\[ V_{PS} - 1A \\ V_i = V_{GS} + \hat{V}_i - V_t \]

Adding in AC gain

\[ 4.4V - 3.3 \hat{V}_i = 4.4V + V_i - 1.5V \]

\[ \hat{V}_i = 0.34V \]

Example (5.11 in 6th edition, Fig 5.42)

\[ V_{DD} \]
\[ R_D \]
\[ V_0 \]
\[ V_i \]
\[ -V_{GS} \]

> Assume \( R_D \) & \( I \) are such that MOSFET in saturation

> \( C_c1 \) & \( C_c2 \) are large coupling capacitors

> Find \( R_{in} \) & voltage gain.

Replace with \( T \) equivalent circuit

\[ G \]
\[ V_{gs} \]
\[ D \]
\[ R_D \]
\[ V_0 \]

\[ V_i \]
\[ S \]
\[ R_{in} \]
\[ R_{in} = \frac{V_i}{-i} = \frac{1}{g_m} \]

\[ V_o = -i \cdot R_D = \frac{V_i}{\left(\frac{1}{g_m}\right)} \quad R_D = g_m \cdot R_D \cdot V_i \]

\[ A_V = \frac{V_o}{V_i} = g_m \cdot R_D \]

**Summary**

\[ \text{NMOS} \quad g_m = U_n \cdot \text{Cox} \cdot \frac{W}{L} \cdot \frac{1}{V_{ov}} \]

\[ = \sqrt{2U_n \cdot \text{Cox} \cdot \frac{W}{L} \cdot \frac{I_D}{V_{ov}}} \]

\[ = \frac{2I_D}{V_{ov}} \]

\[ R_0 = \frac{V_A}{I_D} = \frac{1}{\lambda \cdot I_D} \]

**PMOS same except** \[ |V_{ov}|, |V_{tp}|, \lambda > 1 \]

### 7.3 Basic MOSFET Amplifier Configurations

![Diagram of MOSFET amplifier configuration]
Input resistance

\[ R_{\text{in}} = \frac{v_i}{i_i} \]

unilateral amplifier
no feedback

\[ R_i = \frac{v_i}{i_i} \mid R_L = \infty \]

Output resistance

\[ V_s i_g = 0 \]

\[ R_{\text{out}} = \frac{V_x}{i_x} \mid V_{s i g} = 0 \]

\[ V_i = \frac{R_{\text{in}}}{R_{\text{in}} + R_{\text{sig}}} V_{s i g} \]

If \( R_{\text{in}} \) is independent of \( R_L \), no feedback \( \Rightarrow \) unilateral

\[ A_{v0} = \frac{v_0}{v_i} \mid R_L = \infty \text{ open circuit voltage gain} \]

\[ R_0 = \frac{V_x}{i_x} \text{ looking back into amplifier w/ } V_i = 0 \]
\[ V_o = \frac{R_L}{R_L + R_o} \] \[ A_v = \frac{V_o}{V_i} = A_v \frac{R_L}{R_L + R_o} \] voltage gain

\[ G_v = \frac{V_o}{V_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}} A_v \frac{R_L}{R_L + R_o} \]

- \( R_i, R_o, A_v, g_m \) depend on amplifier itself but not \( R_{sig} \) or \( R_L \)
- \( R_{in}, R_{out}, A_v, G_v \) may depend on \( R_{sig} \) or \( R_L \)

7.3.3 Common source amplifier

(section 5.6.3 in 6th edition)

* MOSFET part only!
- most widely used amplifier configuration
- Supply bulk of voltage gain in amplifier chain

**Fig 7.35**

[Diagram of common source amplifier]
Ex: Take 2 mos & draw small signal model

Small signal model

1) \( R_{in} = \infty \) since \( i_g = 0 \)

2) \( V_o = -G_{m}V_{gs} (R_o \parallel R_D) \)
   
   Since \( V_{gs} = V_i \) \( \Rightarrow A_{vo} = \frac{V_o}{V_i} = -G_{m}(R_D \parallel R_o) \)

\[ R_o = R_D \parallel R_o \]

\( \text{Set } V_{gs} = 0, G_{m}V_{gs} = 0 \)

\( \) & straightforward to find \( R_o \)

Since \( V_{sig} = V_i \), \( G_v = \frac{V_o}{V_{sig}} \), \( A_v = \frac{V_o}{V_i} \)

Ideal CS amplifier

1) \( R_{in} = \infty \)
2) \( R_o = \text{moderate} \rightarrow \text{high} (K ohm \rightarrow 10 \text{}K ohm) \)
3) \( A_{vo} \) can be high
\[ A_{v0} = \frac{V_{o}}{V_{i}} = \frac{1 + \frac{g_m R_S}{1/g_{m}}}{1/g_{m} R_D} \]

\[ V_{o} = -R_D \cdot I \]

\[ I_g = 0 \quad \Rightarrow \quad R_{in} = 0 \]

Replace with an equivalent circuit model.

Fig. 7.3: Ignore \( R \) for now.
Unlike CS w/o Rs

> $V_{gs} \neq V_i$
>
> $R_s$ controls $V_{gs}$ to be sufficiently small for small signal operation
>  \Rightarrow \text{avoid non linear distortion}
>
> $R_s$ provides negative feedback but reduces voltage gain by
> $(1 + g_m R_s)$

7.3.5 Common gate amplifier

---

**Fig 7.39**

---

> Gate grounded
>
> Signal fed into source
>
> Output is Drain

---

$R_{sg}$ in series with source $\Rightarrow$ use T model

---

**Exercise:**

Draw hybrid $\Pi$ model
\[ R_{in} = \frac{v_i}{i_i} = \frac{1}{g_m} \]

\[ N_0 = -iD = -\left(\frac{-v_i}{\frac{1}{g_m}}\right)D = g_m R_D V_i \]

\[ A_{v_0} = g_m R_D \]

\[ R_0 = R_D \]

\[ \frac{v_i}{v_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}} = \frac{1}{g_m} \frac{1}{\frac{1}{g_m} + R_{sig}} \]

\[ G_{vo} = \frac{1}{g_m} \frac{g_m R_D}{\frac{1}{g_m} + R_{sig}} \]

\[ g_m R_D = \frac{R_D}{R_{sig} + \frac{1}{g_m}} \]

7.3.6 Source Follower (Common Drain Amplifier)

Fig 7.41
Need for Voltage Buffer
1) Connect directly — what is $V_{out}$?

$$V_{out} = \frac{11k\Omega \cdot (1V)}{1k\Omega + 1M\Omega} = 1mV$$

2) Alternative: add voltage buffer

$$V_0 = 0.9 \cdot V_i = \left(\frac{1000}{1000+100}\right)1V$$

How to work?

- $V_{gate}$ cannot change
- $V_{source}$ can change
- $V_{source}$ follower