{2}$$

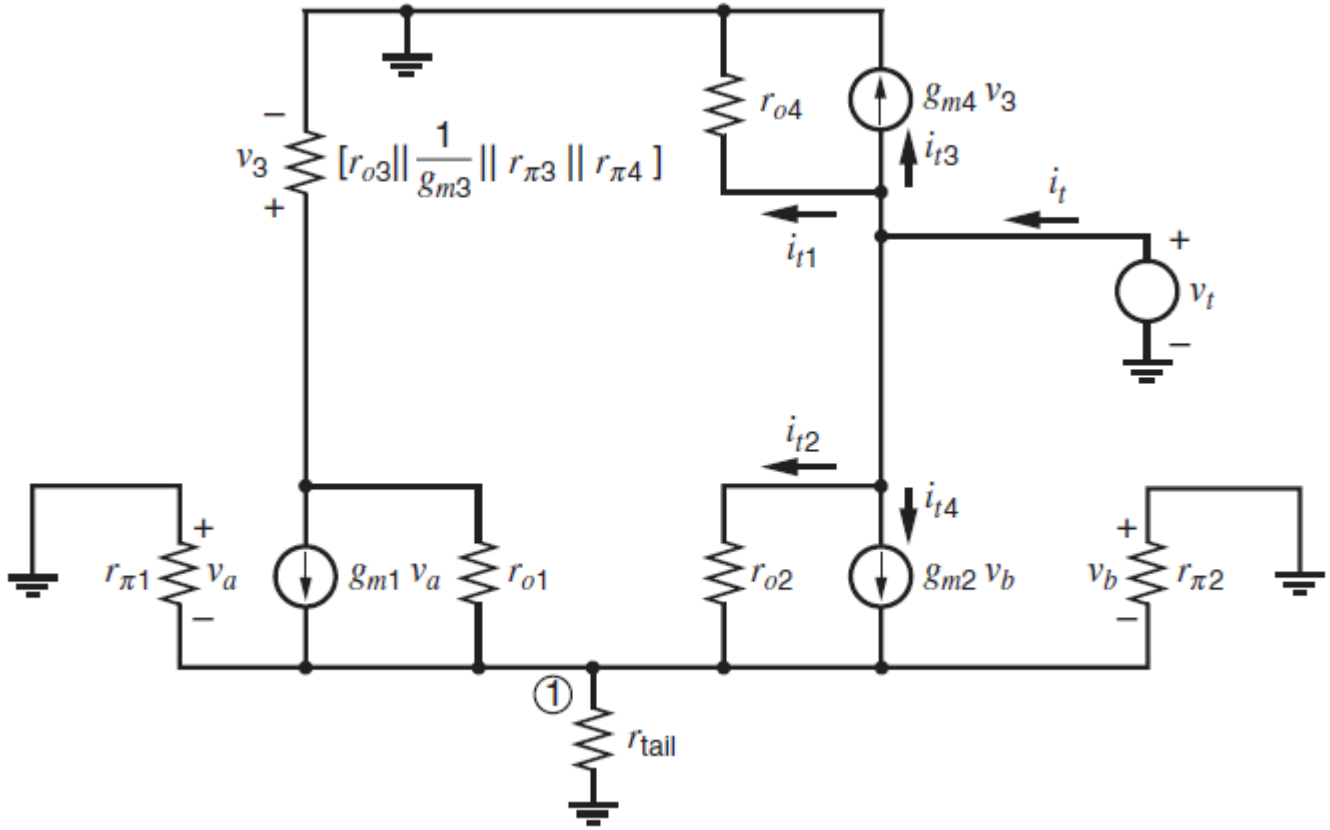
$$i_{\text{out}} = -(1 - \epsilon_m) i_3 - i_2$$

$$\epsilon_m = 0$$

$$i_3 = -i_1$$

$$i_{\text{out}} = g_{m(dp)} v_{id}$$

Šema za određivanje izlazne otpornosti diferencijalnog para sa aktivnim opterećenjem



Izlazna otpornost diferencijalnog para sa aktivnim opterećenjem i jednostrukim izlazom

$$i_{t1} = \frac{v_t}{r_{o4}}$$

$$R_{o2} \simeq r_{o2}\left(1 + g_{m2}\frac{1}{g_{m1}}\right) = 2r_{o2}$$

Efektivna izlazna otpornost T2

$$i_{t2} + i_{t4} \simeq \frac{v_t}{2r_{o2}}$$

$$r_{\text{tail}} \gg 1/g_{m1}$$

$$i_{t3} \simeq i_{t2} + i_{t4} \simeq \frac{v_t}{2r_{o2}}$$

Strujno ogledalo T3 – T4.

$$i_t = i_{t1} + i_{t2} + i_{t3} + i_{t4} \simeq v_t\left(\frac{1}{r_{o4}} + \frac{1}{r_{o2}}\right)$$

$$r_{o2} = r_{o(dp)}$$

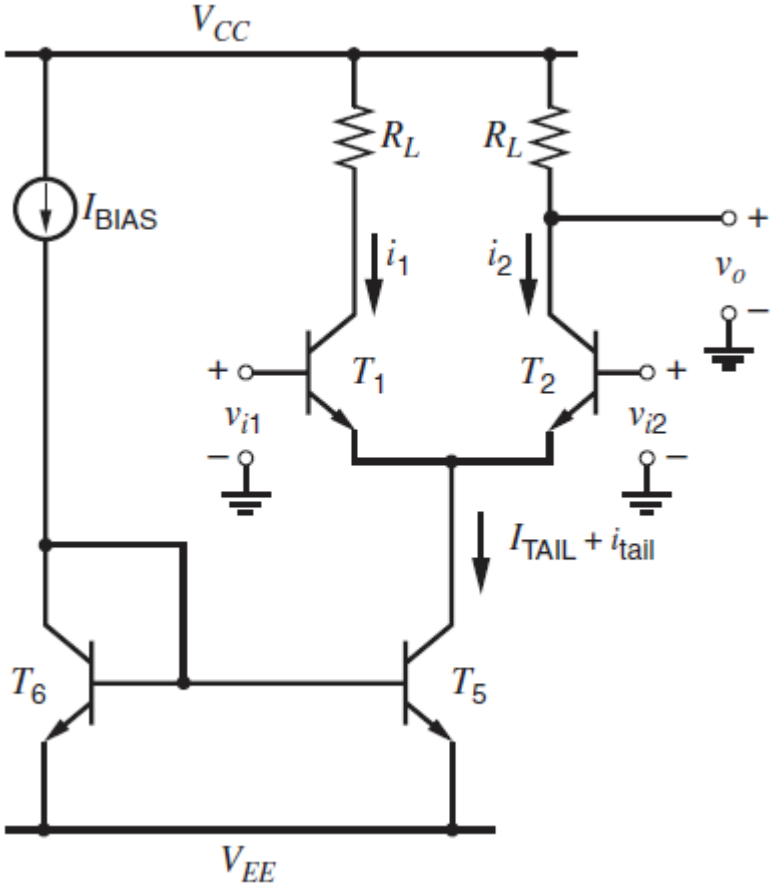
Diferencijalni pojačavač

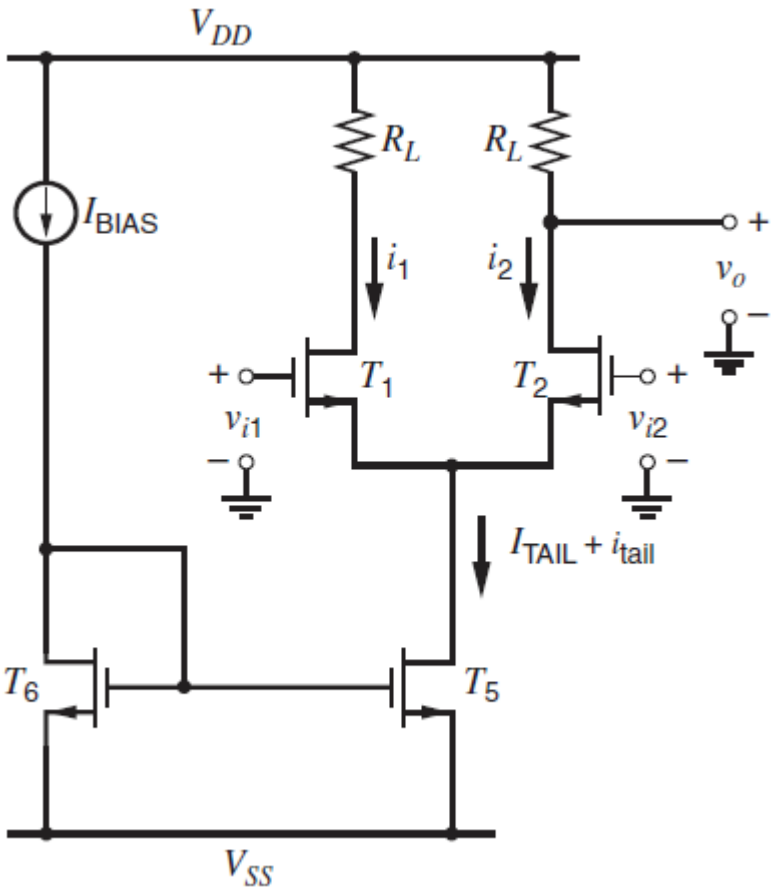
$$R_o = \left.\frac{v_t}{i_t}\right|_{\substack{v_{i1}=0\\v_{i2}=0}} \simeq \frac{1}{\dfrac{1}{r_{o(dp)}} + \dfrac{1}{r_{o(mir)}}} = r_{o(dp)} || r_{o(mir)}$$

$$r_{o4} = r_{o(mir)}$$

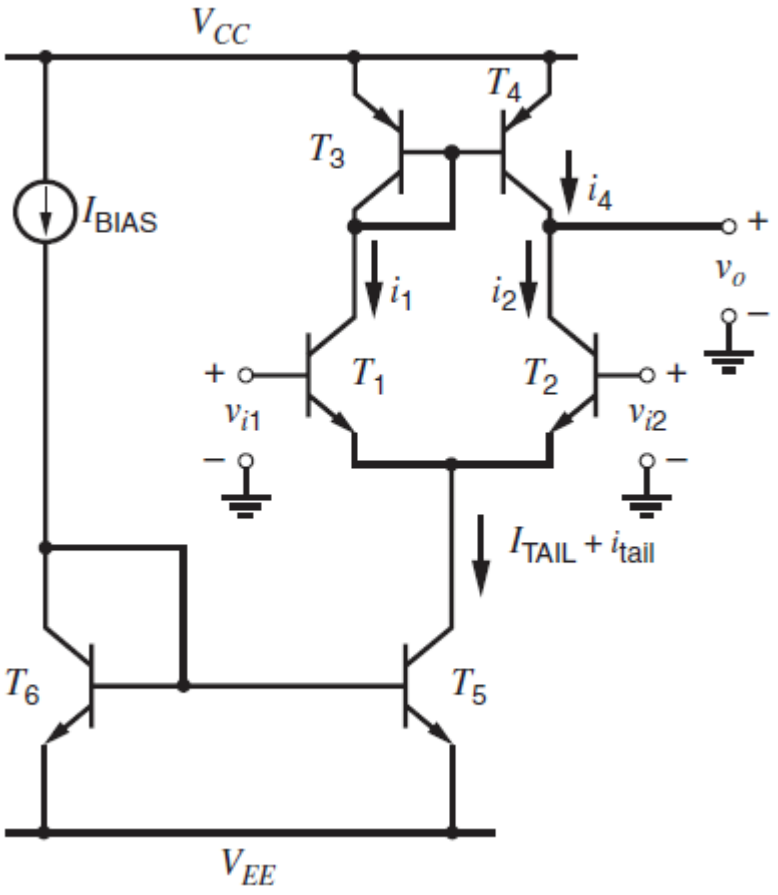
Strujno ogledalo

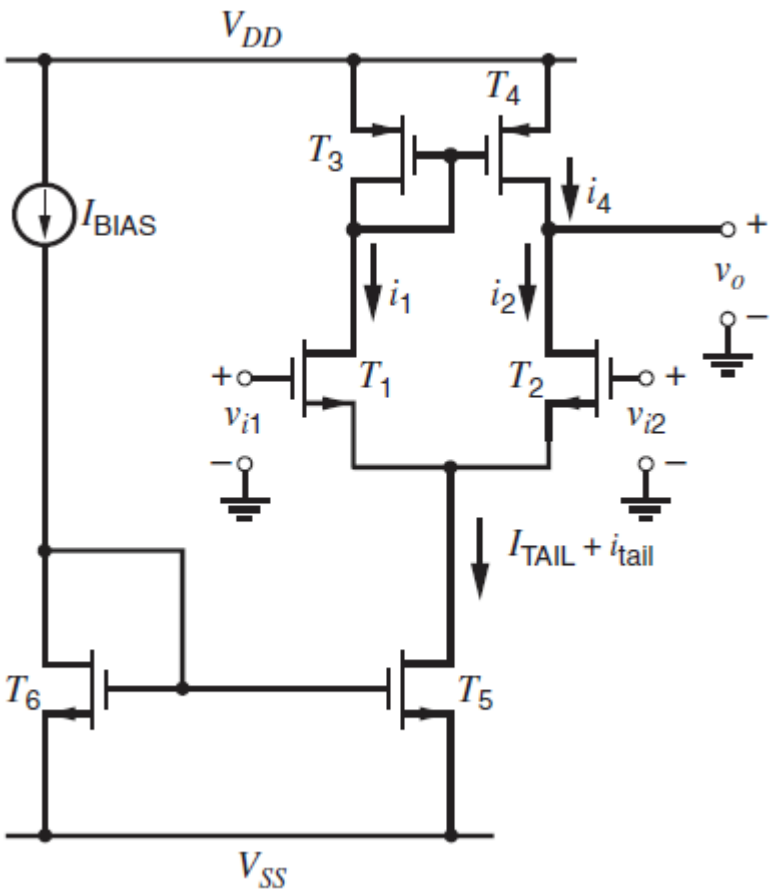
Diferencijalni par sa otpornim opterećenjem i jednostrukim izlazom





Diferencijalni par sa aktivnim opterećenjem za svođenje na jednostruki izlaz





Osnove elektronike
III semestar

AKTIVNO OPTEREĆENJE