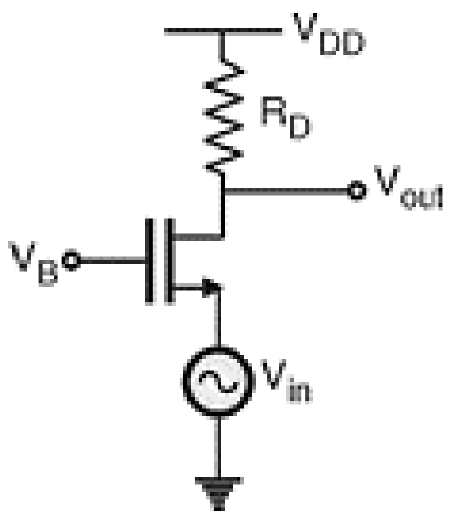
Electronic Devices

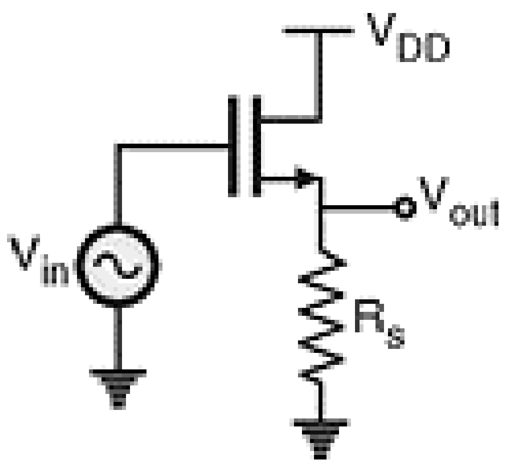
Lecture 19
Field Effect Transistor
“MOSFFT”

Dr. Roaa Mubarak

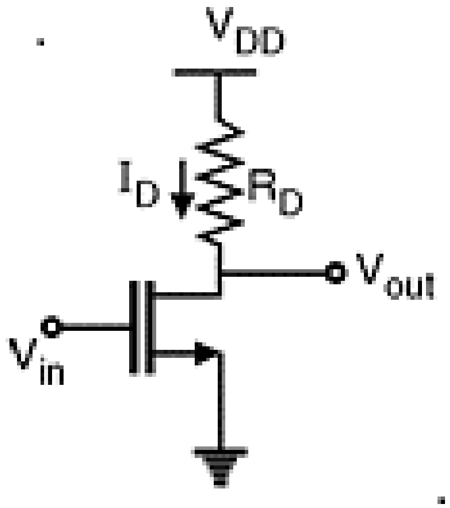
MOSFET as an amplifier



Common gate amplifier

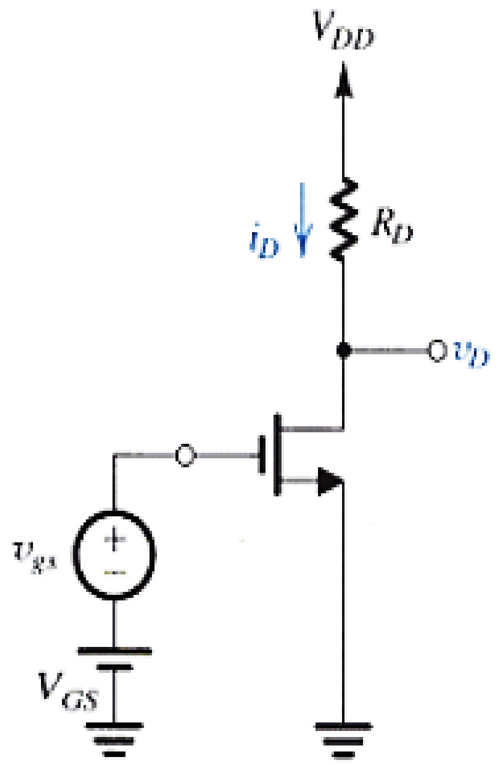


Common drain amplifier



Common source amplifier

Common Source Amplifier



$$v_{GS} = V_{GS} + v_{gs}$$

$$i_D = \frac{1}{2}k_n' \frac{W}{L}(V_{GS} + v_{gs} - V_t)^2$$

$$= \frac{1}{2}k_n' \frac{W}{L}(V_{GS} - V_t)^2 + k_n' \frac{W}{L}(V_{GS} - V_t)v_{gs} + \frac{1}{2}k_n' \frac{W}{L}v_{gs}^2$$

For small input signal that $\frac{1}{2}k_n' \frac{W}{L}v_{gs}^2 \ll k_n' \frac{W}{L}(V_{GS} - V_t)v_{gs}$

which results in $\boxed{v_{gs} \ll 2(V_{GS} - V_t)}$ $V_{gs} < 0.2(V_{GS} - V_t)$ is commonly required.

we obtain, $i_D = \underbrace{\frac{1}{2}k_n' \frac{W}{L}(V_{GS} - V_t)^2}_{I_D} + \underbrace{k_n' \frac{W}{L}(V_{GS} - V_t)v_{gs}}_{i_d}$

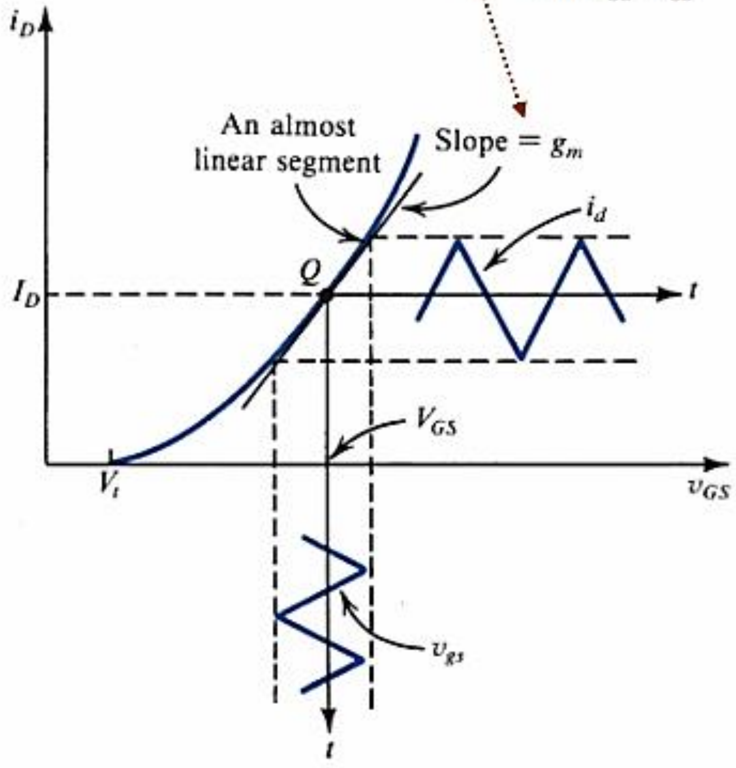
Transconductance g_m

$$i_D = \underbrace{\frac{1}{2}k_n'\frac{W}{L}(V_{GS}-V_t)^2}_{I_D} + \underbrace{k_n'\frac{W}{L}(V_{GS}-V_t)v_{gs}}_{i_d}$$

$$\Rightarrow \quad g_m = \frac{i_d}{v_{gs}} = k_n'\frac{W}{L}(V_{GS}-V_t)$$

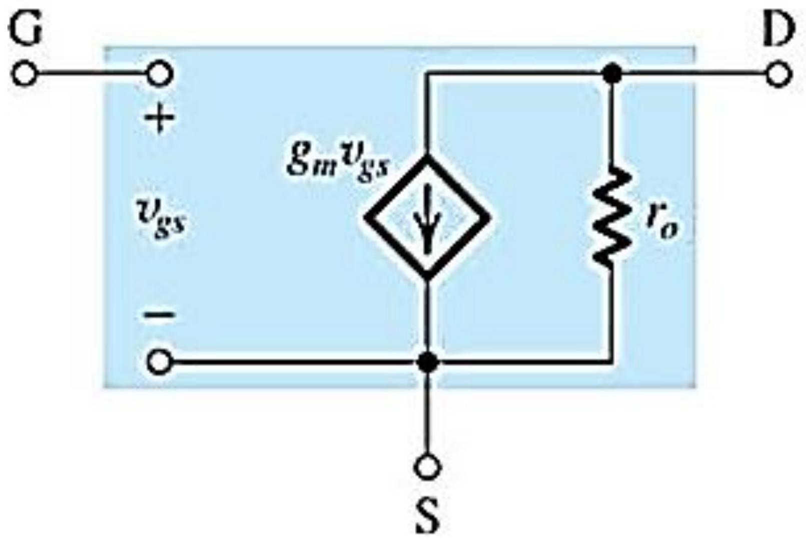
Graphic interpretation:

$$g_m \equiv \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}}$$

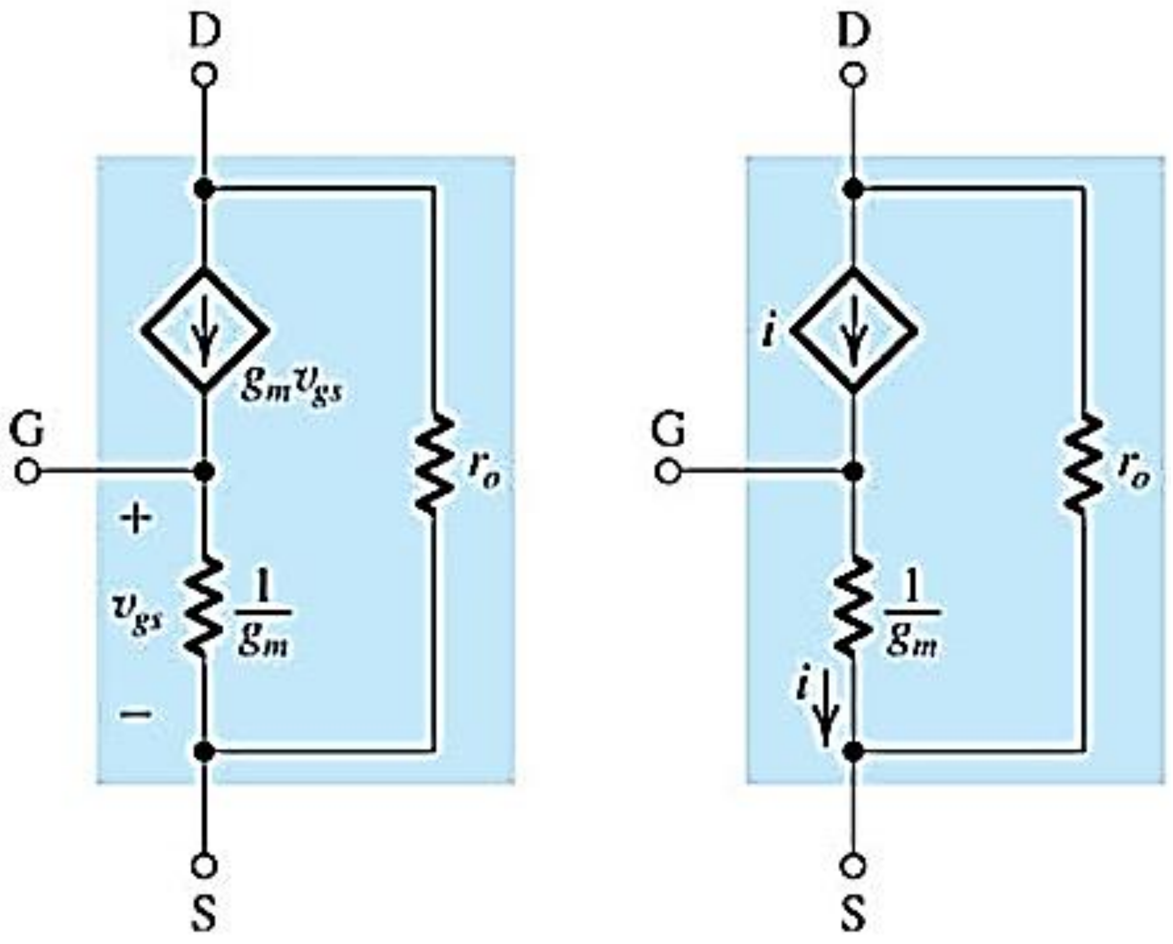


MOSFET small signal model (Hybrid Model)

π Model



T- Model



NMOS Hybrid π Model

- Small signal parameters:

Transconductance “ g_m “

MOSFET works in saturation mode to act as an amplifier:

$$g_m = \left[\frac{\partial i_D}{\partial v_{GS}}\right] Q\ point$$

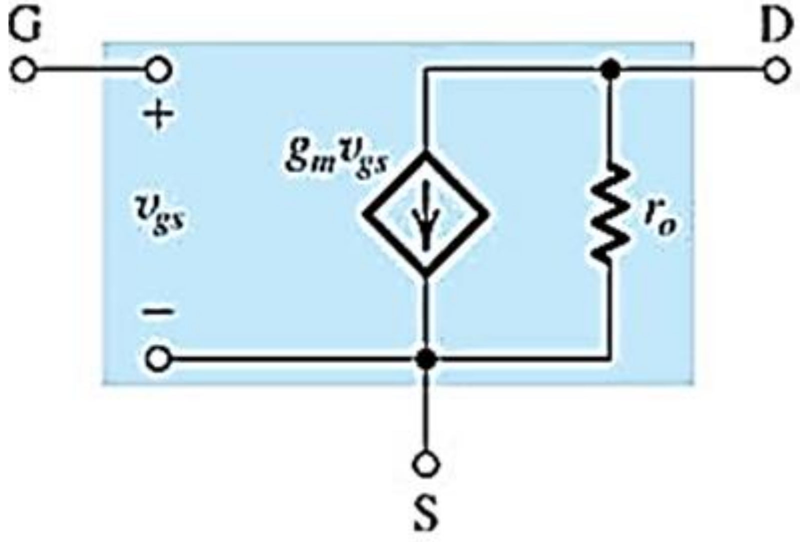
$$i_D = \frac{1}{2} K_n (V_{GS} - V_{th})^2$$

$$g_m = K_n\,(V_{GS} - V_{th}) = \frac{2I_D}{(V_{GS}-V_{th})}$$

$$K_n = \mu_n\, C_{ox} \left(\frac{W}{L}\right)$$

$$r_o = \frac{V_A}{I_D}$$

(replacing μ_n by μ_p for PMOS)

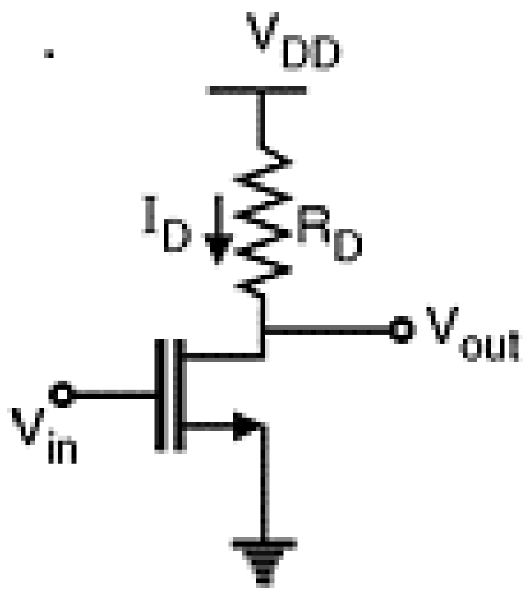


$$g_m \equiv \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}} = \frac{i_d}{v_{gs}} = k_n' \frac{W}{L}(V_{GS} - V_t)$$

$$r_0 \equiv \left[\frac{\partial i_D}{\partial v_{DS}}\right]^{-1}_{v_{GS}=V_{GS}} = \frac{1+\lambda V_{DS}}{\lambda I_D} \cong \frac{1}{\lambda I_D}$$

r_o is output resistance due to channel length modulation effect.

Common source Amplifier



$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})^2$$

$$i.e.\ \ I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in}-V_{TH})^2$$

But by KVL,

$$V_{DD} - I_D R_D = V_{out}$$

$$\therefore\ V_{out} = V_{DD} - \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in}-V_{TH})^2 R_D$$

Differentiating this equation with respect to V_{in}

$$\frac{dV_{out}}{dV_{in}} = -\mu_n C_{ox}\frac{W}{L}(V_{in}-V_{TH})R_D$$

Hence, The voltage gain $A_v = -g_m R_D \qquad \left[\because\ g_m = \mu_n C_{ox}\frac{W}{L}(V_{in}-V_{TH})\right]$

Common source Amplifier

By applying KVL

We get

$V_{in} - V_{GS} = 0$

i.e. $V_{in} = V_{GS}$

By applying KCL at node A

We get,

$$g_m V_{GS} + \frac{V_{out} - 0}{r_o} + \frac{V_{out} - 0}{R_D} = 0$$

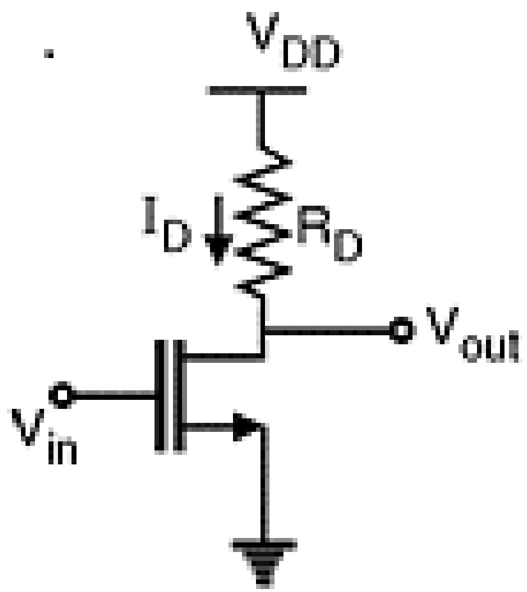
$$\therefore\ g_m V_{in} = -\left[\frac{V_{out}}{r_o} + \frac{V_{out}}{R_D}\right]$$

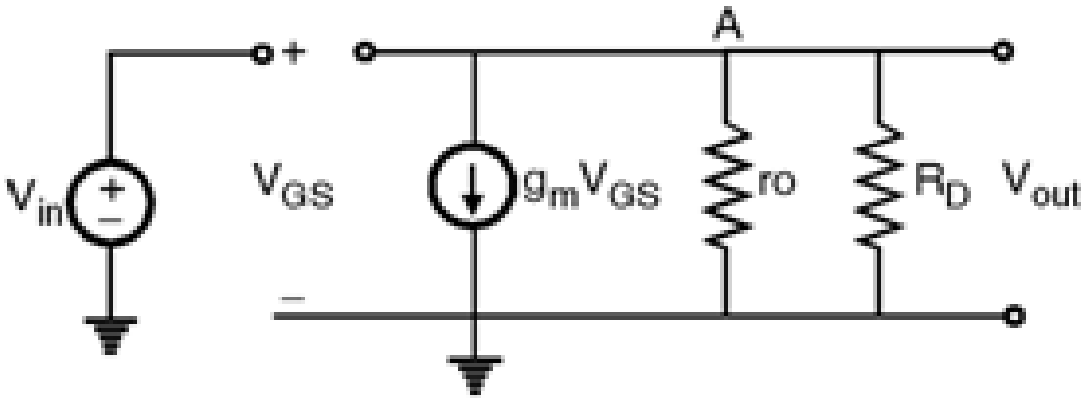
$$\therefore\ g_m V_{in} = -V_{out}\left(\frac{1}{r_o} + \frac{1}{R_D}\right)$$

$$\therefore\ \frac{V_{out}}{V_{in}} = A_v = \frac{-g_m}{\left(\frac{1}{r_o} + \frac{1}{R_D}\right)}$$

$$\therefore\ A_v = -g_m(r_o \| R_D)$$

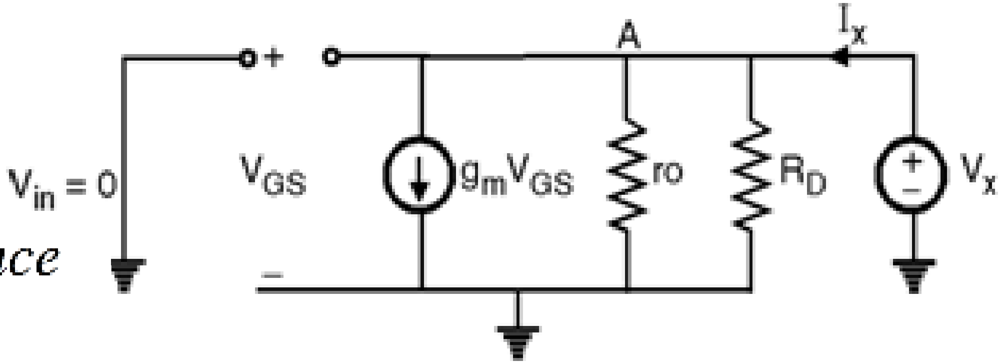
$\therefore$ *The voltage gain of CS amplifier is* $-g_m(r_o \| R_D)$





Common source Amplifier

Determine the output resistance and input resistance



[$V_{GS} = V_{in} = 0$]

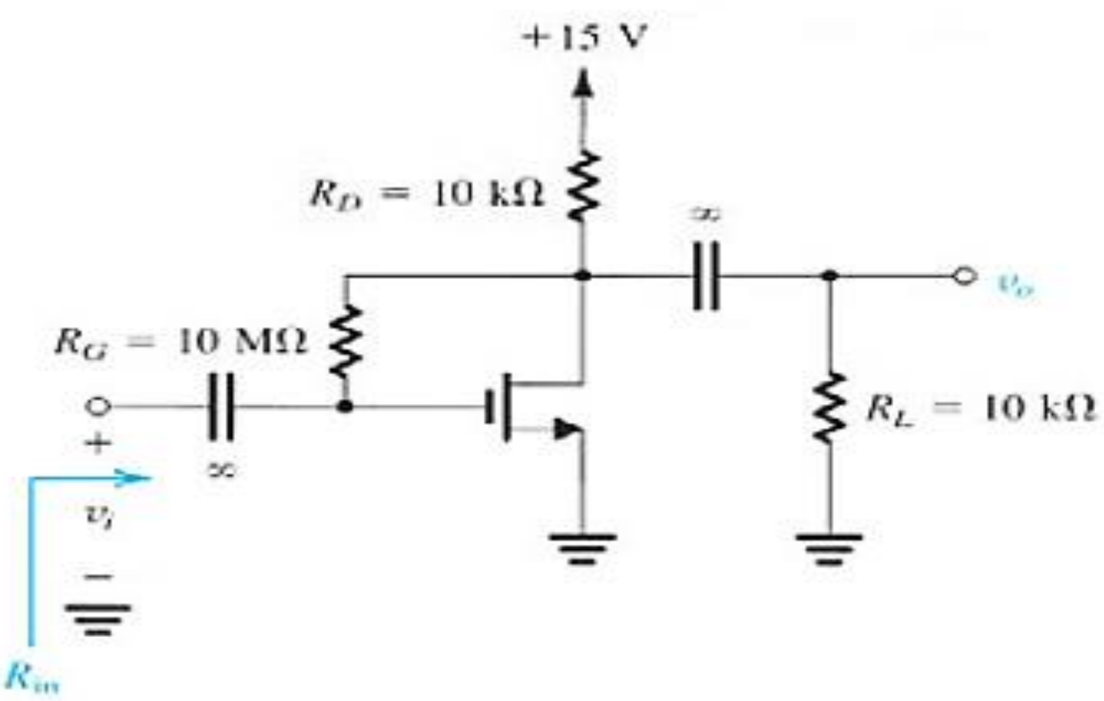
Also, because of zero gate current the input impedance of CS amplifier is also infinite.

$\therefore\ R_{in} = \infty$

$R_{out} = (ro \,||\, R_D)$

Example

A discrete common source MOSFET amplifier utilizing the drain to gate feedback biasing arrangement. The input signal is coupled to the gate via a large capacitor, and the output signal at the drain is coupled to the load resistance via another large capacitor. Analyze the amplifier to determine its small signal voltage gain. The transistor has V_{th}= 1.5 V, K_n = 0.25 mA/V^2 and V_A = 50 V.



Solution

First find I_D and V_D and then find g_m, r_o and A_v from the following equations.

$$I_D = \frac{1}{2} K_n' \left(\frac{W}{L}\right)(V_{GS} - V_t)^2 \qquad \text{(No gate current so } V_{GS} = V_D\text{)}$$

$$I_D = \frac{1}{2} * 0.25 * (V_D - 1.5)^2$$

$$V_D = V_{DD} - R_D I_D$$

$$g_m = K_n' \left(\frac{W}{L}\right)(V_{GS} - V_t)$$

$$r_o = \frac{|V_A|}{I_D}$$

$$A_v = \frac{v_o}{v_i} = -g_m (R_D \parallel R_L \parallel r_o)$$