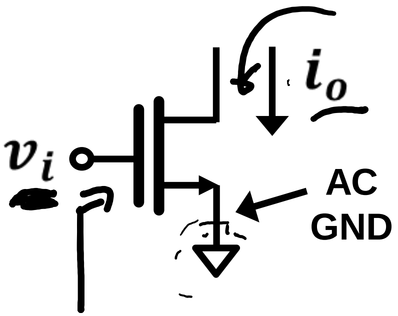
Lecture #3, Jan 10th, 2022

- Review Chapter 1 and 2 of Razavi book as needed. Course will start with Chapter 3. Read and Review Chapter 3.1 – 3.5
- Homework #1 & CAD 1 coming.
- Discuss Single-Transistor Amplifier Configurations
  - Common-Source Amplifier
  - Common-Source w/ Active Load
  - Common-Source w/ Degeneration
  - Common-Gate Amplifier
  - Common-Drain Amplifier

Three Basic Amplifier Configurations

Assume devices are properly biased in saturation Region

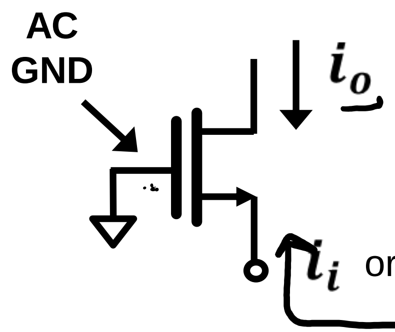
Common Source



Ri

- WANT Ri LARGE
- WANT Ro LARGE

Common Gate



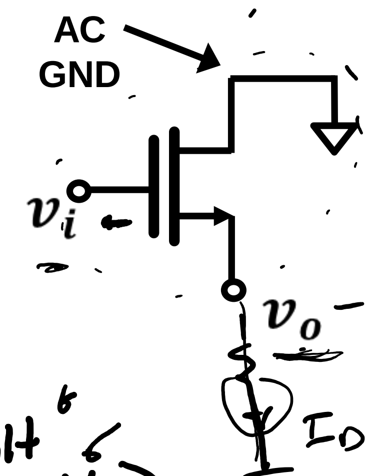
$R_i \approx \frac{1}{g_m}$

- IF i_i WANT R_i LOW
- IF v_i WANT R_i HIGH

$$R_i \approx 1/g_m \approx \frac{(V_{GS}-V_{tn})}{2I_D}$$

$$R_i = 50\Omega = \frac{(V_{GS}-V_{tn})}{2I_D}$$

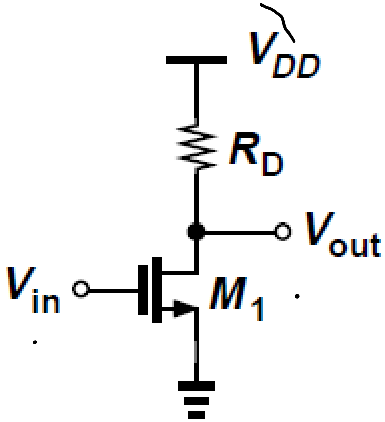
Common Drain or "Source Follower"



$$a_v = \frac{v_o}{v_i} = ?$$

1

Common-Source amplifier w/ Resistive load
A Large-Signal Perspective



- Very high input impedance at low frequencies
- For $V_{in} < V_{TH}$, M_1 is off and $V_{out} = V_{DD}$

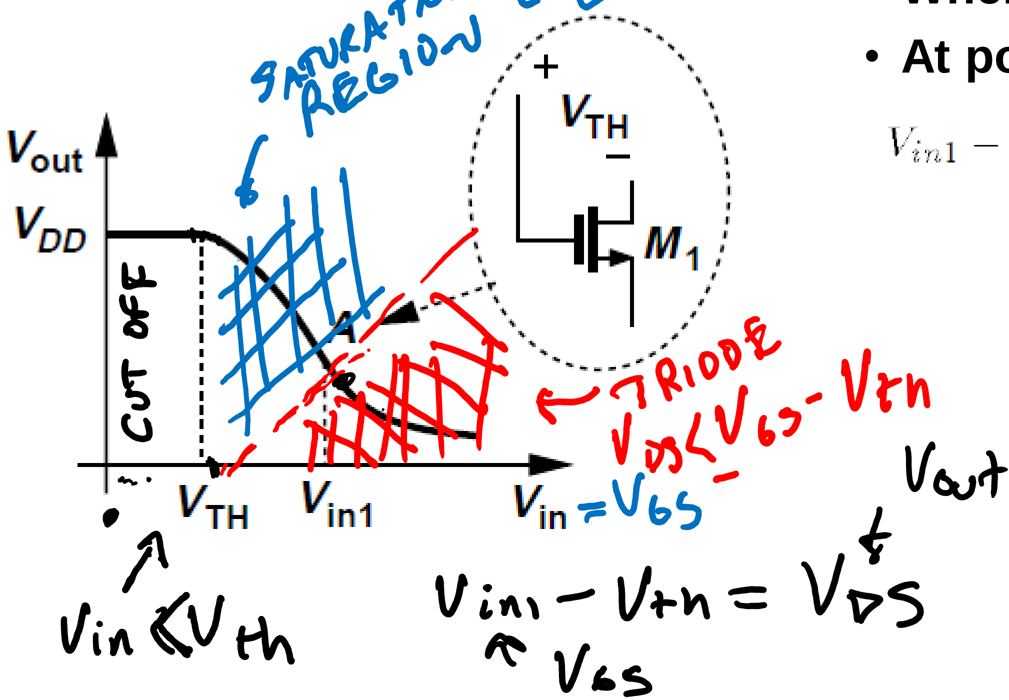
$$V_{out} = V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in} - V_{TH})^2$$

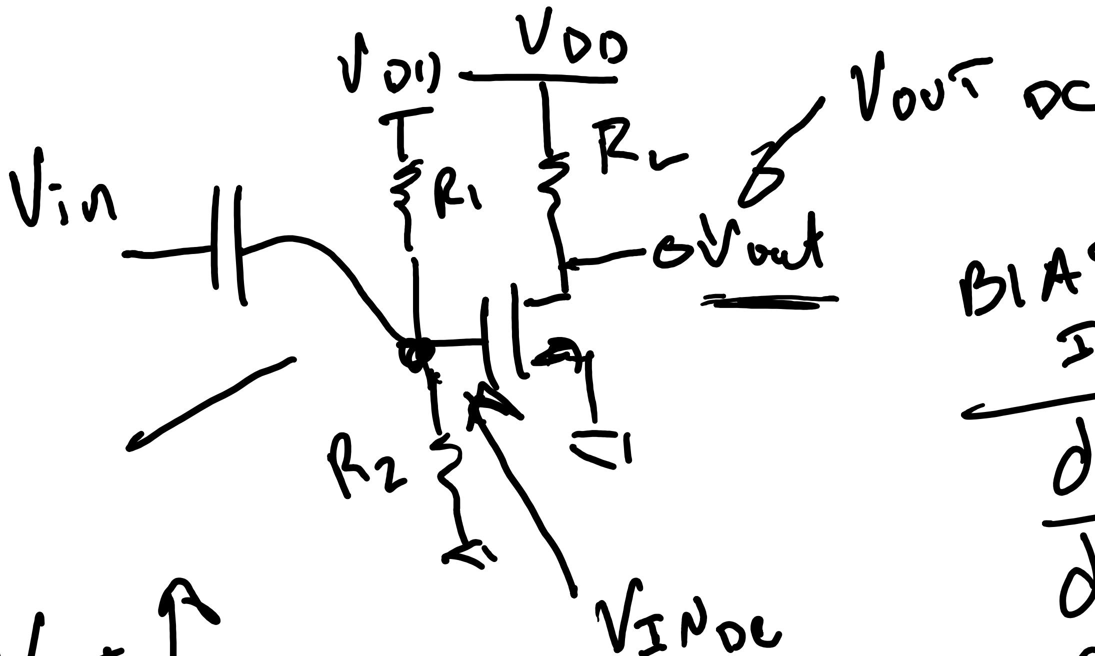
$V_{TH} < V_{in}$ ✓

$(V_{GS} - V_{TH}) \leq V_{DS}$

- When $V_{in} > V_{TH}$, M_1 turns on in saturation region, V_{out} falls
- When $V_{in} > V_{in1}$, M_1 enters triode region
- At point A, $V_{out} = V_{in1} - V_{TH}$

$$V_{in1} - V_{TH} = V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in1} - V_{TH})^2$$

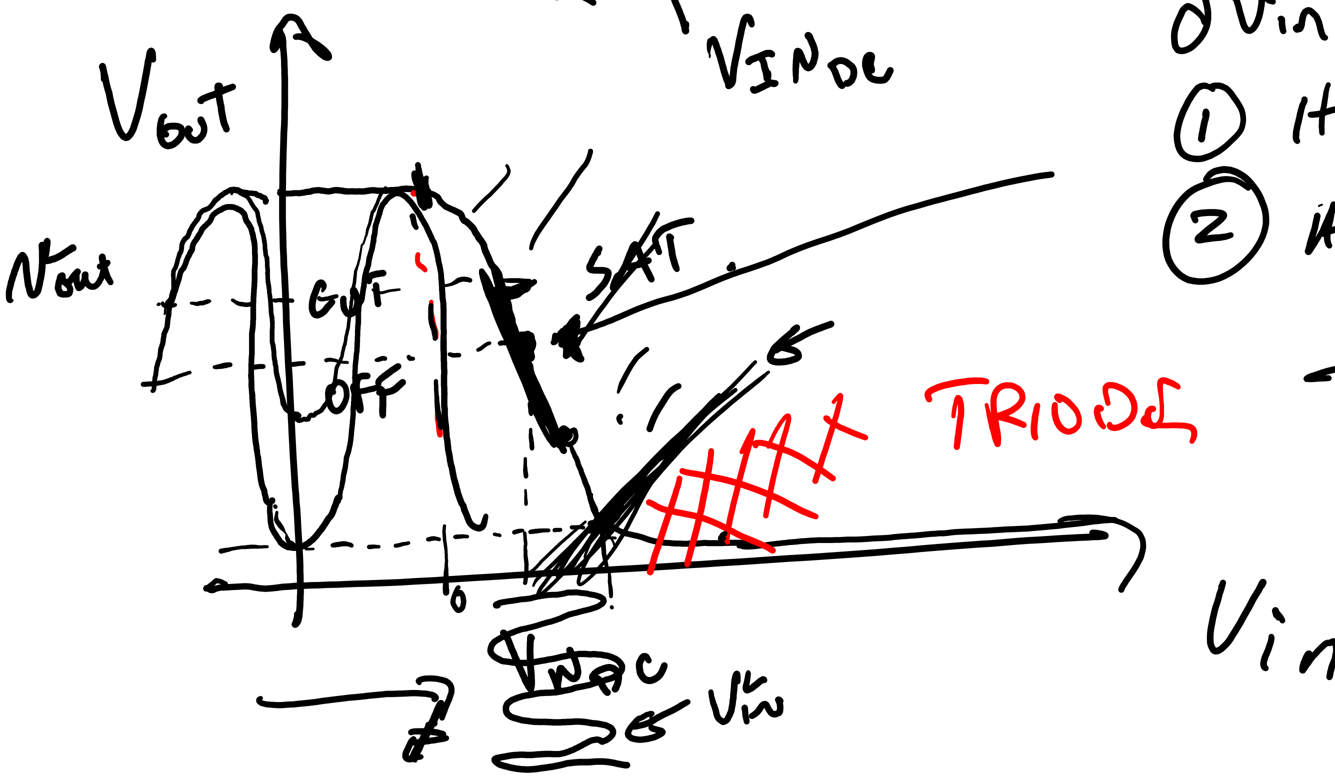




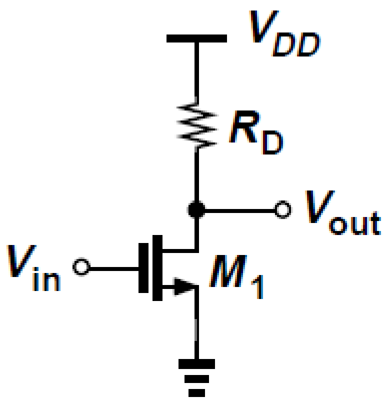
BIAS POINT INFLUENCES

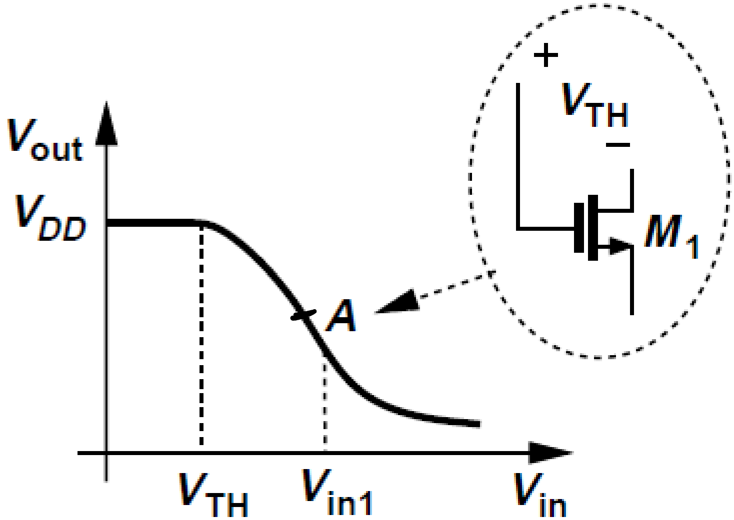
$$\frac{dV_{out}}{dV_{in}} = \underline{a_v}$$

1. HIGH GAIN
2. HIGH OUTPUT SWING.



Common-Source amplifier w/ Resistive load
A Large-Signal Perspective





- **Very high input impedance at low frequencies**
- **For $V_{in} < V_{TH}$, M_1 is off and $V_{out} = V_{DD}$**

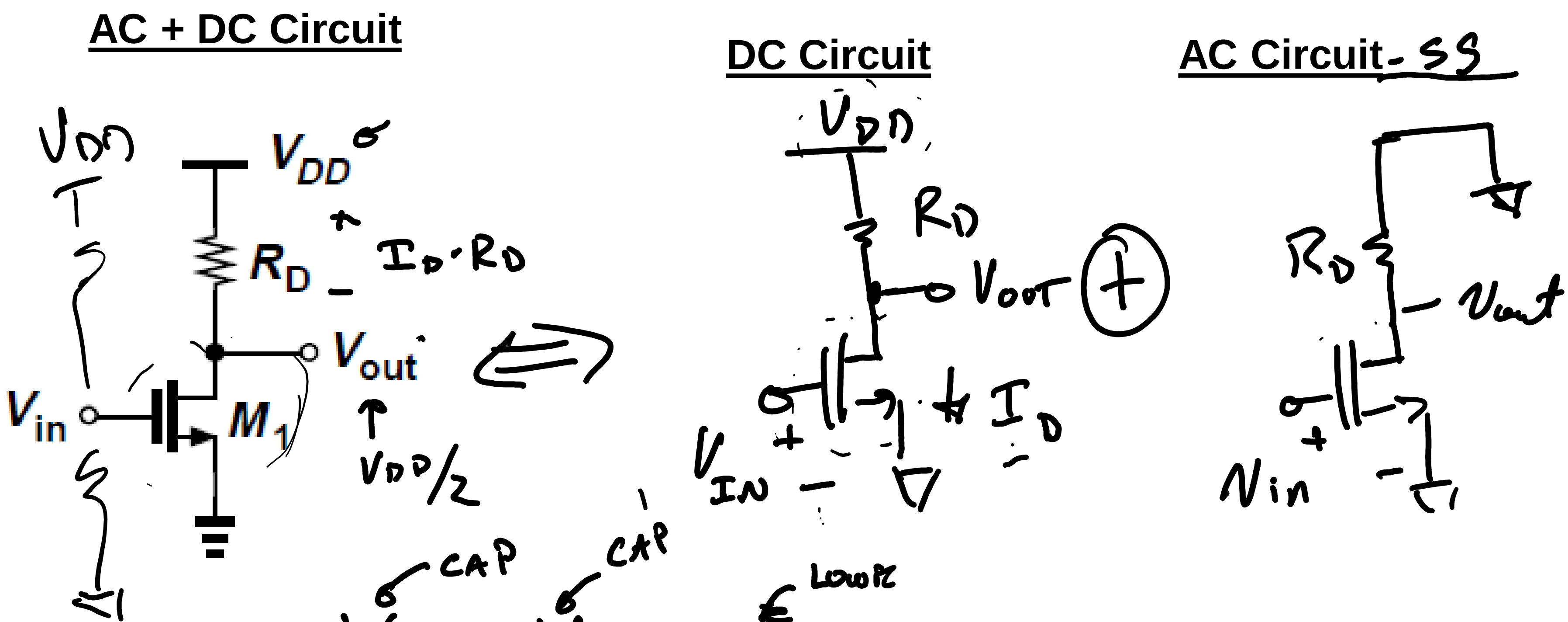
$$V_{out} = V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in} - V_{TH})^2$$

- **When $V_{in} > V_{TH}$, M_1 turns on in saturation region, V_{out} falls**
- **When $V_{in} > V_{in1}$, M_1 enters triode region**
- **At point A, $V_{out} = V_{in1} - V_{TH}$**

$$V_{in1} - V_{TH} = V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in1} - V_{TH})^2$$

- **Note: The VTC defines the output voltage range or the "Output Swing" of the amplifier. In this example, the amplifier output can swing from $V_{OUT(min)}$ = Vdsat to $V_{OUT(MAX)} = V_{DD}$ & M1 will remain in saturation.**

Common-Source Small-Signal Gain, R_i and R_o



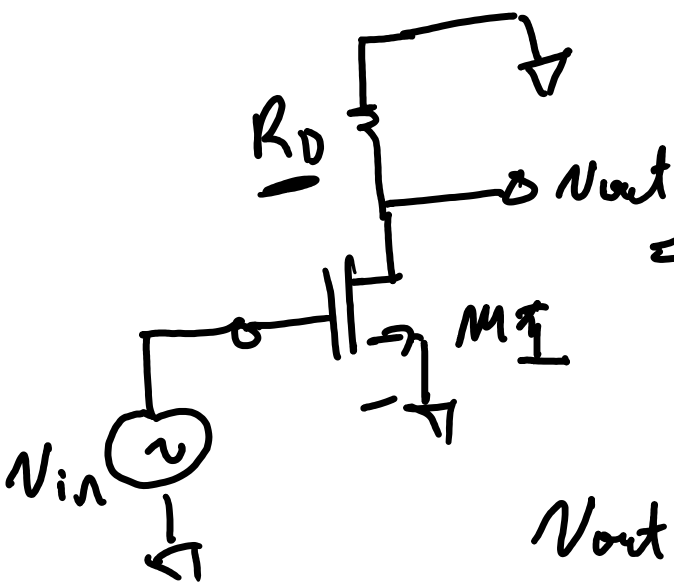
$$\underset{\text{LOWER}}{\overset{\text{CAP}}{V_{in}}} = \underset{\text{CAP}}{\overset{\text{CAP}}{V_{IN}}} + \underset{\text{LOWER}}{\overset{\text{LOWER}}{v_{in}}}$$

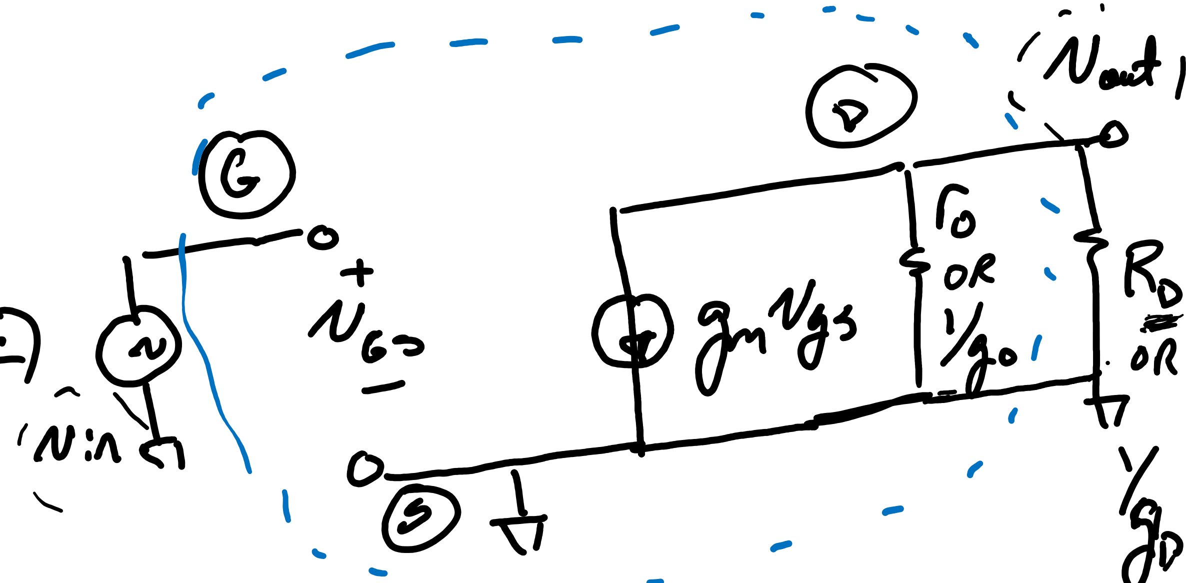
Step 1) DC Analysis to find DC I_D, V_{GS}-V_{TH}, V_{DS}, DC values used to find small-signal values such as gm, ro, gmb, etc.

Common-Source Small-Signal Signal Analysis

Step 1) DC Analysis to find DC I_D, $V_{GS}-V_{TH}$, V_{DS}, DC values used to find small-signal values such as gm, ro, gmb, etc.

SMALL-SIGNAL





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

$$v_{out} = -g_m \cdot \overset{i_o}{v_{in}} \cdot \left(\frac{1}{r_o} + \frac{1}{R_D}\right)$$

Ex: $R_D << r_o$

$$a_v = \frac{v_{out}}{v_{in}} = -g_m \cdot \left(\frac{1}{r_o} + 1/R_D\right) = -g_m \cdot \frac{r_o R_D}{r_o + R_D} \cong -g_m \cdot R_D$$

$$a_v \cong -g_m \cdot R_D \cong -\frac{2I_D}{(V_{GS}-V_{tn})} \cdot R_D$$

$$\cong -\frac{2}{(V_{GS}-V_{tn})} \cdot \underbrace{I_D \cdot R_D}_{\text{VOLTAGE DROP ACROSS } R_D}$$

$$V_{out} \cong \frac{V_{DD}}{2}$$

$$= \underbrace{V_{DD} - I_D \cdot R_D}$$

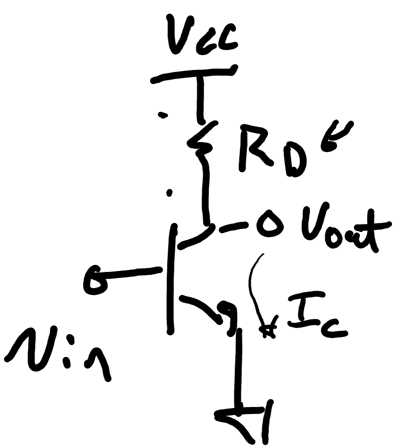
$$I_D \cdot R_D = V_{DD}/2$$

$$\cong -\overset{2V}{V_{DD}}/(\underset{200\,mV}{V_{GS}-V_{tn}}) \cong -10\ V/V$$

TECH. SCALING

$V_{DD}\downarrow$ --- $1V\downarrow$ $\Big\} \Rightarrow \cong -5\ V/V$.

- COMPARISON TO BJT.

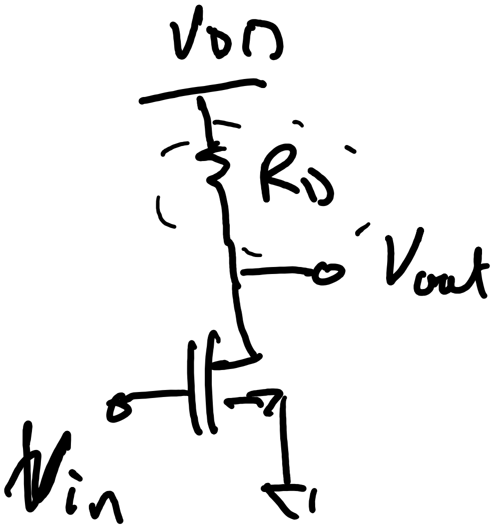


$$\frac{a_v(BJT)}{a_v(MOS)} = \frac{-\cancel{V_{CC}}/2V_T}{-\cancel{V_{DD}}/(V_{GS}-V_{tn})} = \frac{\overset{200\,mV}{(V_{GS}-V_{tn})}}{\underbrace{2V_T}_{50\,mV}}$$

$V_T \cong 25\,mV$

$\therefore$ BJT GAIN IS TYPICALLY 4x-5x

CMOS Intrinsic Gain

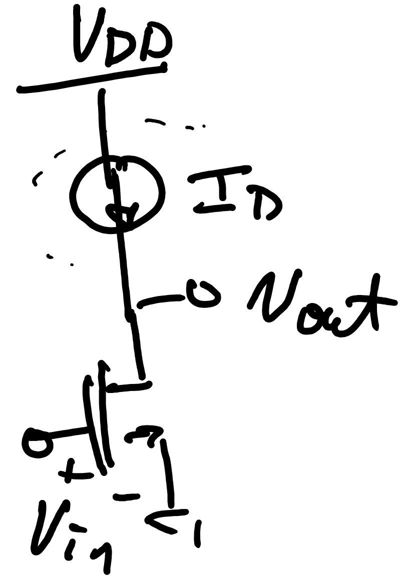


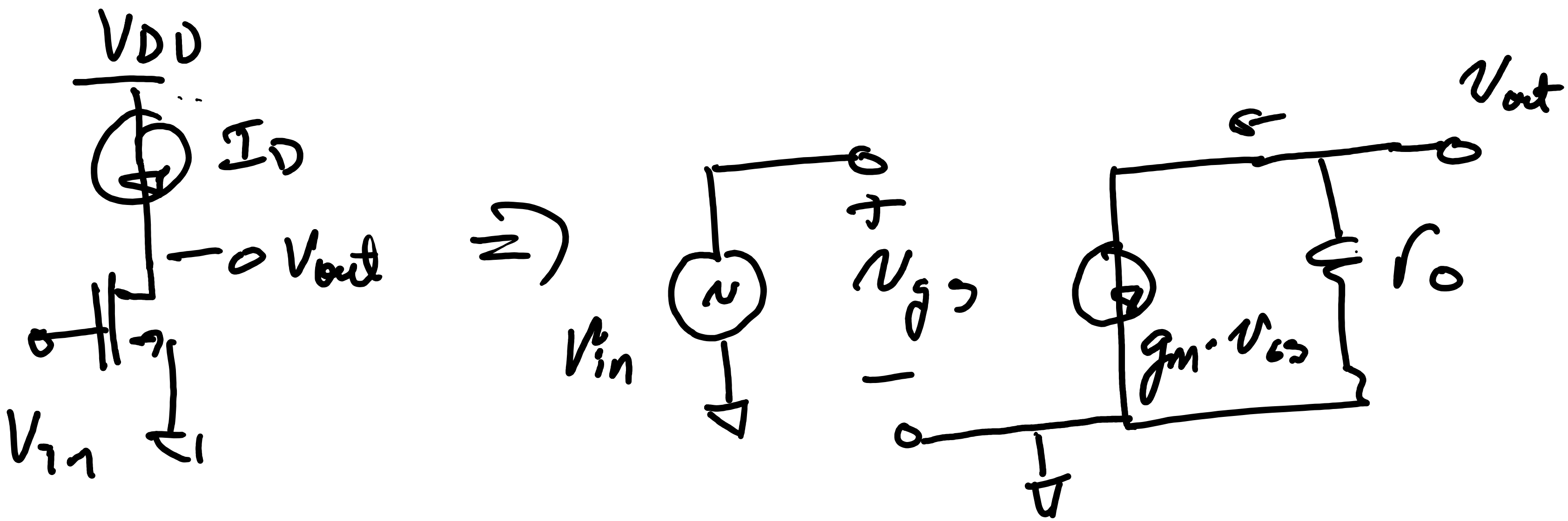
$\Rightarrow$

LOOK AT

IDEAL CASE

$R_D \to \infty$





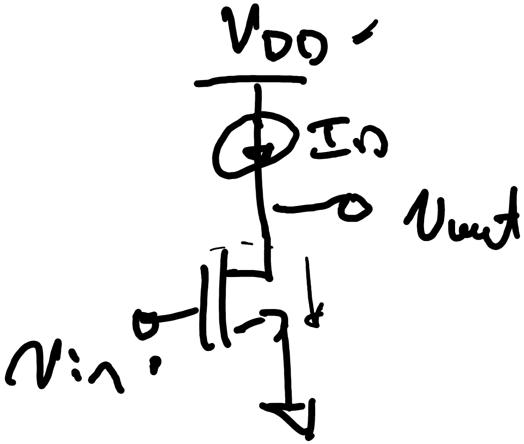
$$v_{out} = -g_m \cdot \underbrace{v_{gs}}_{v_{in}} \cdot r_o$$

$$v_{GS} = v_{in}$$

$$\boxed{A_v = -g_m \cdot r_o} \leftarrow$$

DEVICE
INTRINSIC
GAIN

MOSFET Gain Limitations



$$a_v = -g_m \cdot r_o$$

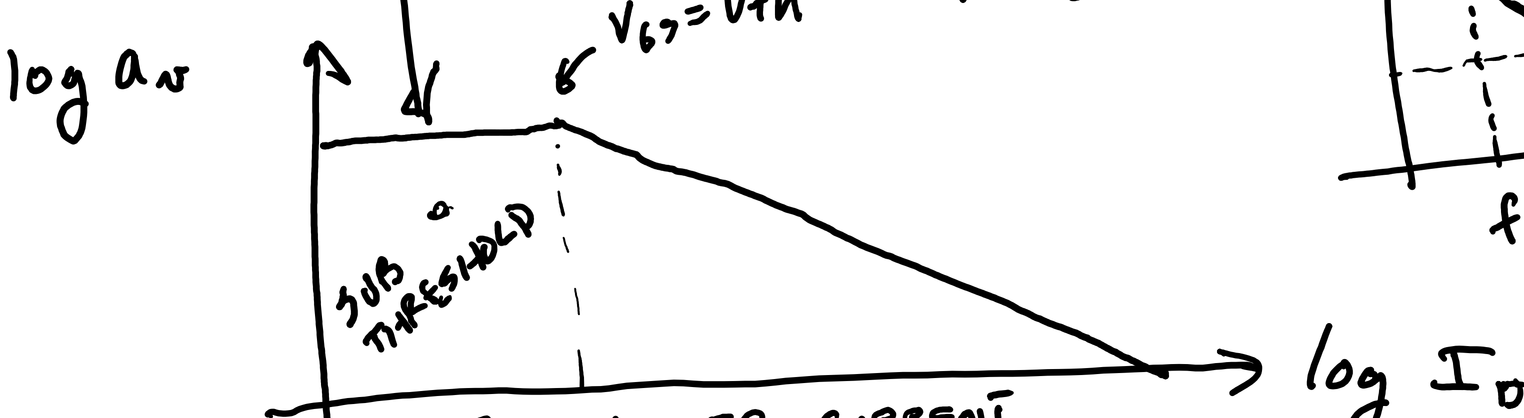
$$r_o = \frac{1}{\lambda I_D}$$

λ : TECH DEP.

$$a_v = -\frac{\overbrace{\sqrt{2K_n'(W/L)I_D}}^{g_m}}{\lambda I_D}$$

$$a_v \propto \frac{1}{\sqrt{I_D}}$$

SUBTHRESHOLD OR WEAK INVERSION



← LOWER CURRENT ⟹ HIGHER GAIN

GBWP

$a_{sub} \cdot f_{sub} = f_{sat} \cdot a_{sat}$