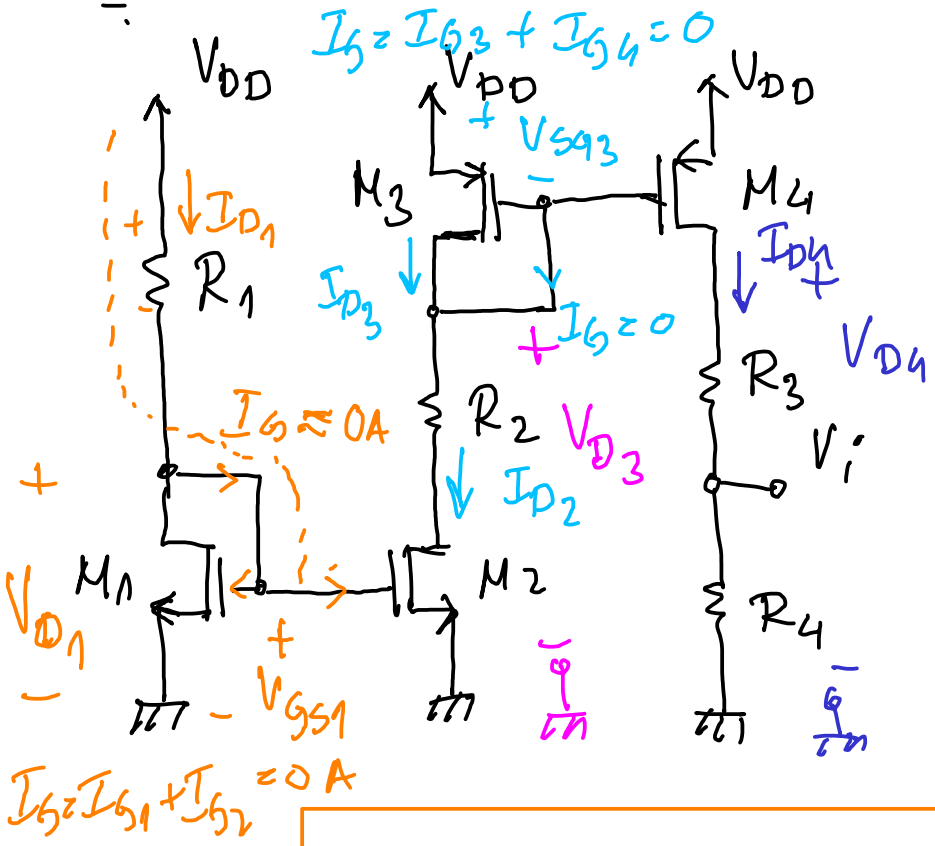
P1 POZNATI SU SVI PARAMETRI MOS-FET (A_i, V_{TH_i}, V_{A_i}) I POZNATI SU SVI ELEMENTI KOLA (R_i, V_{DD}).



ZA DC: $I_D \approx A(V_{GS} - V_{TH})^2$

$V_{DD} = I_{D_1} \cdot R_1 + V_{GS_1}$ ⇐ SA OBE STRANE ODUZETI V_{TH_1}

$V_{DD} - V_{TH_1} = A \cdot R_1 (V_{GS_1} - V_{TH_1})^2 + V_{GS_1} - V_{TH_1}$

$A \cdot R_1 V_{OV_1}^2 + V_{OV_1} - (V_{DD} - V_{TH_1}) = 0$

$V_{OV_1} = V_{GS_1} - V_{TH_1}$

$$V_{OV_1} = \frac{-1 + \sqrt{1 + 4 \cdot AR_1 \cdot (V_{DD} - V_{TH_1})}}{2 \cdot A \cdot R_1}$$

$\Rightarrow I_{D_1} = A_1 \cdot V_{OV_1}^2$

$V_{G_1} = V_{GS_1} = V_{TH_1} + V_{OV_1}$

ZADATO

$A_2 \neq A_1$, $V_{GS_2} = V_{GS_1} \Rightarrow \underbrace{V_{TH_1} + \sqrt{\frac{I_{D_1}}{A_1}}}_{V_{GS_1}} = \underbrace{V_{TH_2} + \sqrt{\frac{I_{D_2}}{A_1}}}_{V_{GS_2}} \Rightarrow \frac{I_{D_1}}{A_1} = \frac{I_{D_2}}{A_2}$

$V_{TH_2} = V_{TH_1}$ SA ŠEME

$$I_{D_2} = \frac{A_2}{A_1} \cdot I_{D_1}$$

$$I_{D_3} = I_{D_2}$$

$$V_{D_3} = V_{DD} - V_{SG_3}$$

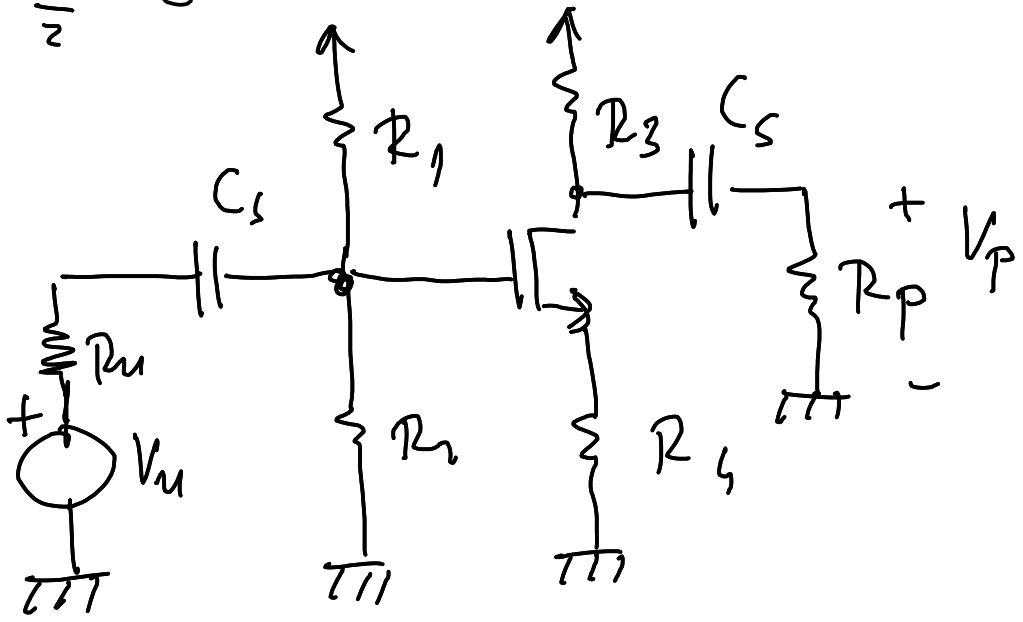
$$A_3 \neq A_4 \Rightarrow \frac{I_{D_3}}{A_3} = \frac{I_{D_4}}{A_4} \Rightarrow I_{D_4} = \frac{A_4}{A_3} I_{D_3} \Rightarrow V_{SG_3} = |V_{TH_3}| + \sqrt{\frac{I_{D_3}}{A_3}} = V_{SG_4}$$

$$V_{D_1} = V_{G_1} = V_{GS_1} = V_{TH_1} + \sqrt{\frac{I_{D_1}}{A_1}} = V_{DD} - I_{D_1} \cdot R_1$$

$$V_{D_4} = I_{D_4} \cdot (R_3 + R_4)$$

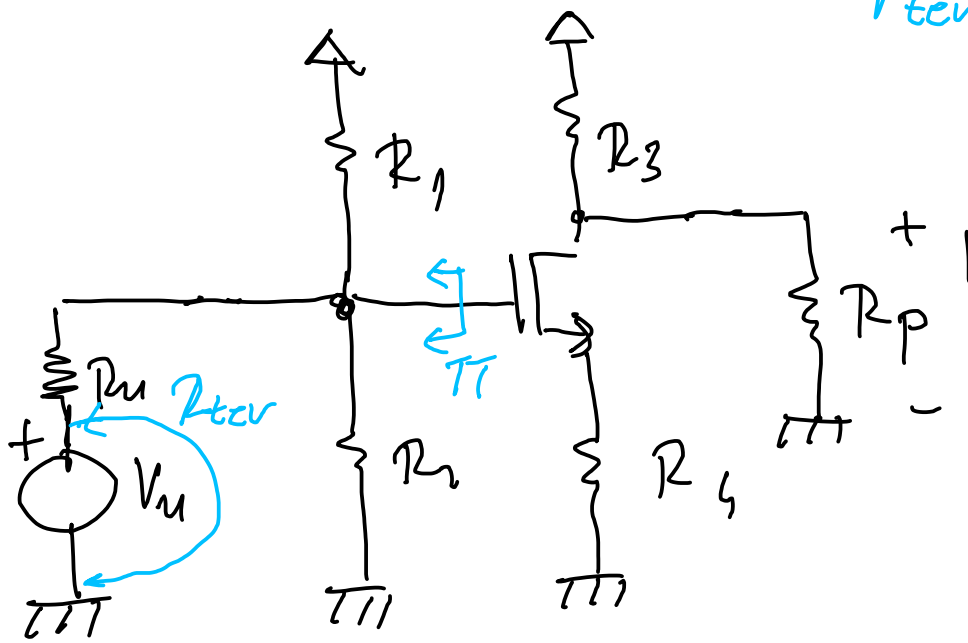
$$V_i = I_{D_4} \cdot R_4 = \frac{R_4}{R_3 + R_4} \cdot V_{D_4}$$

P2 $\{A_n, R_{ul}, R_{iz}\} = ?$

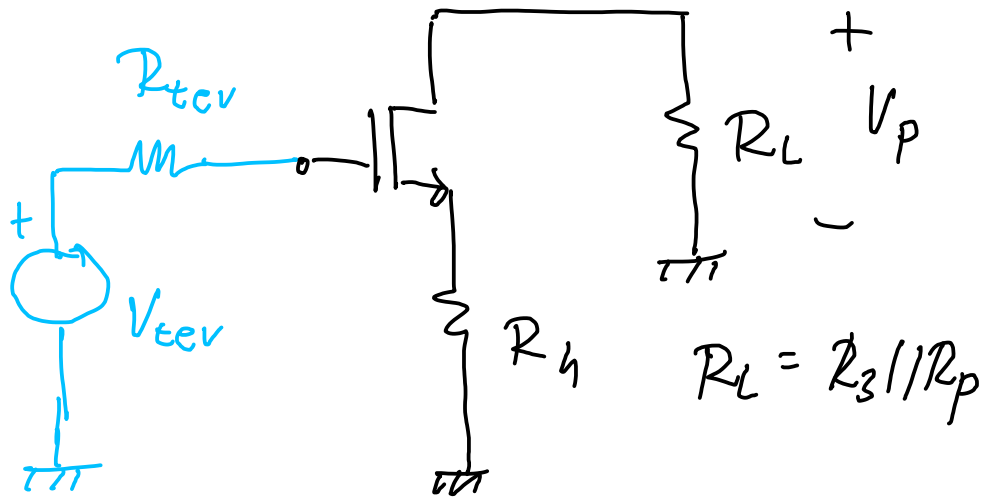


ŠEMA ZA AC ("SS")

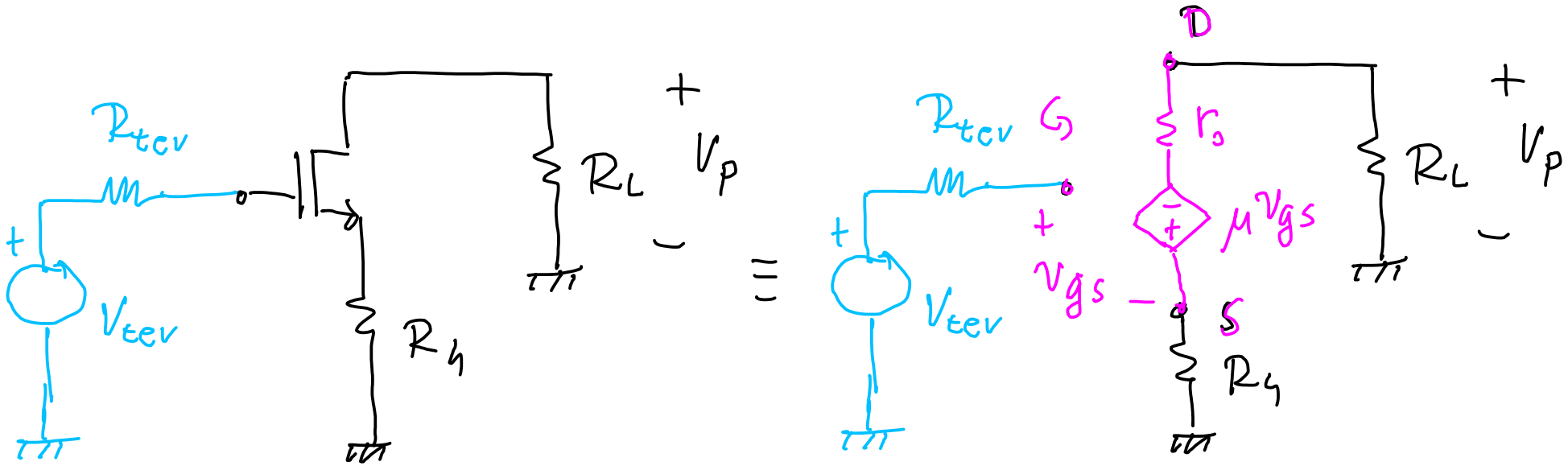
$V_{tev} = \frac{R_G}{R_G + R_u} \cdot V_M$, $R_G = R_1 \| R_2$, $R_{tev} = R_G \| R_u$

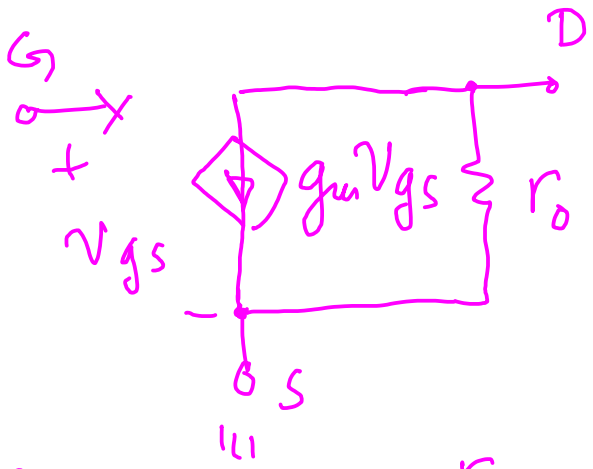


$V_p \equiv$



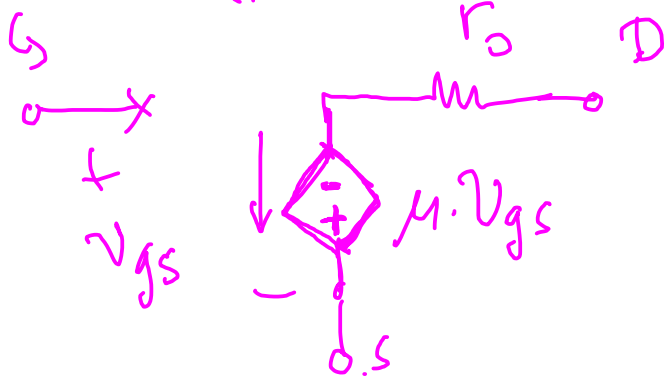
$R_L = R_3 \| R_p$





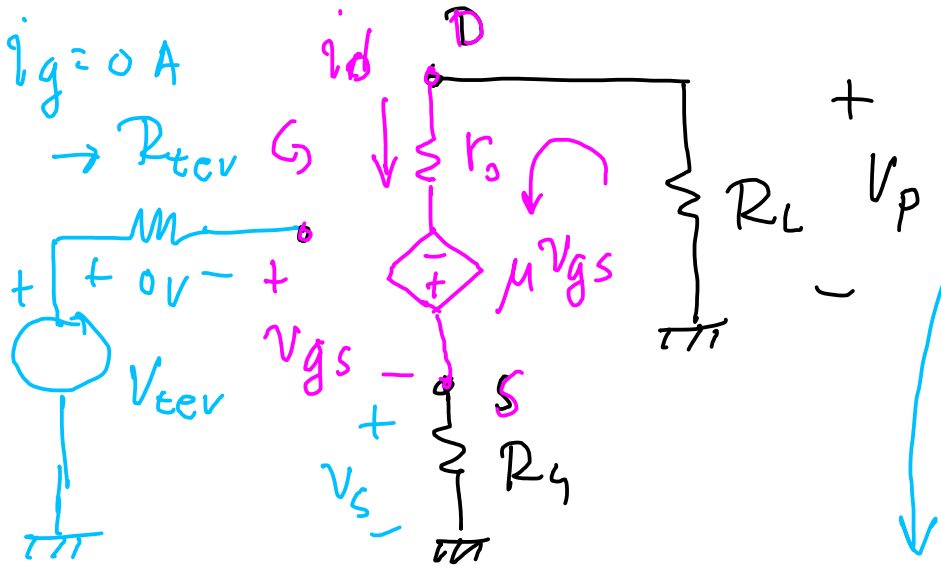
$I_n' = g_m V_{gs}$

$R_n' = r_o$



$V_{tev}' = I_n' \cdot R_n' = g_m r_o V_{gs} = \mu V_{gs} \Rightarrow \boxed{\mu = g_m \cdot r_o}$

$R_{tev}' = R_n' = r_o$



$$V_g = V_{tev} \quad ; \quad V_S = i_d R_4$$

$$0 = i_d (R_L + r_o) - \mu V_{gs} + i_d R_4$$

$$V_{gs} = V_g - V_S = V_{tev} - i_d \cdot R_4$$

$$V_p = - i_d \cdot R_L$$

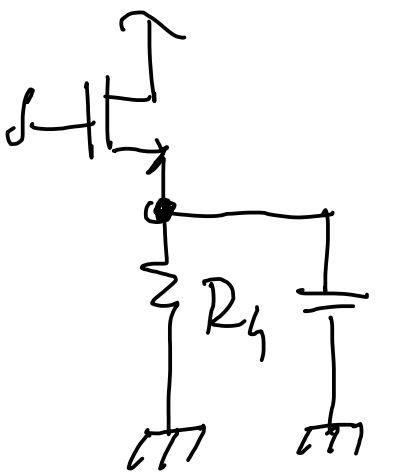
$$0 = i_d (R_L + r_o + R_4) - \mu V_{tev} + \mu i_{d4} R_4$$

$$i_d = \frac{\mu \cdot V_{tev}}{R_L + r_o + (1+\mu) R_4}$$

$$V_p = - i_d \cdot R_L = - \frac{\mu R_L \cdot V_{tev}}{R_L + r_o + (1+\mu) R_4} = \frac{R_G V_u}{R_G + R_u} \cdot \frac{-\mu R_L}{R_L + r_o + (1+\mu) R_4}$$

$$A_u = \frac{V_p}{V_u} = \frac{R_G}{R_G + R_u} \cdot \frac{-\mu R_L}{R_L + r_o + (1+\mu) R_4}$$

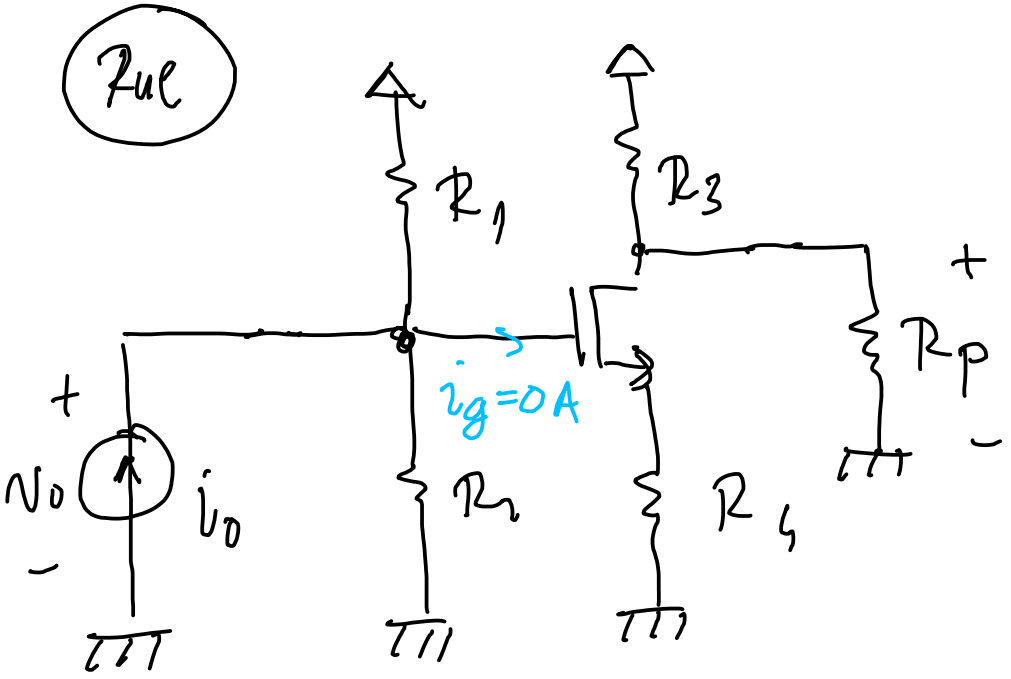
ZA POJAČAVAČ SA ZS BEZ DEGENERACIJE SORSA:



ZA AC: $z_h = \frac{R_L}{1+sC_SR_L}$ | $\to 0\,\Omega$, $C_S \to \infty$ F

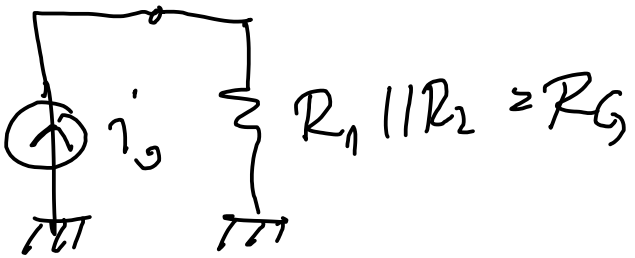
$$A_n = \frac{R_G}{R_G+R_{in}} \cdot \frac{-\mu \cdot R_L}{R_L + r_0} = \frac{R_G}{R_G+R_{in}} \cdot \left(-g_m(R_L \| r_0)\right)$$

| $\mu = g_m r_0$

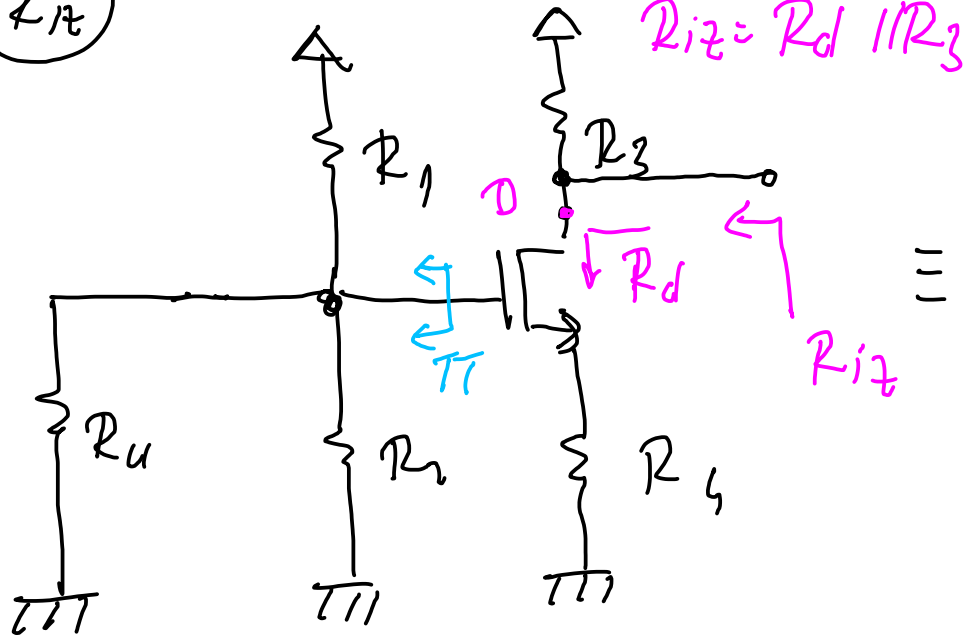


$$R_{ul} = \frac{V_0}{i_0} = R_G = R_1 \| R_2$$

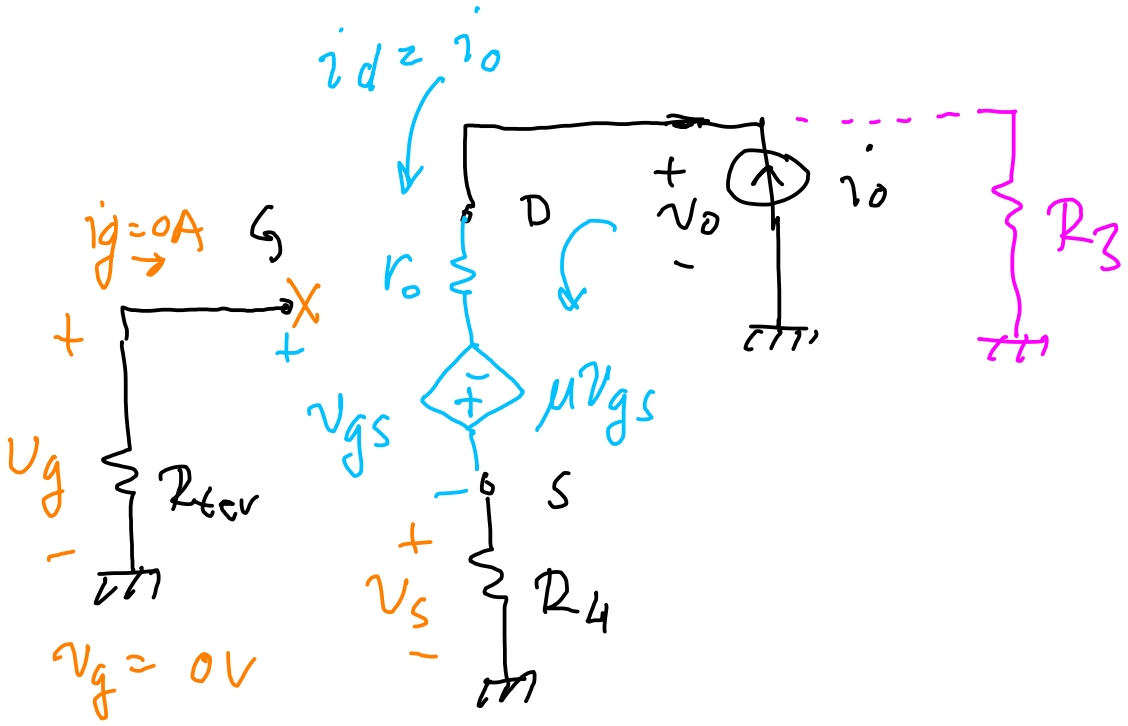
$\equiv$



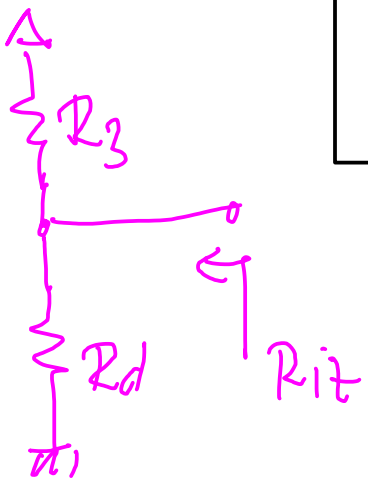
R_{iz}



$\equiv$



III



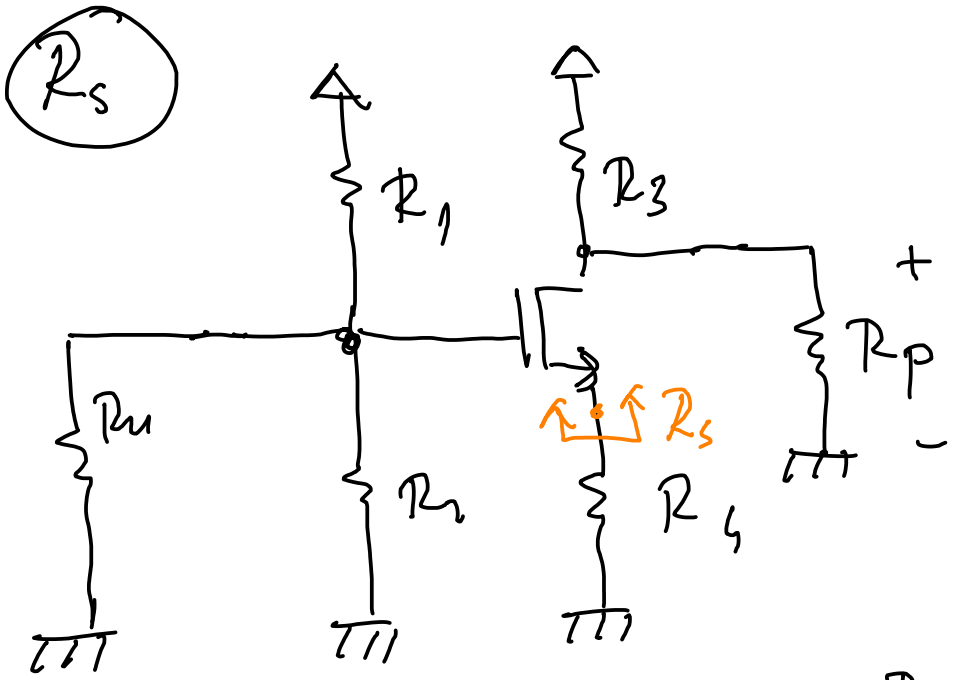
$$R_{iz} = R_d \,||\, R_3$$

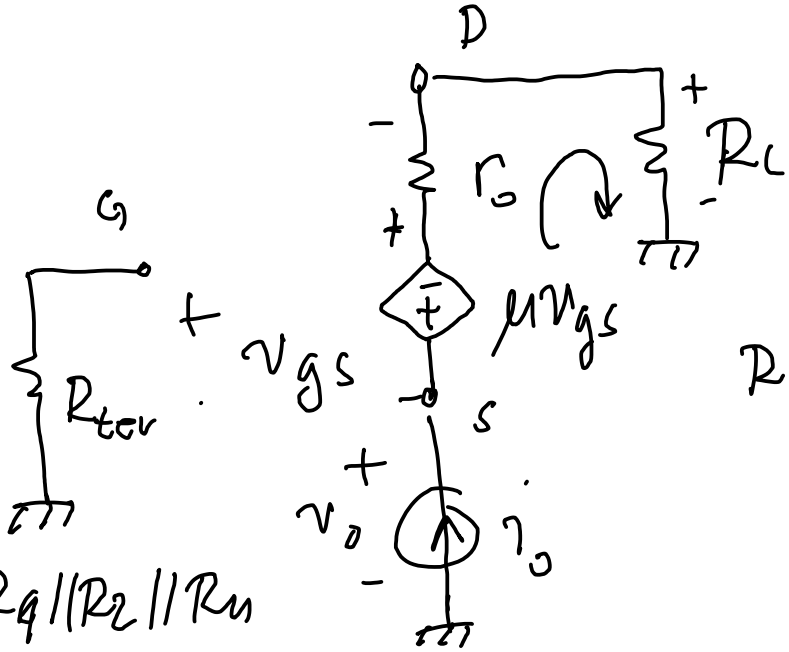
$$v_o = i_o \cdot r_o - \mu v_{gs} + i_o R_4$$

$$v_{gs} = v_g - v_s = -v_s = -i_o R_4$$

$$v_o = i_o (r_o + R_4) + \mu i_o R_4$$

$$R_{ol} = \frac{v_o}{i_o} = r_o + (1+\mu) R_4$$





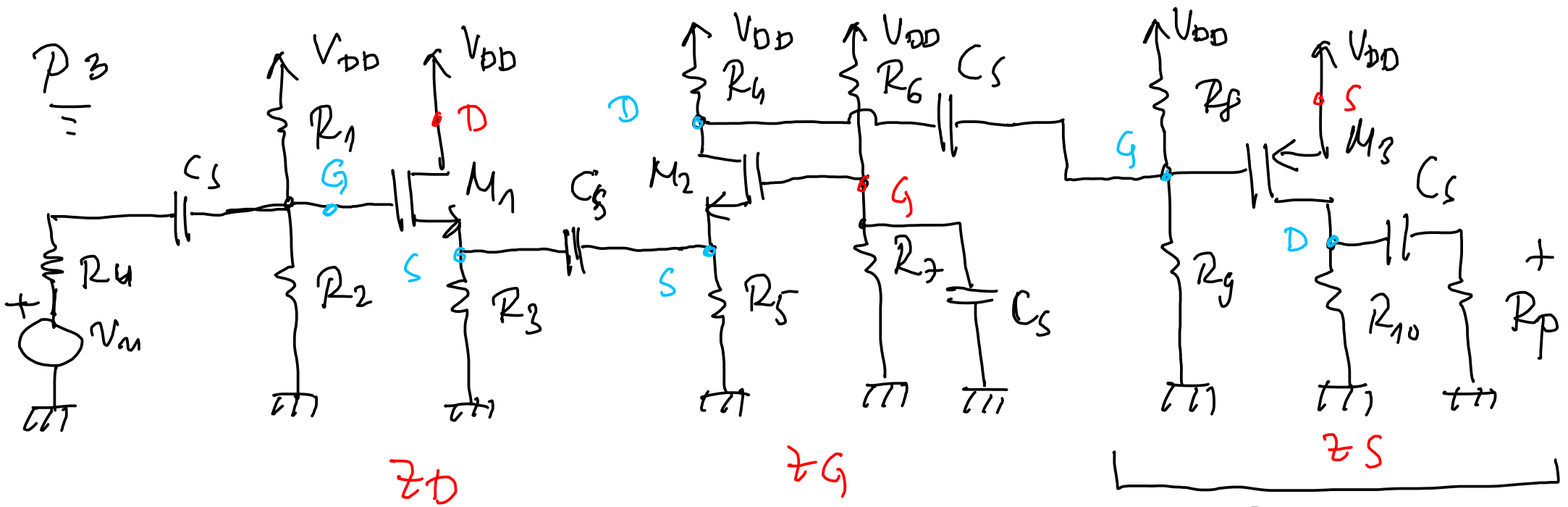
$R_L = R_3 \| R_p$

$R_{tev} = R_4 \| R_2 \| R_1$

$v_o = \mu v_{gs} + i_o (r_o + R_L)$; $v_{gs} = v_g - v_s = 0 - v_o$

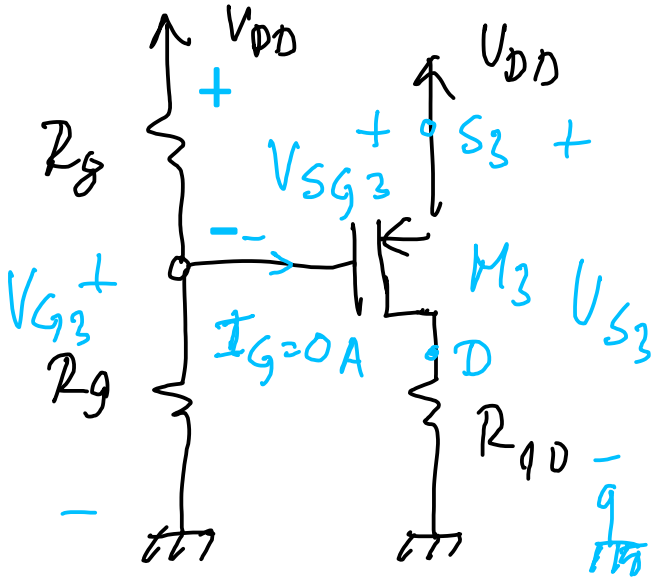
$v_o = -\mu v_o + i_o (r_o + R_L) \Rightarrow$

$$R_s = \frac{v_o}{i_o} = \frac{r_o + R_L}{1 + \mu}$$



NAPOMENA: ZA DOMAĆI URADITI DC ZA (ZD) ; (ZG)

ZS SA PMOS

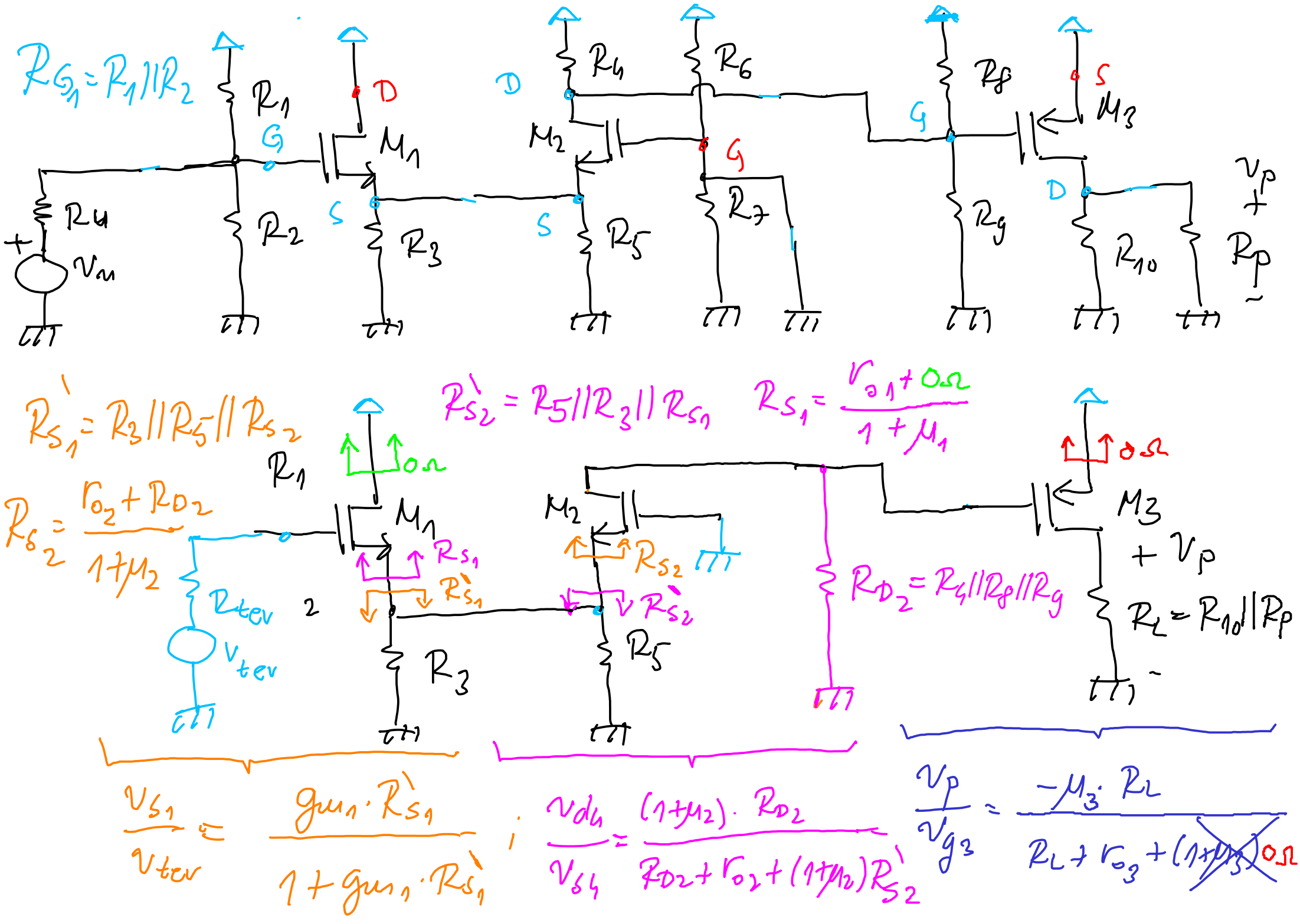


$$V_{G3} = \frac{R_g}{R_g + R_g} \cdot V_{DD} \; ; \qquad V_{SG3} = V_{S3} - V_{G3}$$

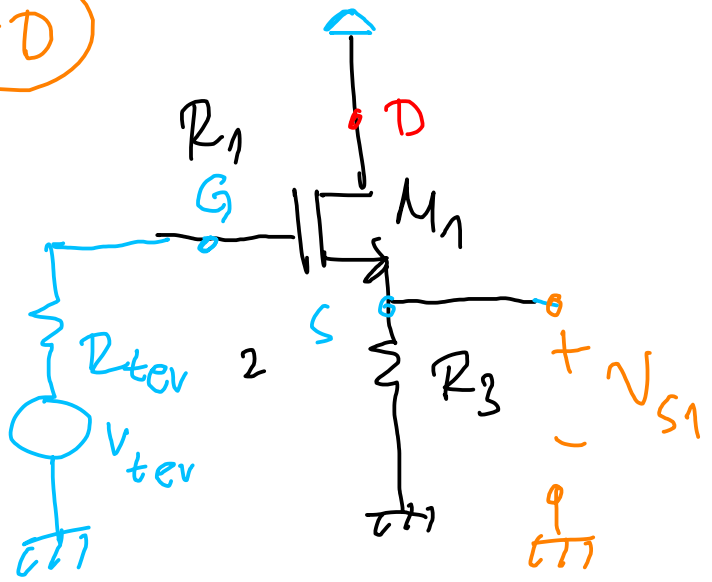
$$= V_{DD} - \frac{R_g}{R_g + R_g} \cdot V_{DD}$$

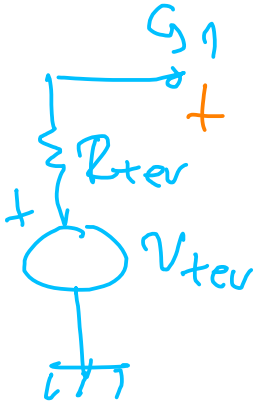
$$V_{D3} = I_{D3} \cdot R_{10}$$

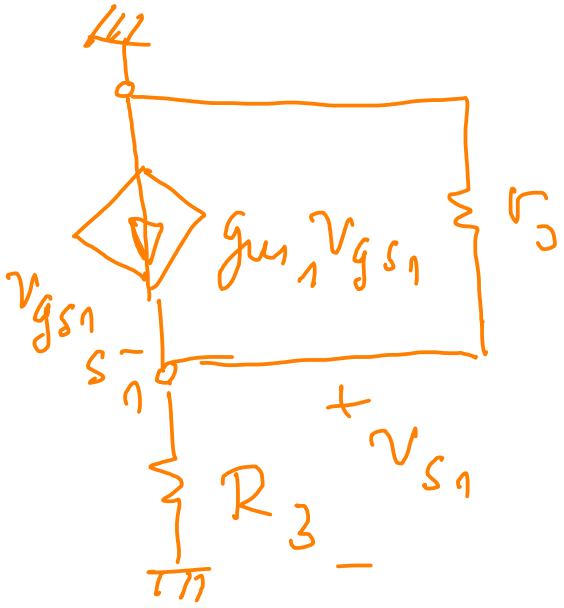
$$I_{D3} = A_3 \left(V_{SG3} - |V_{TH3}| \right)^2 \Leftarrow \boxed{V_{SG3} = \frac{R_g}{R_g + R_g} \cdot V_{DD}}$$


$R_{G_1} = R_1 \| R_2$
R_1
G
D
M_1
R_4
R_2
S
R_3
v_{in}
+
D
R_4
R_6
M_2
G
S
R_5
R_7
G
R_8
S
M_3
D
R_9
R_{10}
v_p
+
R_p
~
$R_{S_1}' = R_3 \| R_5 \| R_{S_2}$
$R_{S_2}' = R_5 \| R_3 \| R_{S_1}$
$R_{S_1} = \frac{r_{o_1} + 0\Omega}{1 + \mu_1}$
$R_{G_2} = \frac{r_{o_2} + R_{D_2}}{1 + \mu_2}$
R_{tev}
v_{tev}
2
R_{S_1}
R_{S_1}'
R_{S_2}
R_{S_2}'
$R_{D_2} = R_4 \| R_8 \| R_9$
$R_L = R_{10} \| R_p$
0Ω
$\frac{v_{S_1}}{v_{tev}} = \frac{g_{m_1} \cdot R_{S_1}'}{1 + g_{m_1} \cdot R_{S_1}'}$
$\frac{v_{d_4}}{v_{S_4}} = \frac{(1+\mu_2) \cdot R_{D_2}}{R_{D_2} + r_{o_2} + (1+\mu_2) R_{S_2}'}$
$\frac{v_p}{v_{g_3}} = \frac{-\mu_3 \cdot R_L}{R_L + r_{o_3} + (1+\mu_3) 0\Omega}$

ZD





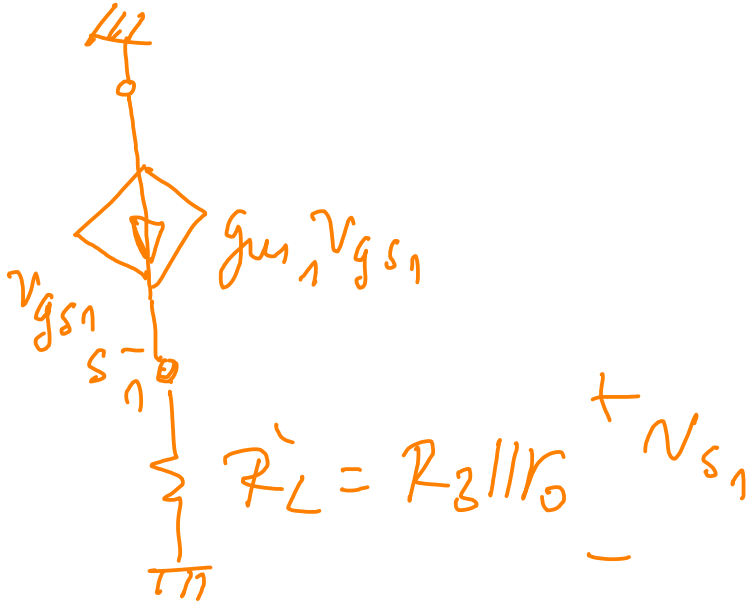


$$A_{v1}' = \frac{v_{s1}}{v_{tev}} = \frac{g_{m1} R_L'}{1 + g_{m1} R_L'} \lesssim 1$$

$$v_{s1} = (g_{m1} \cdot v_{gs1}) \cdot R_L'$$

$$v_{gs1} = v_{g1} - v_{s1}$$

$$= v_{tev} - v_{s1} \Rightarrow v_{s1} = g_{m1} R_L' \cdot (v_{tev} - v_{s1})$$

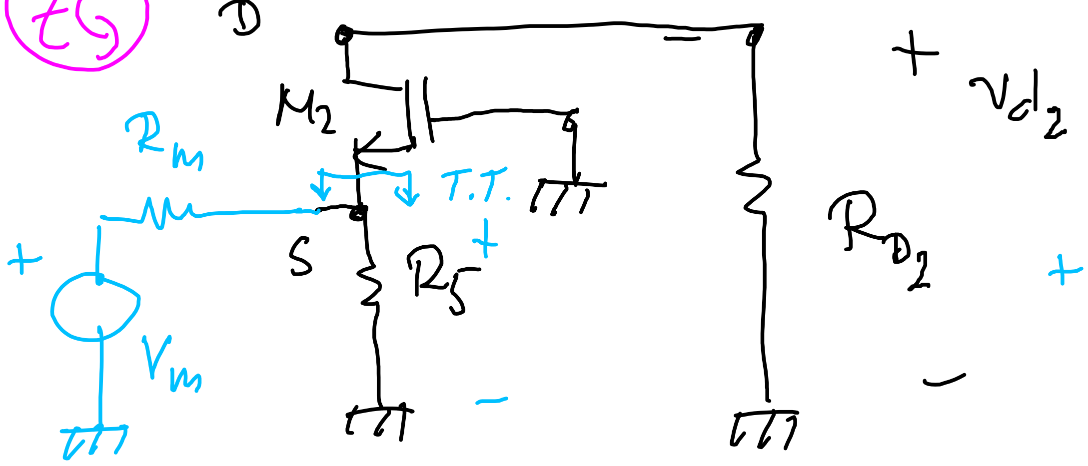


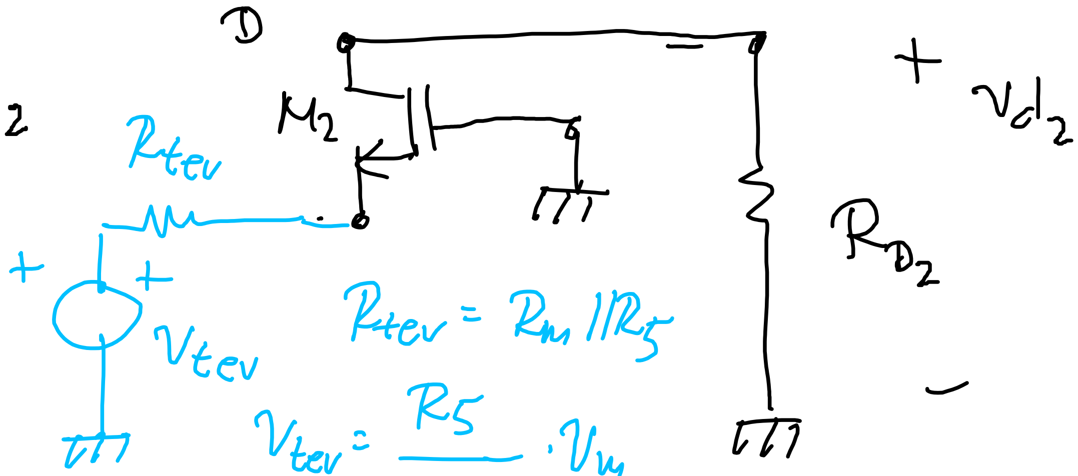
$$A_u = \frac{v_{s1}}{v_{ter}} = \frac{g_{m1} R_L'}{1 + g_{m1} R_L'} = \frac{g_{m1}}{\frac{1}{R_L'} + g_{m1}} = \frac{g_{m1} \quad / r_{o1} R_3}{\frac{1}{r_{o1}} + \frac{1}{R_3} + g_{m1} / r_{o1} R_3}$$

$$A_u' = \frac{\mu_1 R_3}{R_3 + r_{o1} + \mu_1 \cdot R_3} = \frac{\mu_1 R_3}{r_{o1} + (1 + g_{m1}) R_3}$$

$$A_u = \frac{v_{s1}}{v_m} = \frac{v_{s1}}{v_{ter}} \cdot \frac{v_{ter}}{v_u} = A_u' \cdot \frac{R_G}{R_G + R_u} \quad ; \quad R_G = R_1 // R_2$$

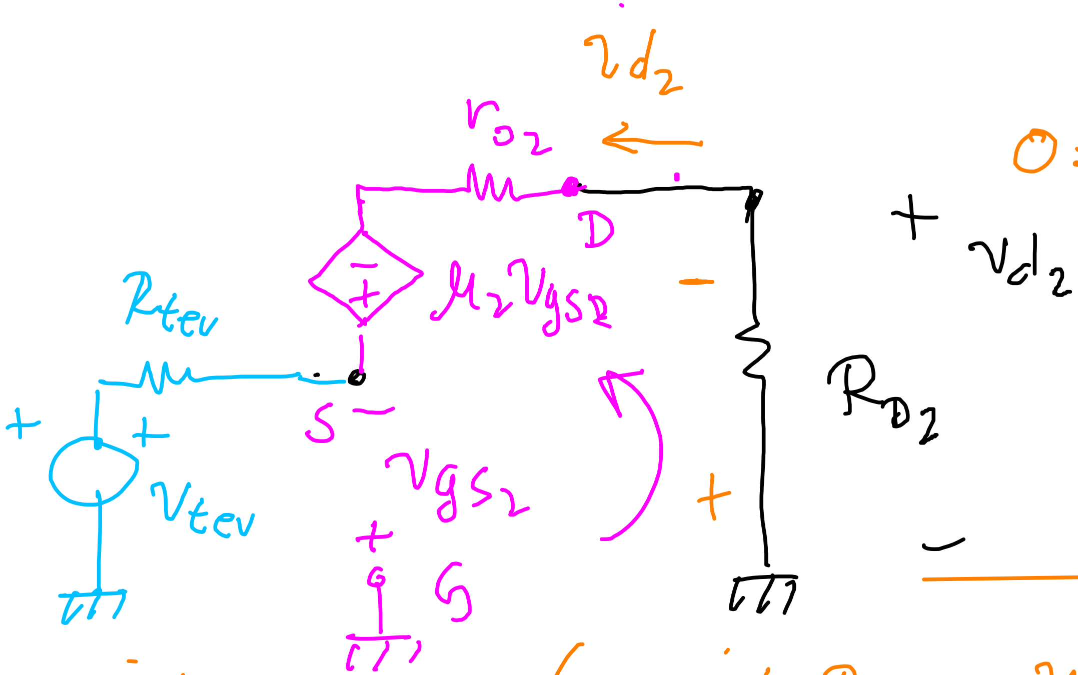
25





$$R_{tev} = R_{in} \parallel R_5$$

$$V_{tev} = \frac{R_5}{R_5 + R_{in}} \cdot V_{in}$$



$$0 = i_{d_2}(R_{D_2} + r_{o_2}) - \mu_2 v_{gs_2} + i_{d_2} R_{tev} + V_{tev}$$

$$v_{gs_2} = 0 - (i_{d_2} R_{tev} + V_{tev})$$

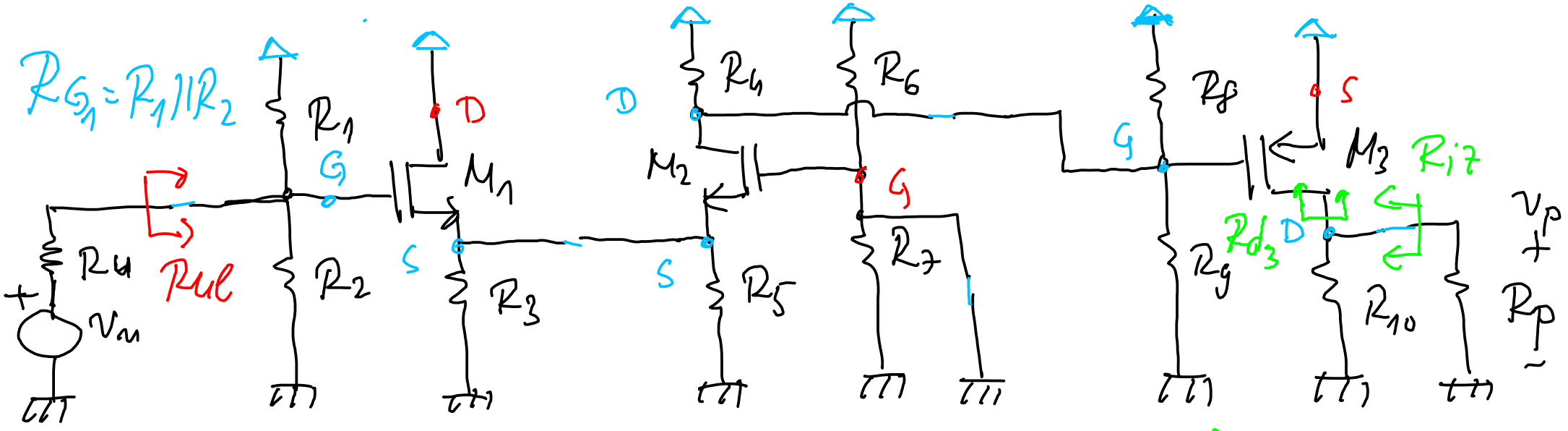
$$0 = i_{d_2} r_{o_2} - \mu_2(-i_{d_2} R_{tev} - V_{tev}) + i_{d_2} R_{tev} + V_{tev} + i_{d_2} R_{D_2}$$

$$i_{d_2} = \frac{-(1+\mu_2)V_{tev}}{r_{o_2} + (1+\mu_2)R_{tev} + R_{D_2}} \Rightarrow v_d = -i_{d_2} \cdot R_{D_2}$$

$$A_n = \frac{v_{d_2}}{v_{ter}} = \frac{(1+\mu_2)\,R_{D_2}}{r_{o_2} + R_{D_2} + (1+\mu_2)\,R_{ter}}$$

$$A_v = \frac{v_{d_2}}{v_m} \cdot \frac{R_5}{R_5 + R_m} \cdot A_n$$

$$A_v = \frac{v_p}{v_u} = \frac{R_{G_1}}{R_{G_1} + R_u} \cdot \frac{g_{m_1} \cdot R'_{s_1}}{1 + g_{m_1} \cdot R'_{s_1}} \cdot \frac{(1+\mu_2)\cdot R_{D_2}}{R_{D_2} + r_{o_2} + (1+\mu_2) R'_{s_2}} \cdot \frac{-\mu_3 \cdot R_L}{R_L + r_{o_3}}$$



$$R_{ul} = R_1 // R_2 = R_{G_1}$$

$$R_{i7} = R_{10} // R_{d_3}, \qquad R_{d_3} = r_{o_3} + (1+\mu_3)\cdot \cancel{0\ \Omega}$$