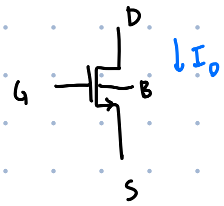
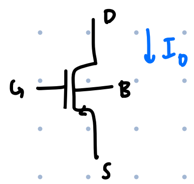
I. MOSFET Overview (Large - Signal)

N - Channel MOSFET (NMOS)



P - Channel MOSFET (PMOS)



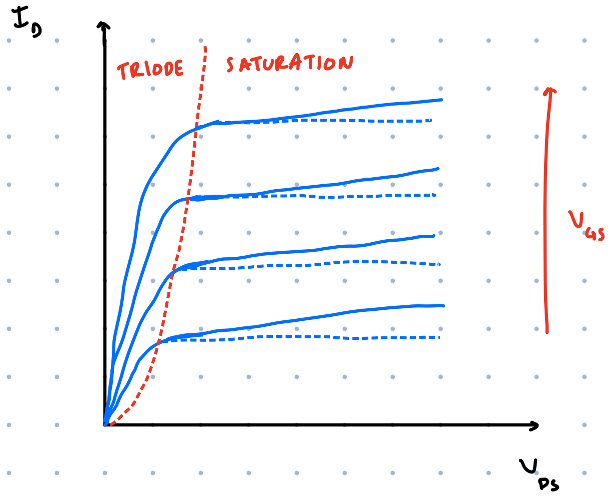
D: Drain

G: Gate

S: Source

B: Bulk

Operating Region	NMOS	PMOS
Cutoff	$V_{GS} < V_{TH}$	$V_{SG} < \lvert V_{TH} \rvert$
Triode	$V_{GS} > V_{TH}$ $V_{DS} < V_{GS} - V_{TH}$	$V_{SG} > \lvert V_{TH} \rvert$ $V_{SD} < V_{SG} - \lvert V_{TH} \rvert$
Saturation	$V_{GS} > V_{TH}$ $V_{DS} > V_{GS} - V_{TH}$	$V_{SG} > \lvert V_{TH} \rvert$ $V_{SD} > V_{SG} - \lvert V_{TH} \rvert$



Cutoff: device is OFF

- $I_D = 0$

Triode: device is ON, linear region (resistor)

- $I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_{TH}) V_{DS} - \frac{V_{DS}^2}{2}\right](1 + \lambda V_{DS})^*$

Saturation: device is ON, amplification region (voltage-controlled current source)

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

* These equations are for N-channel devices, which we will use for the rest of the recitation. P-channel devices behave analogously (but inversely).

Parameter Description:

$\left.\begin{array}{l} \mu_n \text{ - electron mobility} \\ C_{ox} \text{ - oxide capacitance / unit area} \\ W \text{ - width of inversion channel} \\ L \text{ - length of inversion channel} \end{array}\right\} k_n$

λ - channel length modulation

- effective channel length decreases as V_{DS} increases

II: Small-Signal Model

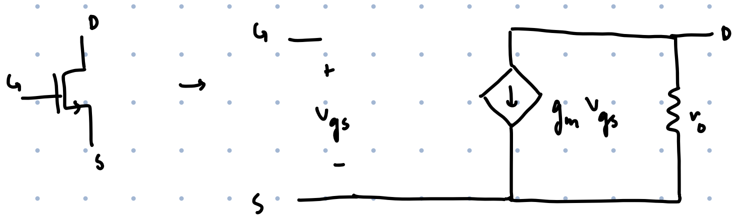
As we can see, the MOSFET is a non-linear device. This makes circuit analysis hard.

We can linearize our MOSFET by biasing it at a DC operating point to ensure saturation, and look at how small changes in input-voltage (AC) affect the output.

From Rec 3: $V_{in} = V_{IN} + v_{in}$

$$\left.\begin{aligned} V_{in} &= V_{IN} + v_{in} \\ \underbrace{V_{out}}_{\text{total}} &= \underbrace{V_{OUT}}_{\text{DC}} + \underbrace{v_{out}}_{\text{AC}} \end{aligned}\right\} \quad v_{out} = \underbrace{A_v}_{\text{gain}} v_{in}$$

Simplified Small-Signal Model:



$$g_m = \frac{\partial I_D}{\partial V_{GS}} \qquad r_o = \frac{\partial V_{DS}}{\partial I_D}$$

For an NMOS in saturation:

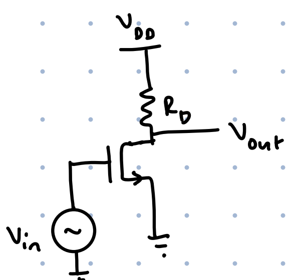
$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH}) = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D} = \frac{2 I_D}{V_{GS} - V_{TH}}$$

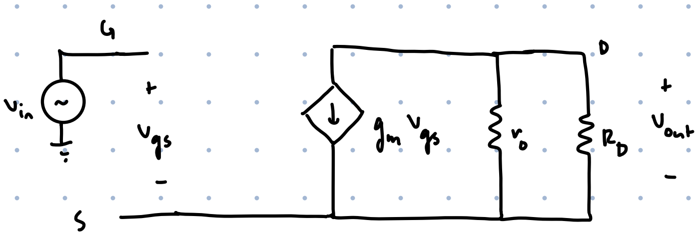
$$r_o = \frac{\partial V_{DS}}{\partial I_D} = \frac{1}{\lambda I_D}$$

Using our small-signal model, we can apply KCL/KVL to compute gain.

III. MOSFET Amplifiers

Common-Source





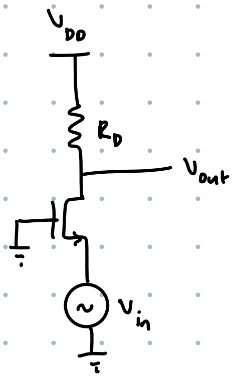
· high input resistance

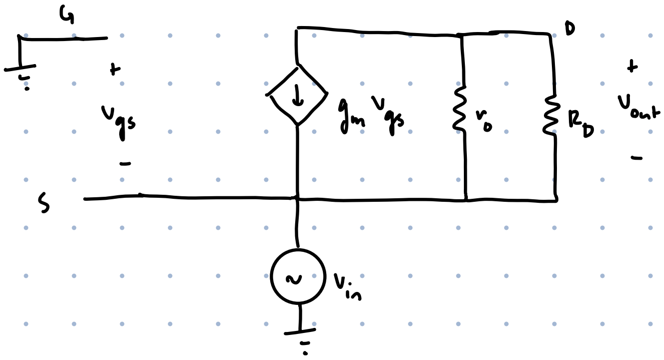
$v_{in} = v_{gs}$

$v_{out} = -g_m v_{gs} (r_o // R_D)$

$$a_v = \frac{v_{out}}{v_{in}} = -g_m (r_o // R_D)$$

Common - Gate





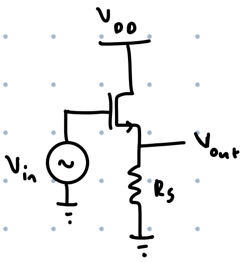
$v_{in} = -v_{gs}$

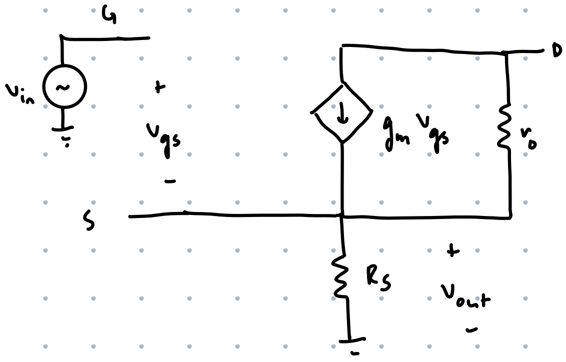
$v_{out} = -g_m v_{gs} (r_o // R_D)$

$a_v = \frac{v_{out}}{v_{in}} = g_m (r_o // R_D)$

- low input resistance

Common - Drain





$v_{in} = v_{gs} + v_{out} \rightarrow v_{gs} = v_{in} - v_{out}$

$v_{out} = g_m v_{gs} R_S$
$= g_m (v_{in} - v_{out}) R_S$

$v_{out} = g_m v_{in} R_S - g_m v_{out} R_S$

$v_{out} (1 + g_m R_S) = g_m v_{in} R_S$

$a_v = \frac{v_{out}}{v_{in}} = \frac{g_m R_S}{1 + g_m R_S}$

- high input resistance
- low output resistance