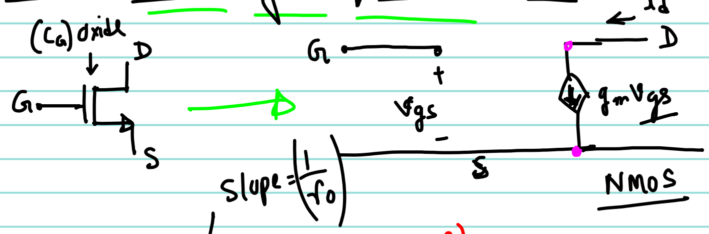
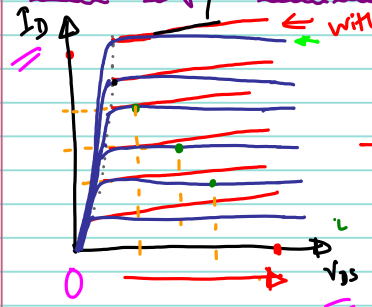
$\uparrow X = \frac{1}{\omega C}$ range of freq. for which gate is open circuit.

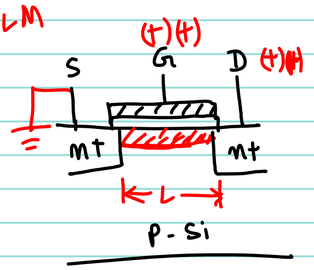
MOSFET Small signal equivalent circuit:

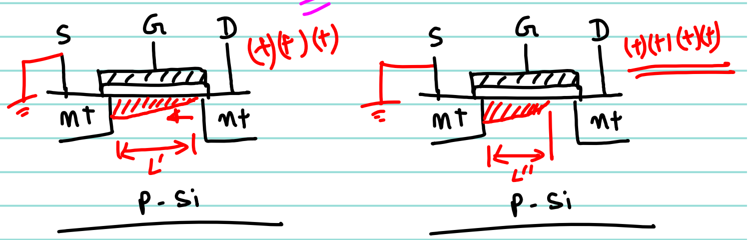


Slope $= \left(\frac{1}{r_o}\right)$

Channel length modulation: (CLM)





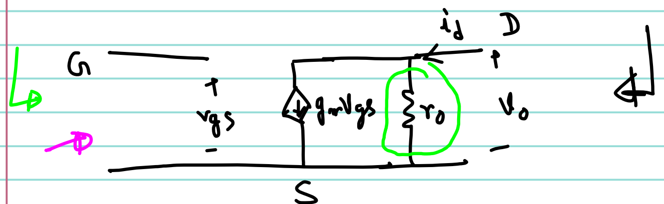


$\uparrow I_D \propto \left(\frac{W}{L}\right)\downarrow \downarrow (L)$ is decreasing.

$$i_D = k_n (V_{GS} - V_{Tn})^2 (1 + \lambda V_{DS})$$; λ = channel length modulation parameter.

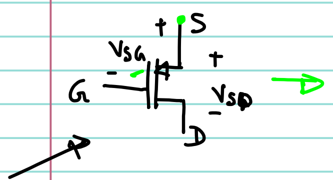
$$r_o = \left(\frac{\partial i_D}{\partial v_{DS}}\right)^{-1} = \left[k_n (V_{GS} - V_{Tn})^2 \lambda\right]^{-1}$$

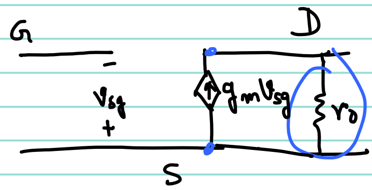
$$r_o = [I_{DQ} \lambda]^{-1} = \frac{1}{\lambda I_{DQ}}$$



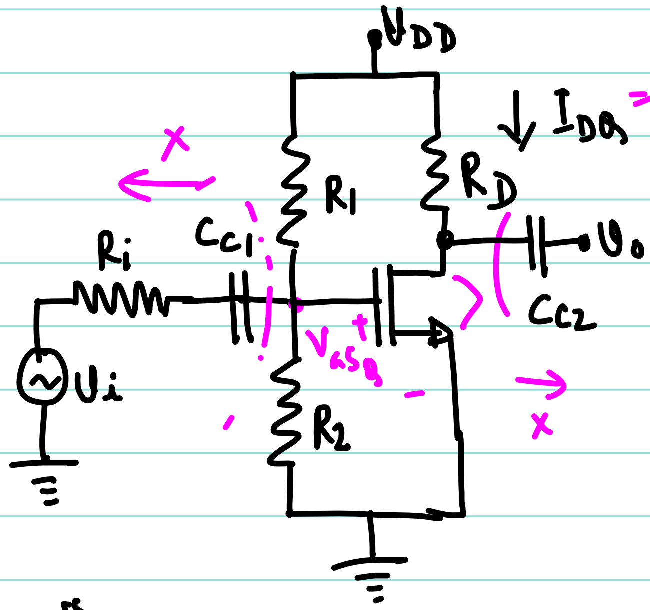
lec-24

For PMOS:





Basic Common-Source Amplifier (CS Amplifier)



$V_{DD} = 10V$
$R_1 = 70.9\ k\Omega$, $R_2 = 29.1\ k\Omega$
$R_D = 5\ k\Omega$
$V_{Tn} = 1.5\ V$
$k_n = 0.5\ mA/V^2$
$\lambda = 0.01\ V^{-1}$
$R_i = 4\ k\Omega$

Find the small-signal gain.

DC Analysis

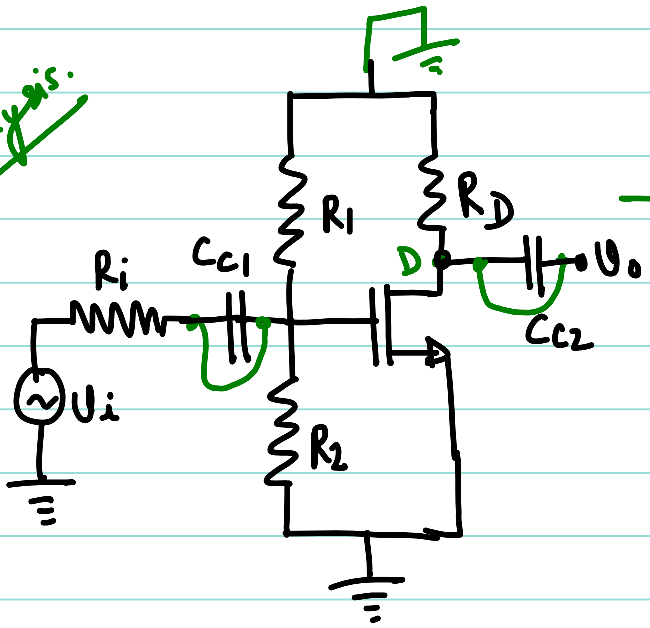
$$V_{GSQ} = V_{DD} \times \frac{R_2}{R_1+R_2} = 2.91\ V$$

Assume, MOSFET is in saturation, $I_{DQ} = k_n(V_{GSQ} - V_{Tn})^2$
$= 1\ mA$

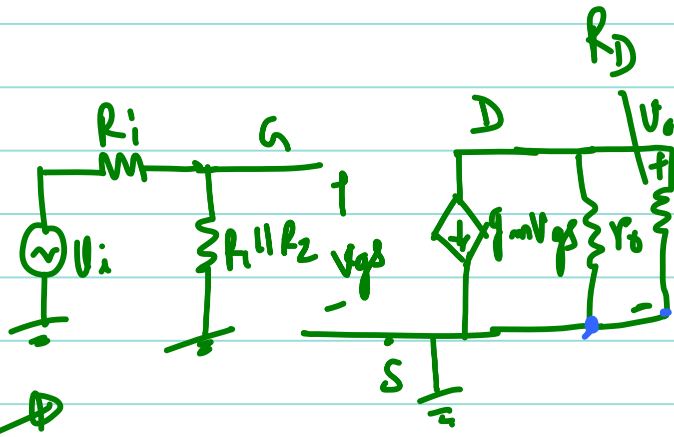
$V_{DSQ} = V_{DD} - I_D R_D = 5\ V$; $V_{DS-sat} = V_{GSQ} - V_{Tn}$
$= 2.91 - 1.5$
$= 1.41 V.$

$V_{DSQ} > V_{DS-sat}$, Saturation

AC Analysis.



$\Rightarrow$



$\Rightarrow$

$$V_{gs} = V_i \times \frac{R_1 \| R_2}{R_1 \| R_2 + R_i}$$

$$\text{Gain} = \frac{V_o}{V_i}$$

$$V_o = -(r_o \| R_D)\, g_m V_{gs}$$

$$V_o = -(r_o \| R_D) \times g_m \times V_i \times \frac{R_1 \| R_2}{R_1 \| R_2 + R_i}$$

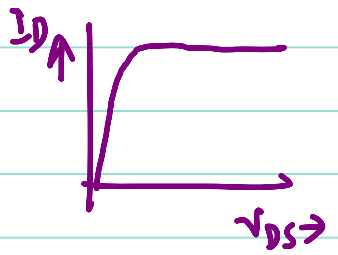
$$g_m = 2K_n(V_{GSQ} - V_{TN})$$
$$= 1.41\, mA/V$$

$$\text{Gain} = \frac{V_o}{V_i} = \underbrace{-g_m (R_D \| r_o) \times \frac{R_1 \| R_2}{R_i + R_1 \| R_2}}$$

$$r_o = \frac{1}{\lambda I_{DQ}}$$
$$= 100\,k\Omega$$

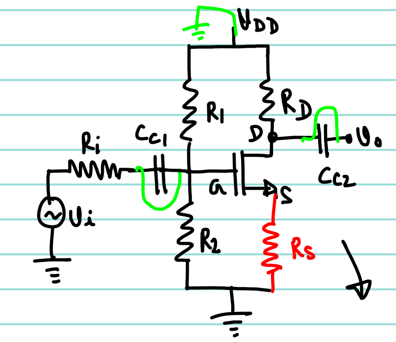
$$\text{Gain} = -5.62$$

if, r_o is infinite

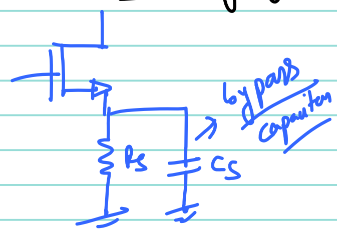


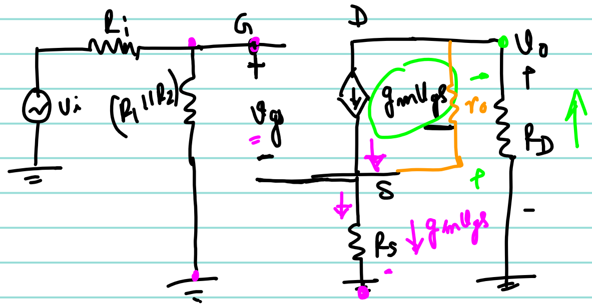
$$\Rightarrow \text{Gain} = \underbrace{-g_m R_D \cdot \frac{R_1 \| R_2}{R_1 \| R_2 + R_i}}$$

CS Amplifier with source resistor:



Assuming, r_o is very high.





$V_{gs} + g_m V_{gs} R_s$ = Voltage drop across $(R_1 \| R_2)$

$$V_{gs} + g_m V_{gs} R_s = V_i \times \left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_i}\right)$$

$$V_{gs}(1 + g_m R_s) = V_i \times \left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_i}\right)$$

$$V_{gs} = \frac{V_i}{1 + g_m R_s} \cdot \frac{R_1 \| R_2}{R_1 \| R_2 + R_i}$$

$$V_o = -g_m V_{gs} \times R_D$$

$$V_o = -g_m \cdot \frac{V_i}{1 + g_m R_s} \cdot \frac{R_1 \| R_2}{R_1 \| R_2 + R_i} \times R_D$$

$$\text{Gain} = \frac{V_o}{V_i} = -\frac{(g_m R_D)}{1 + g_m R_s} \cdot \left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_i}\right) \rightarrow (1)$$; with R_s

$$\text{Gain} = -(g_m R_D) \cdot \left(\frac{R_1 \| R_2}{R_1 \| R_2 + R_i}\right)$$ without R_s.

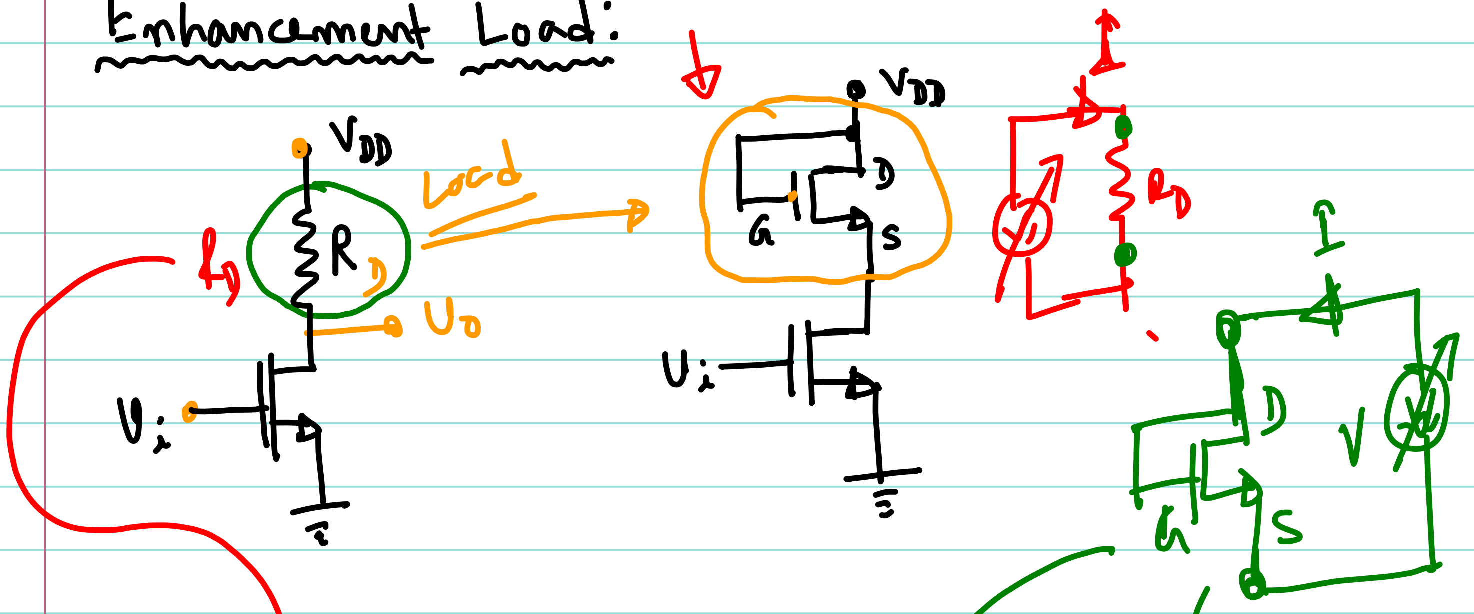
Gain reduces by $\frac{1}{1 + g_m R_s}$ factor.

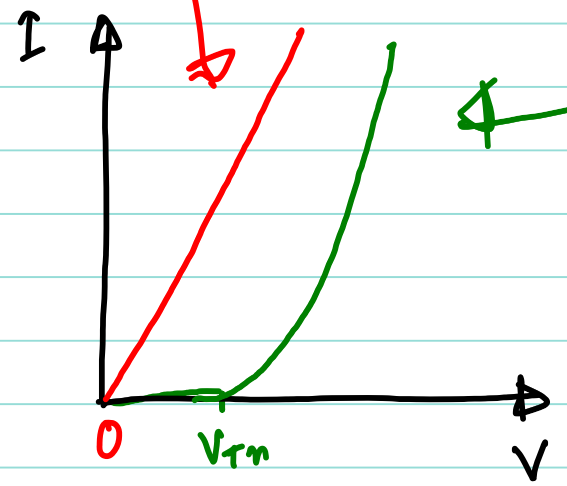
if, $(R_1 \| R_2) \gg R_i$; and, $g_m R_s \gg 1$

with R_s

$$\text{Gain} = \frac{V_o}{V_i} \simeq -\frac{\cancel{g_m} R_D}{\cancel{g_m} R_s} \simeq \left(-\frac{R_D}{R_s}\right)$$

Enhancement Load:





Saturation

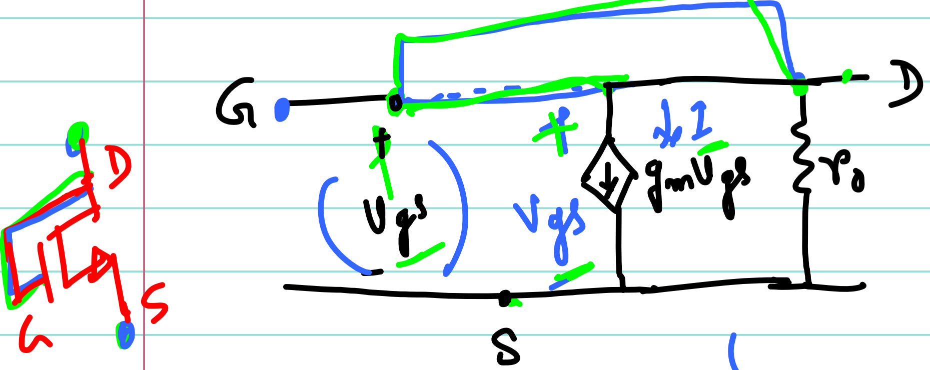
$V_{GS} = V_{DS} > V_{DS-sat}$

$= V_{GS} - V_{Tn}$

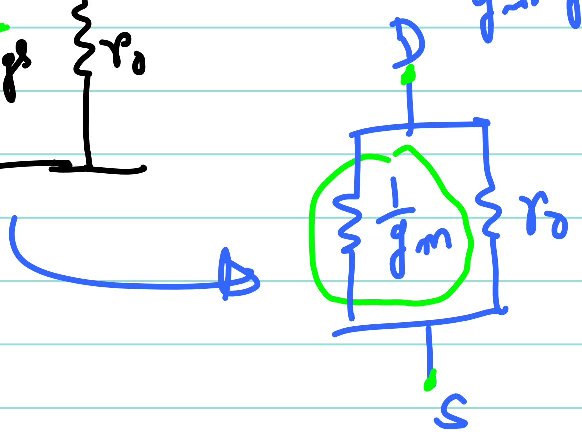
$I = k_n (V_{GS} - V_{Tn})^2$

$\Rightarrow I = k_n (V_{DS} - V_{Tn})^2$

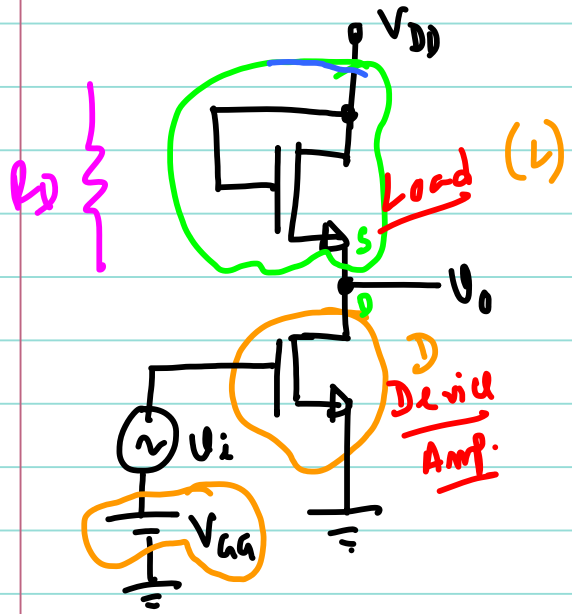
Small signal model:

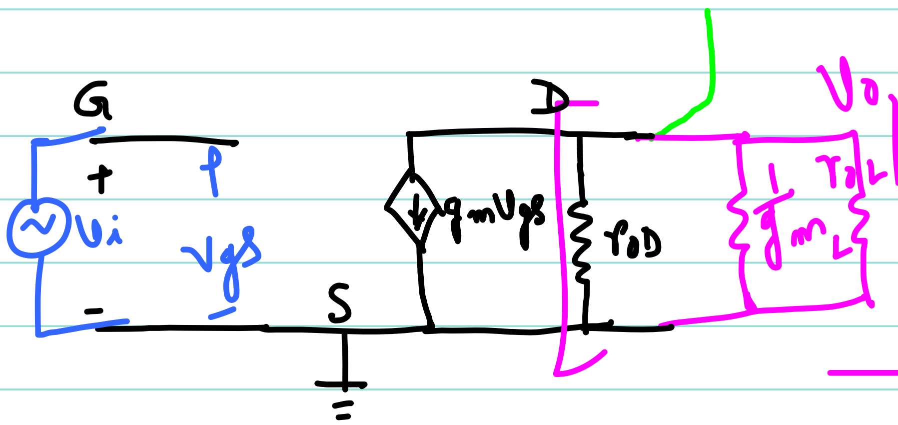


$$r = \frac{v_{gs}}{g_m v_{gs}} = \frac{1}{g_m}$$



NMOS Amplifier with Enhancement Load:





$$V_{gs} = V_i$$

$$V_o = -g_m V_{gs}\left(r_{oD} \parallel \frac{1}{g_{mL}} \parallel r_{oL}\right)$$

$$V_o = -g_m V_i\left(r_{oD} \parallel \frac{1}{g_{mL}} \parallel r_{oL}\right)$$

$$\text{Gain} = \frac{V_o}{V_i} = -g_m\left(r_{oD} \parallel \frac{1}{g_{mL}} \parallel r_{oL}\right)$$