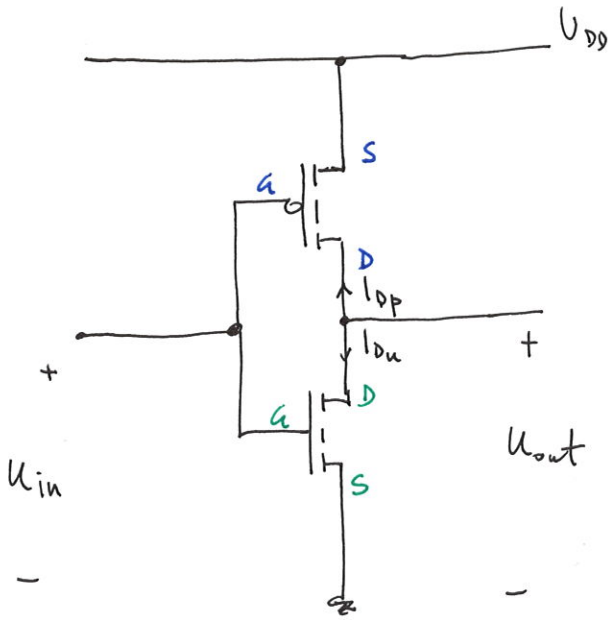


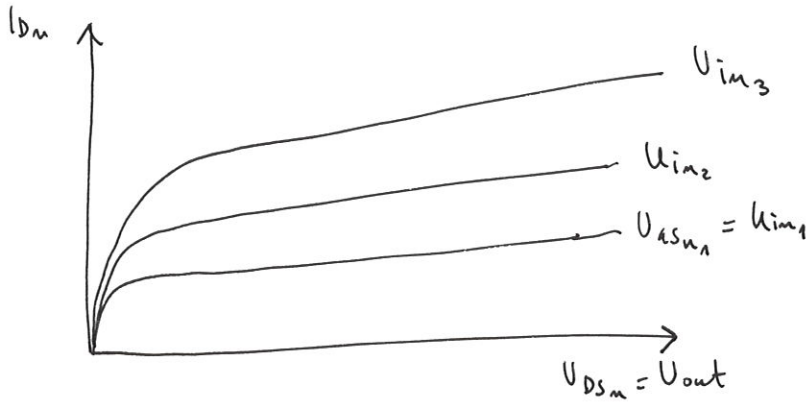
$U_{in} = U_{GSn}$

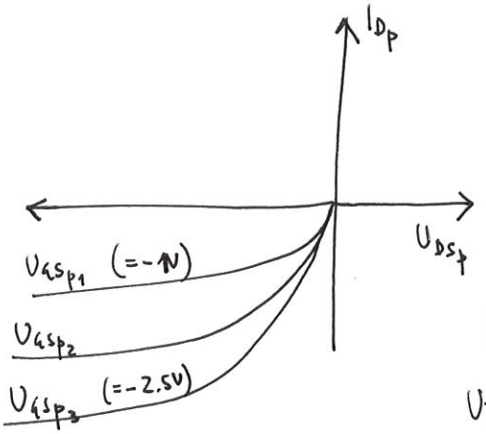
$U_{out} = U_{DSn}$

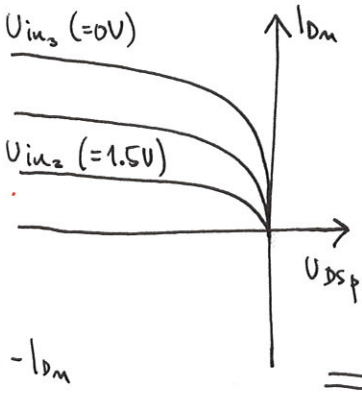
$U_{in} = U_{DD} + U_{GSp}$

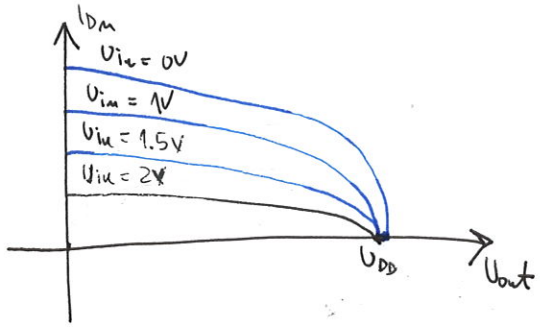
$U_{out} = U_{DD} + U_{DSp}$

$I_{Dn} = - I_{Dp}$





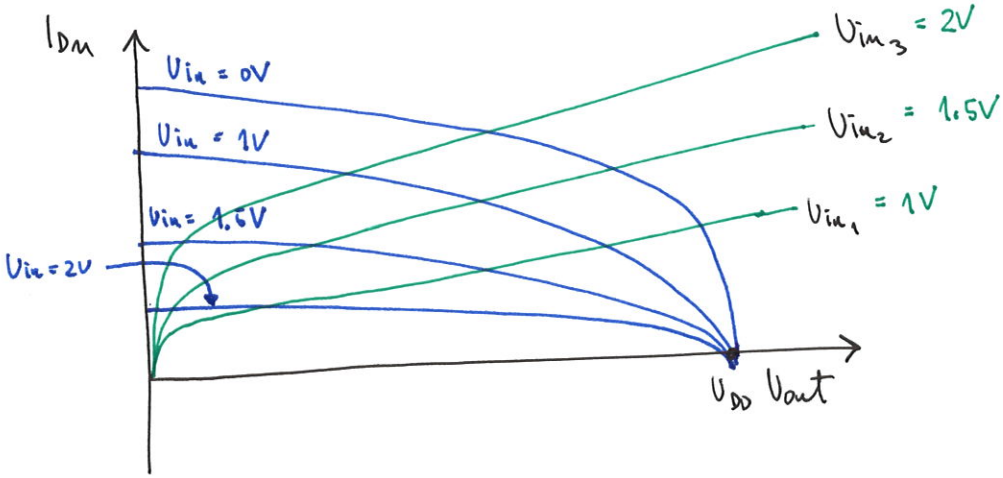


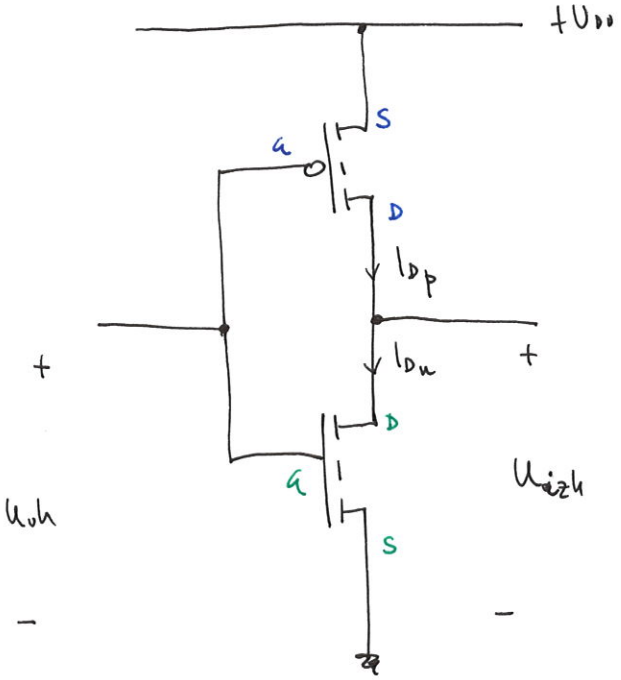


$I_{Dp} = - I_{Dn}$

$U_{in} = U_{DD} + U_{GSp}$

$\Rightarrow U_{out} = U_{DD} + U_{DSp}$





$$I_{Dp} = K_p \cdot \left(U_{SG_p} - |U_{Tp}| \right)^2 = I_{Dn} = K_n \cdot \left(U_{GSn} - U_{Tn} \right)^2$$

$$U_{GS_n} = U_{ki}$$

$$U_{SG_p} = U_{DD} - U_{ki}$$

$$K_p \cdot \left(U_{DD} - U_{ki} - |U_{Tp}| \right)^2 = K_n \cdot \left(U_{ki} - U_{Tn} \right)^2$$

$$\sqrt{\frac{K_p}{K_n}} \cdot \left(U_{DD} - U_{ki} - |U_{Tp}| \right) = U_{ki} - U_{Tn}$$

$$\sqrt{\frac{K_p}{K_n}} \cdot \left(U_{DD} - |U_{Tp}| \right) + U_{Tn} = U_{ki} \left(1 + \sqrt{\frac{K_p}{K_n}} \right)$$

$$U_{ki} = \frac{\sqrt{\frac{K_p}{K_n}} \cdot \left(U_{DD} - |U_{Tp}| \right) + U_{Tn}}{1 + \sqrt{\frac{K_p}{K_n}}} = \frac{U_{DD}}{2}$$

1.) $\sqrt{\frac{K_p}{K_n}} = 1$

$K_p = K_n$

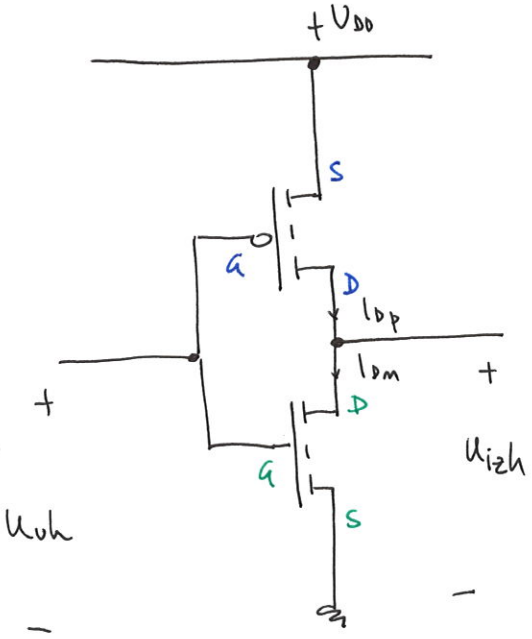
$$\frac{\mu_p \cdot C_{ox}}{2} \cdot \frac{W_p}{L_p} = \frac{\mu_n C_{ox}}{2} \cdot \frac{W_n}{L_n}$$

$\mu_p W_p = \mu_n W_n$

$$W_p = \frac{\mu_n}{\mu_p} \cdot W_n$$

2.) $U_{ki} = \frac{U_{DD} - |U_{Tp}| + U_{Tn}}{2} = \frac{U_{DD}}{2}$

$U_{Tn} = |U_{Tp}|$; $(U_{Tp} = -U_{Tn})$

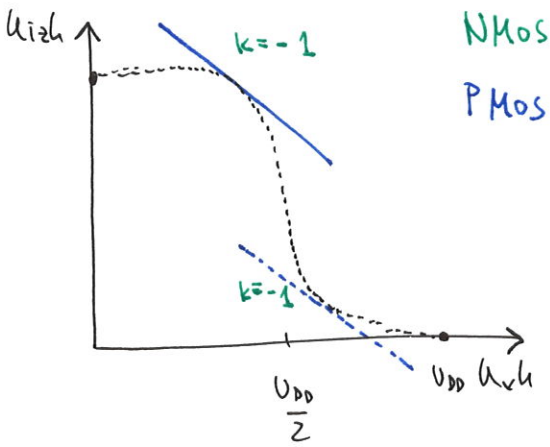


$U_{GS_n} = U_{vh}$

$U_{DS_n} = U_{izh}$

$U_{GS_p} = U_{vh} - U_{DD}$

$U_{DS_p} = U_{izh} - U_{DD}$



NMOS: mešičenje

PMOS: ~~linearno~~ podr.

$I_{D_n} = I_{D_p}$

$$K_n \cdot (U_{GS_n} - U_{T_n})^2 = K_p \left[2 (U_{GS_p} - U_{T_p}) \cdot U_{DS_p} - U_{DS_p}^2 \right]$$

$$K_n \cdot (U_{vh} - U_{Tn})^2 = K_p \cdot \left[2 \cdot (U_{vh} - U_{DD} - U_{Tp}) \cdot (U_{izh} - U_{DD}) - (U_{izh} - U_{DD})^2 \right]$$

$\frac{K_n}{K_p} = \beta$; $\beta (U_{vh} - U_{Tn})^2 = 2 \cdot (U_{vh} - U_{DD} - U_{Tp}) \cdot (U_{izh} - U_{DD}) - (U_{izh} - U_{DD})^2$

upoštevamo $\beta = 1$, $U_{Tp} = -U_{Tn}$ in preuredimo po U_{izh}

$U_{Tn} = U_T$

$$U_{izh}^2 - 2 (U_{vh} + U_T) U_{izh} + (U_{vh} - U_T)^2 + 2 (U_{vh} + U_T) \cdot U_{DD} - U_{DD}^2 = 0$$

Implicitno odvajamo u_{izh} po u_{vh} in upoštevamo $\frac{du_{izh}}{du_{vh}} = -1$

$u_{izh} = f(u_{vh})$

odvod $u_{izh}^2 \Rightarrow 2 \cdot u_{izh} \cdot \frac{du_{izh}}{du_{vh}} = -2 \cdot u_{izh}$ ($\frac{du_{izh}}{du_{vh}} = -1$)

$$-2u_{izh} - 2\left[u_{izh} - (u_{vh} + U_T)\right] + 2(u_{vh} - U_T) + 2 \cdot U_{DD} = 0$$

$$4u_{izh} = 2(u_{vh} + U_T) + 2(u_{vh} - U_T) + 2U_{DD}$$

$$u_{izh} = u_{vh} + \frac{U_{DD}}{2}$$

mejo v izhodiščno enačbo

$$u_{izh}^2 - 2(u_{vh} + U_T) \cdot u_{izh} + (u_{vh} - U_T)^2 + 2(u_{vh} + U_T) \cdot U_{DD} - U_{DD}^2 = 0$$

$$\left(u_{vh} + \frac{U_{DD}}{2}\right)^2 - 2\left(u_{vh} + U_T\right)\left(u_{vh} + \frac{U_{DD}}{2}\right) + (u_{vh} - U_T)^2 + 2(u_{vh} + U_T) \cdot U_{DD} - U_{DD}^2 = 0$$

$$u_{vh} = \frac{\frac{3}{4} \cdot U_{DD}^2 - U_T^2 - U_{DD} \cdot U_T}{2U_{DD} - 4U_T}$$

PRIMER

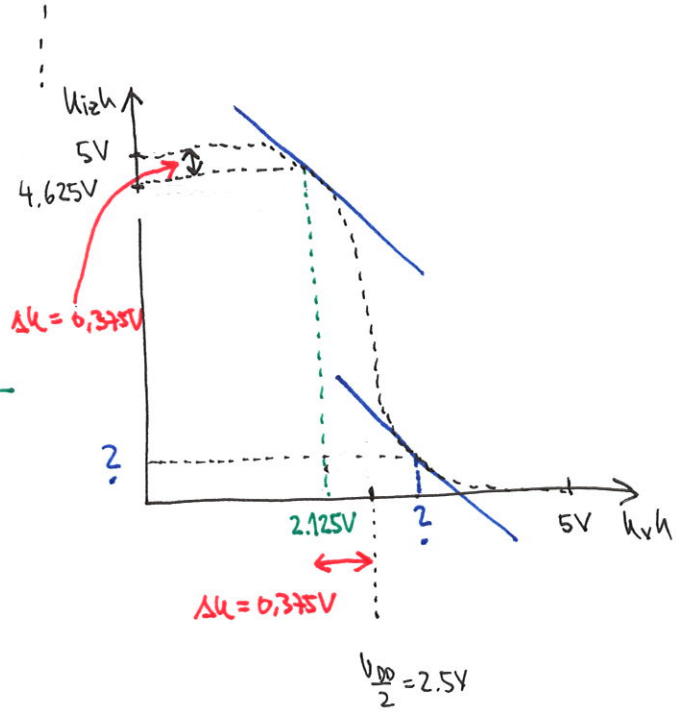
$U_{DD} = 5V$

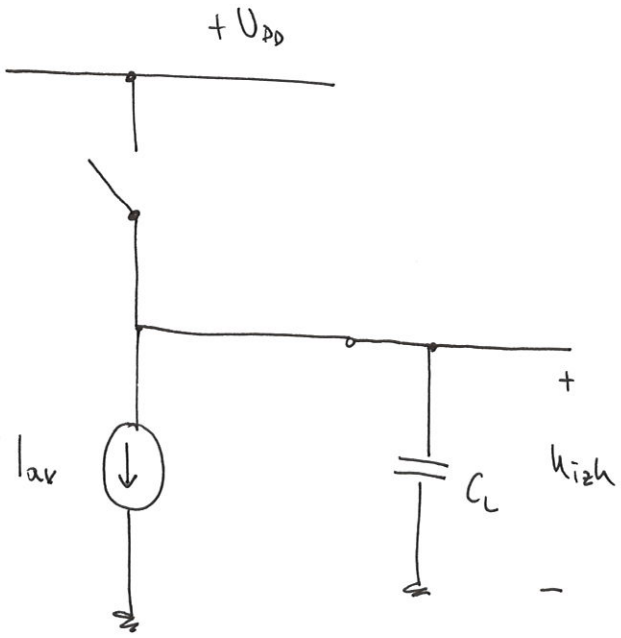
$U_T = 1V$

$$u_{vh} = \frac{\frac{3}{4} \cdot 25V^2 - 1V^2 - 5V \cdot 1V}{2.5V - 4 \cdot 1V} = 2.125V$$

$$u_{izh} = u_{vh} + \frac{U_{DD}}{2} = 2.125V + 2.5V = 4.625V$$

$$\Delta u_{izh} = 5V - 4.625V = 0.375V$$





$$I_{av} = \frac{\Delta Q_{CL}}{\Delta t}$$

$$t_{pHL} \Rightarrow u_{CL}: \quad U_{DD} \rightarrow \frac{U_{DD}}{2}$$

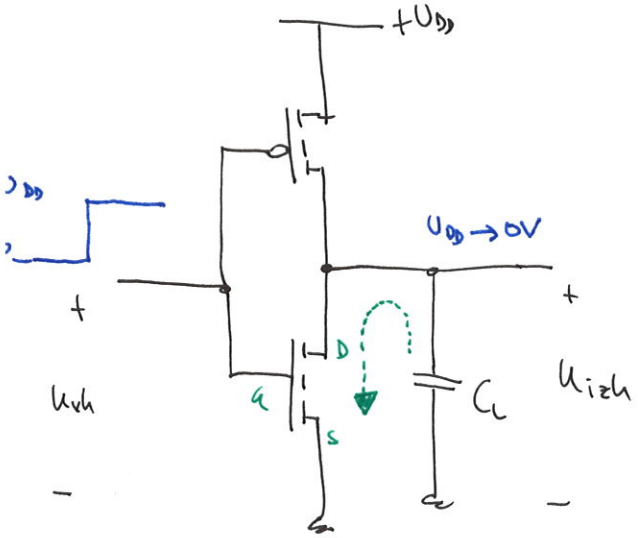
$$I_{av} = \frac{C_L \cdot \Delta u_{CL}}{\Delta t} \Rightarrow I_{av} = C_L \frac{\frac{U_{DD}}{2}}{t_{pHL}}$$

$$t_{pHL} = \frac{C_L \frac{U_{DD}}{2}}{I_{av}}$$

$U_{DD} = U_{swing}$

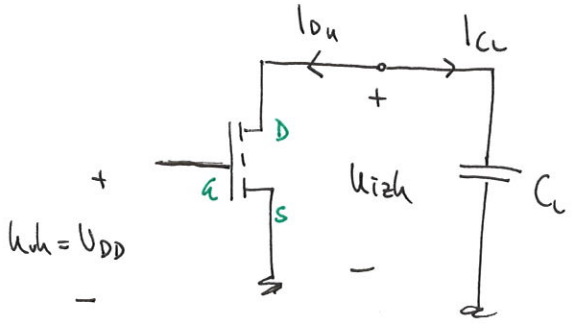
$u_{swing} = u_{out}("1") - u_{out}("0")$

$$t_{pHL} = \sim \frac{C_L \cdot U_{DD}}{I_{av}}$$

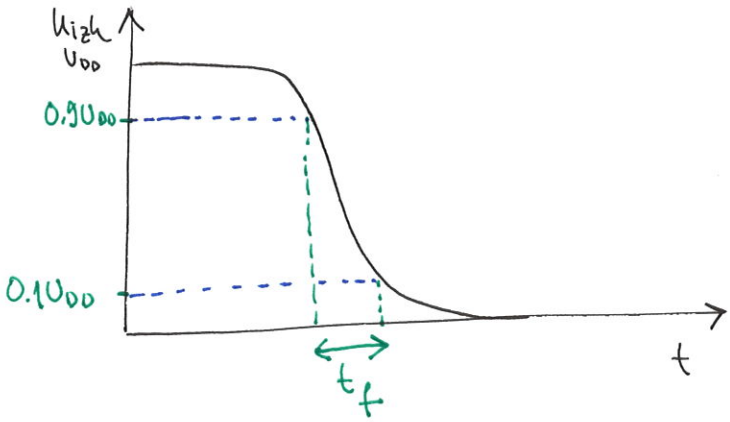


$u_{vh} = U_{GSm}$

$u_{izh} = U_{DSm} = u_{CL}$



$$I_{CL} = C\frac{du_{CL}}{dt} = C\frac{du_{izh}}{dt}$$



$0.1U_{DD} \leq u_{izh} \leq 0.9U_{DD}$

$t_f = t_{f1} + t_{f2}$

1.) t_{f1}: IZHOD V NASIČENJU

$U_{DD} - U_{Tm} \leq u_{izh} \leq 0.9U_{DD}$

2.) t_{f2} IZHOD V LIN. PODROČJU

$0.1U_{DD} \leq u_{izh} \leq U_{DD} - U_{Tm}$

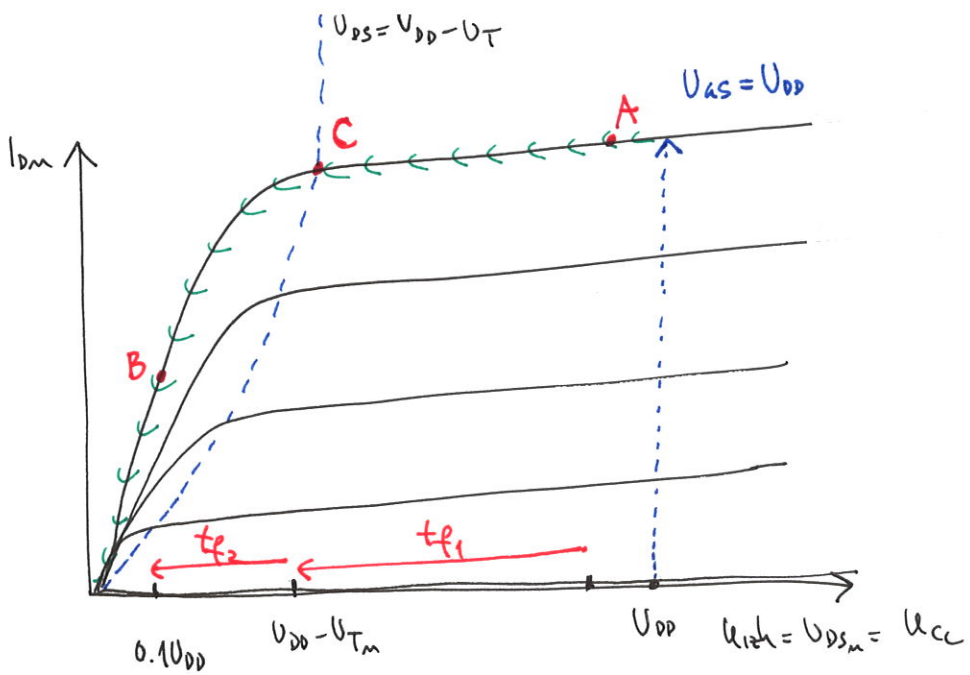
MEJA MED NASIČENJEM IN LIN. PODROČJEM

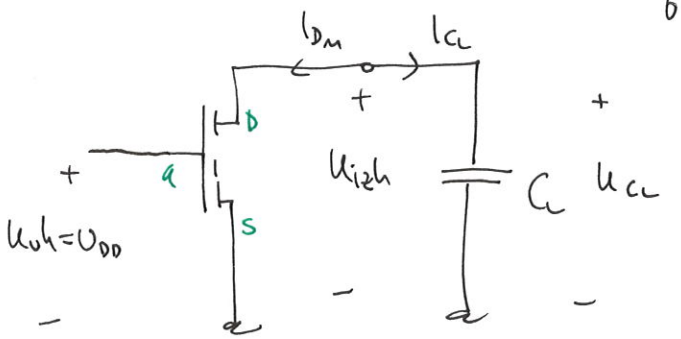
$U_{DS} = U_{GS} - U_{Tm}$

$\uparrow$

U_{DD}

$U_{DS} = U_{DD} - U_{Tm}$





1.) NASIČENJE, t_{f_1}

$$I_{C_L} = -I_{D_M}$$

$$I_{C_L} + I_{D_M} = 0$$

$$C_L \frac{du_{CL}}{dt} + K_M \cdot \left(U_{GS_M} - U_{TM}\right)^2 = 0$$

$$C_L \frac{du_{izh}}{dt} + K_N \left(U_{DD} - U_{TM}\right)^2 = 0$$

$$du_{izh} = -\frac{K_N}{C_L}\left(U_{DD} - U_{TM}\right)^2 dt$$

$$\int_{0.9U_{DD}}^{U_{DD}-U_{TM}} du_{izh} = -\frac{K_N}{C_L}\cdot\left(U_{DD} - U_{TM}\right)^2 \cdot \int_0^{t_{f_1}} dt$$

$$U_{DD} - U_{TM} - 0.9U_{DD} = -\frac{K_N}{C_L}\cdot\left(U_{DD} - U_{TM}\right)^2 \cdot t_{f_1}$$

$$0.1U_{DD} - U_{TM}$$

$$U_{TM} - 0.1U_{DD} = -\frac{K_N}{C_L}\left(U_{DD} - U_{TM}\right)^2 t_{f_1}$$

$$t_{f_1} = \frac{\left(U_{TM} - 0.1U_{DD}\right)\cdot C_L}{K_N \cdot \left(U_{DD} - U_{TM}\right)^2}$$

PRIMER: $U_{TN} = 0.2\,U_{DD}$

$$t_{f_1} = \frac{\frac{1}{10}\cdot U_{DD}\cdot C_L}{K_N \cdot \frac{16}{25}\cdot U_{DD}^2} = \frac{5}{32}\cdot\frac{C_L}{K_N \cdot U_{DD}}$$

2. LIN. PODROČJE, t_{f2}

$$C_L \frac{du_{CC}}{dt} + K_N \cdot \left[2 \cdot (U_{GS_n} - U_{T_n}) U_{DS_m} - U_{DS_m}^2 \right] = 0$$

$$C_L \frac{du_{izh}}{dt} + K_N \cdot \left[2 \cdot (U_{DD} - U_{T_m}) u_{izh} - u_{izh}^2 \right] = 0$$

$$C_L \frac{du_{izh}}{K_N \cdot \left[2(U_{DD} - U_{T_m}) u_{izh} - u_{izh}^2 \right]} = -dt$$

$$\frac{C_L}{K_N \cdot 2 \cdot (U_{DD} - U_{T_m})} \int_{U_{DD} - U_{T_m}}^{0.1 U_{DD}} \frac{du_{izh}}{\frac{u_{izh}^2}{2(U_{DD} - U_{T_m})} - u_{izh}} = \int dt$$

$$\int \frac{du_{izh}}{\frac{u_{izh}^2}{2(U_{DD} - U_{T_m})} - u_{izh}} \Rightarrow \int \frac{dx}{Cx^2 - x} \Rightarrow \frac{1}{x(Cx-1)} = \frac{A}{x} + \frac{B}{Cx - 1}$$

$$C = \frac{1}{2(U_{DD} - U_{T_m})}$$

$$1 = A \cdot Cx - A + Bx$$

$$A = -1$$

$$0 = AC + B$$

$$\int \frac{du_{izh}}{C \cdot u_{izh}^2 - u_{izh}} = \int \frac{(-1)}{u_{izh}} \cdot du_{izh} + \int \frac{C}{C \cdot u_{izh} - 1} \cdot du_{izh} \quad 0 = -C + B \Rightarrow B = C$$

$$= -\int \frac{du_{izh}}{u_{izh}} + \int \frac{\frac{1}{2(U_{DD} - U_{T_m})}}{\frac{u_{izh}}{2(U_{DD} - U_{T_m})} - 1} \cdot du_{izh}$$

$$= \frac{C_L}{K_N \cdot 2(U_{DD} - U_{TN})} \cdot \left[(-1) \cdot \int_{U_{DD}-U_{TN}}^{0.1U_{DD}} \frac{d u_{izh}}{u_{izh}} + \int_{U_{DD}-U_{TN}}^{0.1U_{DD}} \frac{d u_{izh}}{u_{izh} - 2(U_{DD} - U_{TN})} \right]$$

$$= \frac{C_L}{2K_N \cdot (U_{DD} - U_{TN})} \left[\ln \frac{U_{DD} - U_{TN}}{0.1U_{DD}} + \ln \frac{0.1U_{DD} - 2(U_{DD} - U_{TN})}{U_{DD} - U_{TN} - 2(U_{DD} - U_{TN})} \right]$$

PRIMER $U_{TN} = 0.2U_{DD}$

$$= \frac{C_L}{2 \cdot K_N \cdot \frac{4}{5} \cdot U_{DD}} \cdot \left[\ln \frac{\frac{4}{5} \cdot U_{DD}}{\frac{1}{10} \cdot U_{DD}} + \ln \frac{\frac{1}{10} \cdot U_{DD} - 2 \cdot \frac{4}{5} \cdot U_{DD}}{-\frac{4}{5} \cdot U_{DD}} \right]$$

$$= \frac{C_L}{\frac{8}{5} \cdot K_N \cdot U_{DD}} \cdot \left[\ln 8 + \ln \frac{15}{8} \right]$$

$\ln x.y = \ln x + \ln y$

$$t_{f_2} = \frac{5}{8} \cdot \frac{C_L}{K_N \cdot U_{DD}} \cdot \underbrace{\ln 15}_{\uparrow 2.7}$$

$$t_{f_2} = 1.69 \frac{C_L}{K_N \cdot U_{DD}}$$

$$t_f = t_{f_1} + t_{f_2}$$

$$t_f = \left(\frac{5}{32} + 1.69 \right) \cdot \frac{C_L}{K_N \cdot U_{DD}}$$

$$\boxed{t_f = 1.85 \cdot \frac{C_L}{K_N \cdot U_{DD}}}$$