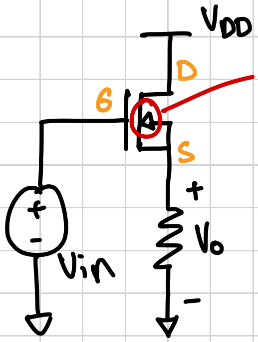
MOSFET PROBLEM



NMOS
- arrow points from p-type body to n-type bridge

Common drain structure - Drain (V_{DD}) is fixed

LARGE SIGNAL ANALYSIS

KVL: $V_{DD} - V_{DS} - V_R = 0$

KCL: $i_{mosfet} = i_R = i$

$V_R = i \times R$

$$i = \begin{cases} \mu_n C_{ox} \frac{W}{L} \left[(V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right] & \text{Linear} \\ \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2 & \text{Saturation} \end{cases}$$

1) Guess Saturation

$$i = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in} - V_o - V_T)^2$$

$$V_o = V_R = iR$$

$$V_o = \underbrace{R \times \frac{1}{2} \mu_n C_{ox} \frac{W}{L}}_{K} (V_{in} - V_o - V_T)^2$$

$$V_o = K (V_{in}^2 + V_o^2 + V_T^2 - 2V_{in}V_o + 2V_oV_T - 2V_{in}V_T)$$

$$\underbrace{-K}_{a} V_o^2 + \underbrace{(2KV_{in} - 2KV_T + 1)}_{b} V_o + \underbrace{K(V_{in}^2 + V_T^2 - 2V_{in}V_T)}_{c} = 0$$

$$V_o = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \qquad V_o = \begin{cases} \text{Option 1} \\ \text{Option 2} \end{cases}$$

Check if $V_{DS} > V_{GS} - V_T$

if $V_{DD} - V_o > V_{in} - V_o - V_T$

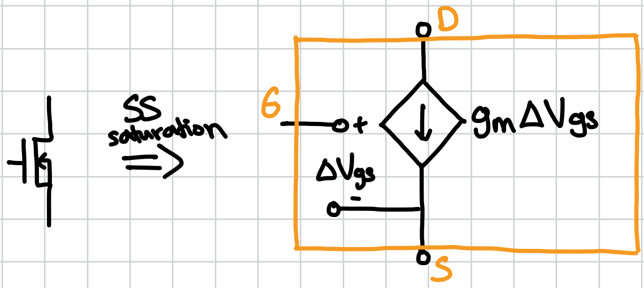
if one solution is true, then saturation

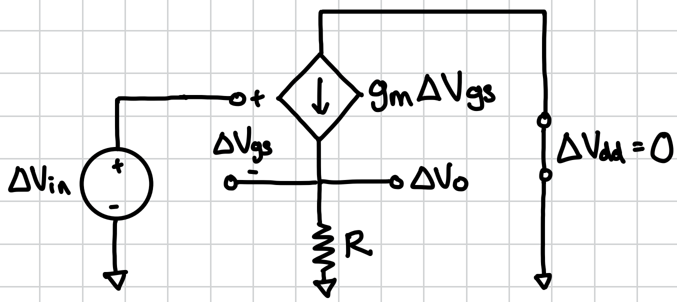
if no solution, then linear

$\Rightarrow$ We now know I, V_{DS}, V_{GS} (Operating Point)

SMALL SIGNAL ANALYSIS

- Perturb input ⇒ Calculate perturbed output(s)



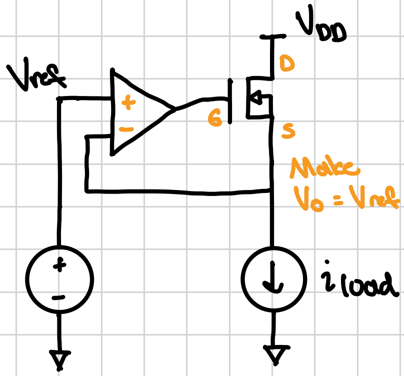


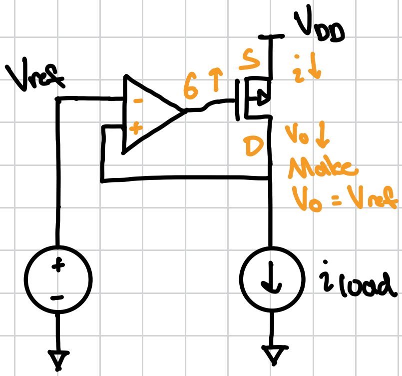
$$\Delta V_o = R\Delta i = R g_m \Delta V_{gs} = R g_m (\Delta V_{in} - \Delta V_o)$$

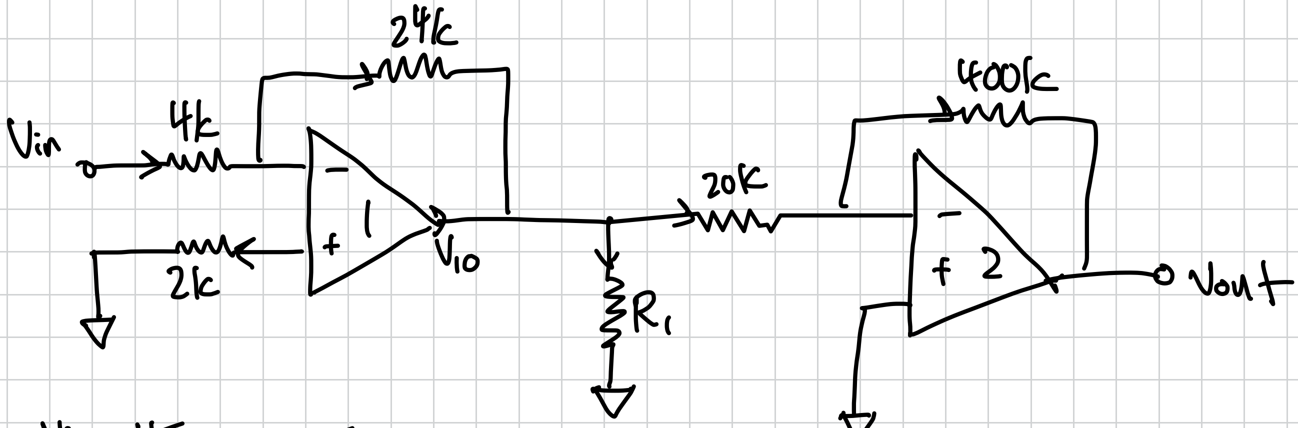
$$(1 + R g_m)\Delta V_o = R g_m \Delta V_{in}$$

$$\Delta V_o = \frac{R g_m}{1 + R g_m}\Delta V_{in} \approx 1\,\Delta V_{in}$$

LDO FEEDBACK







$$\frac{V_{in} - \cancel{V_{1-}}}{4k} = \frac{\cancel{V_{1-}} - V_{10}}{24k}$$

$$\frac{V_{1+} - 0}{2000} = 0$$

$V_{1+} = 0$

$$\frac{V_{in}}{4k} = \frac{-V_{10}}{24k}$$

$V_{10} = -6k\,V_{in}$

$$\frac{-6k\,V_{in}}{20k} = \frac{-V_{out}}{400k}$$

$-2400k\,V_{in} = -20k\,V_{out}$

$$\frac{-2400}{-20} = 120$$

$$\frac{V_s - 0}{R_{s_1}} = \frac{0 - V_{o1}}{R_{f_1}} + \frac{0 - V_o}{R_{f_3}}$$

$$\frac{V_{o_1} - 0}{R_{s_2}} = \frac{0 - V_o}{R_{f_2}}$$

$$V_{o1} = \frac{-R_{s_2}}{R_{f_2}} V_o$$

$$\frac{V_s}{R_{s_1}} = \frac{R_{s_2}}{R_{f_1} R_{f_2}} V_o - \frac{1}{R_{f_3}} V_o$$

$$V_s = V_o \left(\frac{R_{s_2} R_{s_1}}{R_{f_1} R_{f_2}} - \frac{R_{s_1}}{R_{f_3}} \right)$$

$$V_s = V_o \frac{R_{s_2} R_{s_1} R_{f_3} - R_{s_1} R_{f_1} R_{f_2}}{R_{f_1} R_{f_2} R_{f_3}}$$

$$V_o = \frac{R_{f_1} R_{f_2} R_{f_3}}{R_{s_1} R_{s_2} R_{f_3} - R_{s_1} R_{f_1} R_{f_2}} V_s$$

$$\frac{V_s - V_{1+}}{R_1} = 0$$

$$V_s = V_{1+} = V_{1-}$$

$$\frac{V_s}{R_2} + \frac{V_s - V_{10}}{R_3} + \frac{V_s - V_{10}}{R_5} = 0 \quad A$$

$$V_{10} = V_{2+} = V_{2-} = V_e$$

$$\frac{V_s - V_{10}}{R_5} = \frac{V_{10}}{R_6} + \frac{V_{10} - V_o}{R_7} = R_7 V_{10} + R_6 V_{10} - R_6 V_o$$

$$R_3 R_5 V_s + R_2 R_5 V_s - R_2 R_5 V_{10} + R_2 R_3 V_s - R_2 R_3 V_{10} = 0$$

$$V_s - V_{10} = R_5 R_7 V_{10} + R_5 R_6 V_{10} - R_5 R_6 V_o$$

$$V_s + R_5 R_6 V_o = (R_5 R_7 + R_5 R_6 + 1) V_{10}$$

$$R_3 R_5 V_s + R_2 R_5 V_s + R_2 R_3 V_s = (R_2 R_5 + R_2 R_3) \frac{V_s + R_5 R_6 V_o}{\downarrow \; R_5 R_7 + R_5 R_6 + 1}$$

$$V_s \left(R_3 R_5 + R_2 R_5 + R_2 R_3 - \frac{R_2 R_5 + R_2 R_3}{R_5 R_7 + R_5 R_6 + 1} \right) =$$

$$V_s = V_b$$

$$\frac{V_s}{2} + \frac{V_s - V_c}{3} + \frac{V_s - V_c}{5} = 0$$

$$V_c = V_d = V_e$$

$$\frac{V_s - V_c}{5} = \frac{V_c}{6} + \frac{V_c - V_o}{7}$$

$$\frac{31}{30} V_s = \frac{8}{15} V_c$$

$$V_c = \frac{31}{16} V_s$$

$$\frac{V_s}{5} - \frac{31}{16 \cdot 5} V_s = \frac{31}{16 \cdot 6} V_s + \frac{31 V_s}{16 \cdot 7} - \frac{V_o}{7}$$

$$V_s \frac{529}{672} = \frac{V_o}{7}$$

Saturation:

$$V_{DS} > V_{GS} - V_T$$

$$V_{DD} - I_D R_D > Vin - V_T$$

$$-\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(Vin - V_T)^2 R_D > Vin - V_T - V_{DD}$$

$$0 < R_D < \frac{(V_{DD} + V_T - Vin)}{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(Vin - V_T)^2}$$

Linear

$$\frac{(V_{DD} + V_T - Vin)}{\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(Vin - V_T)^2} < R_D < \infty$$

Guess Saturation:

$$V_{DS} > V_{GS} - V_T$$

$$V_{DD} - \cancel{V_o} > V_{in} - \cancel{V_o} - V_T$$

$V_{DD} > V_{in} - V_T$ if $V_{DD} > V_{in} > 0$,

always Saturation

$$\frac{V_{DD} - V_{GS}}{R_D} = \underbrace{\frac{1}{2}\mu_n C_{ox} \frac{W}{L}}_{k} (V_{GS} - V_T)^2$$

$V_{DS} = V_{GS}$

$V_{DS} > V_{GS} - V_T$ } Saturation

$$= k V_{GS}^2 - 2k V_{GS} V_T + k V_T^2$$

$$0 = \underbrace{k}_{a} V_{GS}^2 + \underbrace{\left(\frac{1}{R_D} - 2k V_T\right)}_{b} V_{GS} + \underbrace{k V_T^2 - \frac{V_{DD}}{R_D}}_{c}$$

$$i = \frac{dq}{dt} = \frac{dq}{dx} \times \frac{dx}{dt}$$

$$v = \frac{dx}{dt} = \mu_e E$$

$$\frac{dx}{dt} = \mu_e \frac{dV}{dx}$$

$$dq = \oint \epsilon E_H \cdot dA$$

$$dq = -\epsilon_{ox} E_H A$$

$$dq = -\epsilon_{ox} E_H W \, dx$$

$$\frac{dq}{dx} = -\epsilon_{ox} E_H W$$

$$\frac{dq}{dx} = -\epsilon_{ox} \frac{V_g - V(x)}{t_{ox}} W - \epsilon_{ox} \frac{V_T}{t_{ox}} W$$

$$= -C_{ox} W (V_g - V(x) - V_T)$$

$$i = -C_{ox} W (V_g - V(x) - V_T) \mu_e \frac{dV}{dx}$$

$$\int_0^L i \, dx = \int_{V_{DS}}^{0} - C_{ox} W (V_g - V(x) - V_T) \mu_e \, dV$$

$$-x =$$

$$-\frac{1}{2}x^2$$

$$iL \overset{0}{=} + \mu_e C_{ox} W \left[(V_g - V_T)(V_{DS}) - \frac{1}{2}(-V_{DS})^2 \right]$$

$$i = \mu_e C_{ox} \frac{W}{L} \left[(V_g - V_T) V_{DS} - \frac{1}{2} V_{DS}^2 \right]$$