EE105
Microelectronic Devices and Circuits

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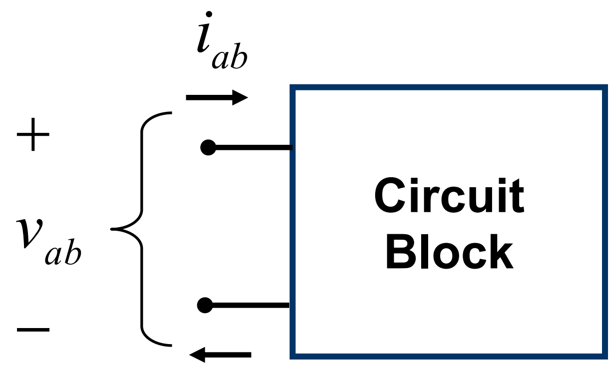
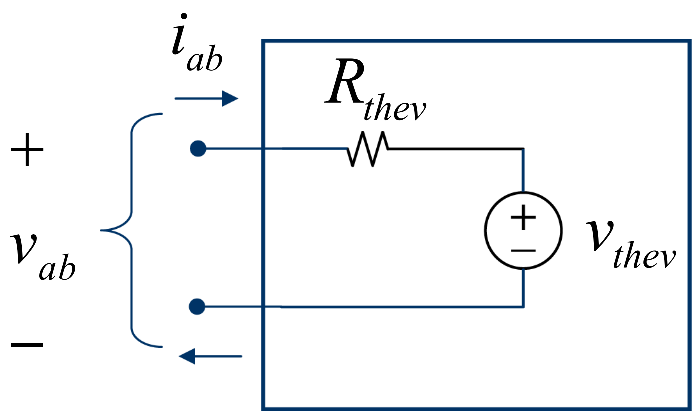
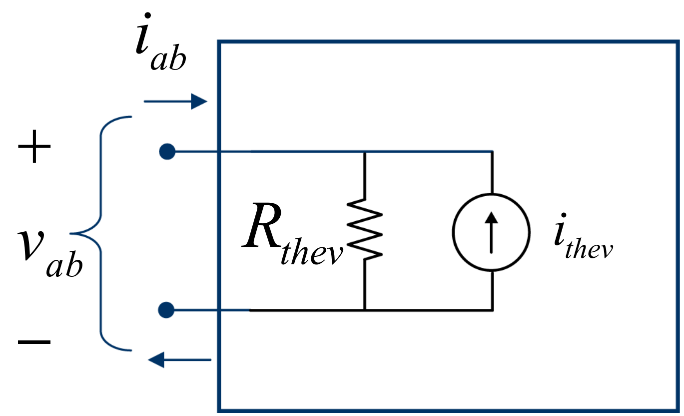
One-Port Models (EECS 16A)

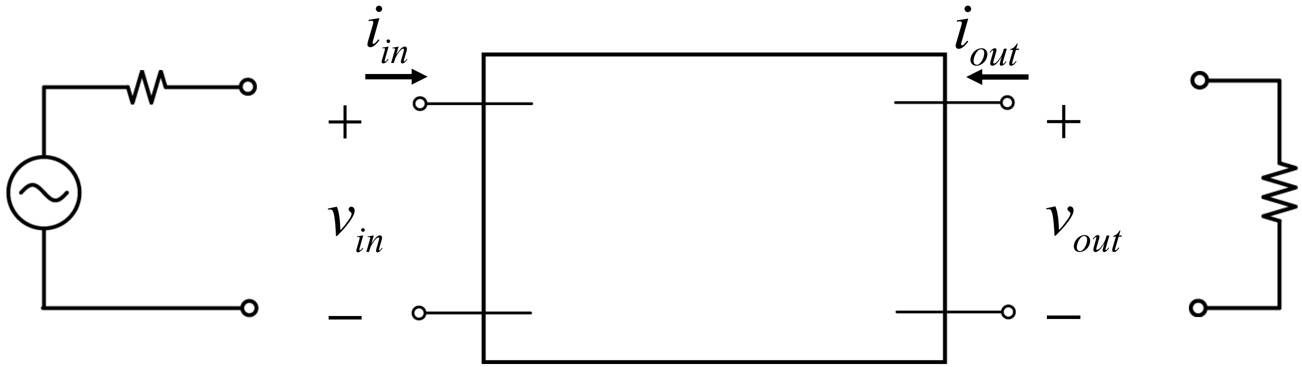
- A terminal pair across which a voltage and associated current are defined





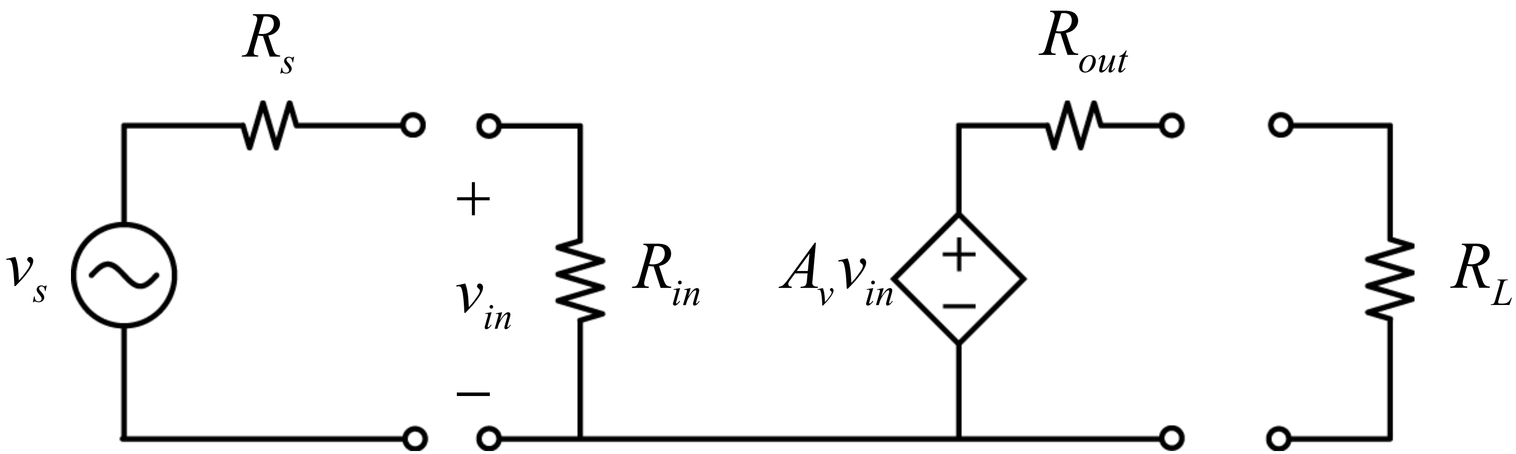


Small-Signal Two-Port Models

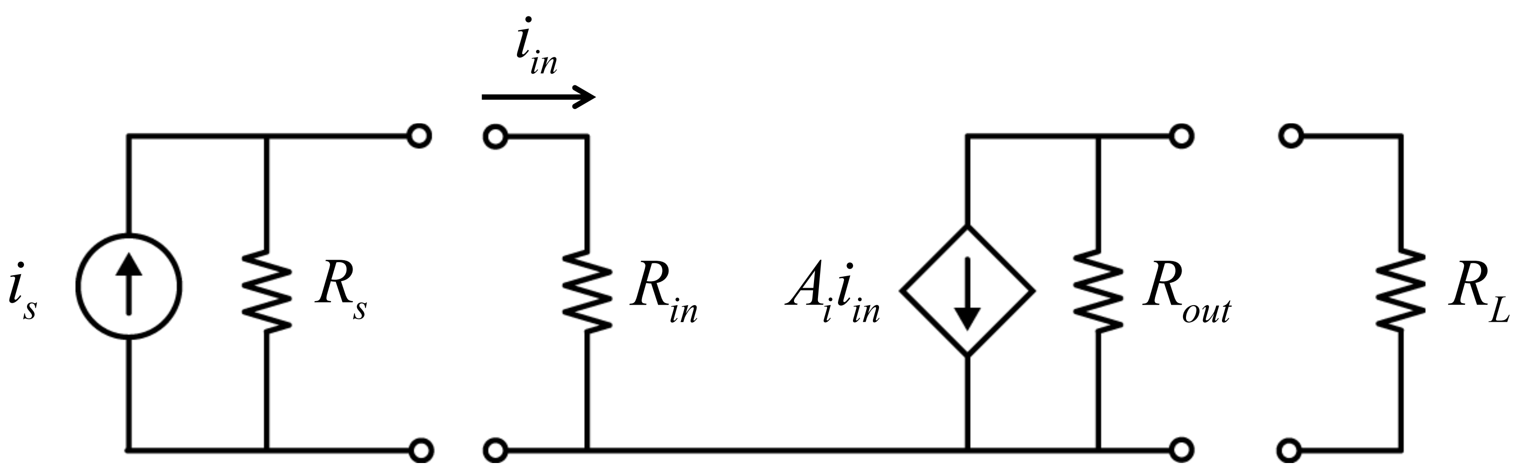


- We assume that input port is linear and that the amplifier is *unilateral*:
  - Output depends on input
  - But input is independent of output.
- Output port: depends linearly on the current and voltage at the input and output ports
- Unilateral assumption is good as long as "overlap" capacitance is small (MOS)

Two-Port Small-Signal Amplifiers

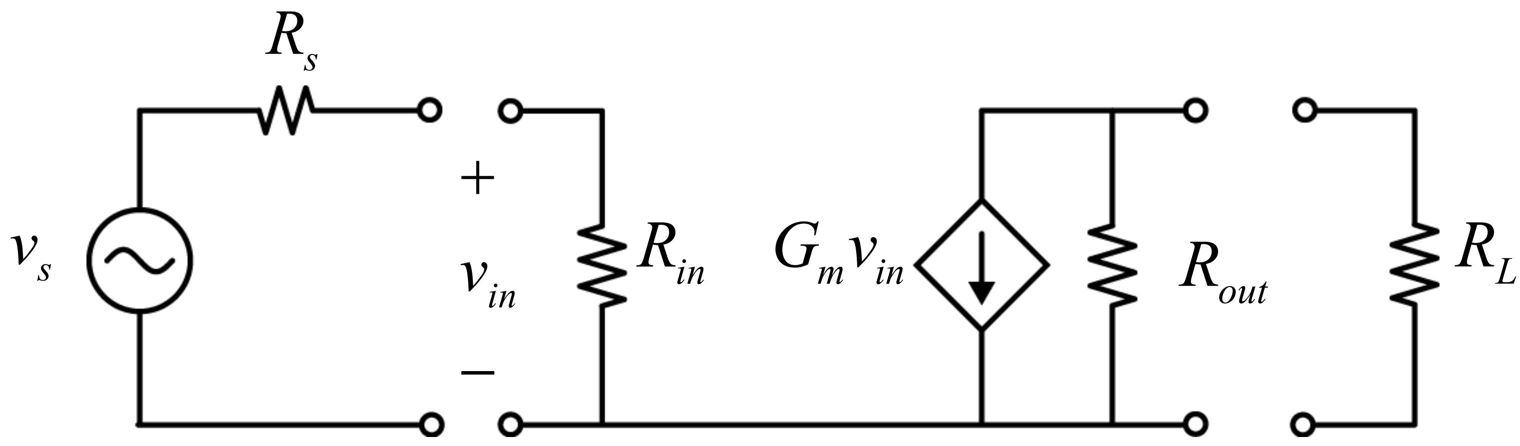


Voltage Amplifier

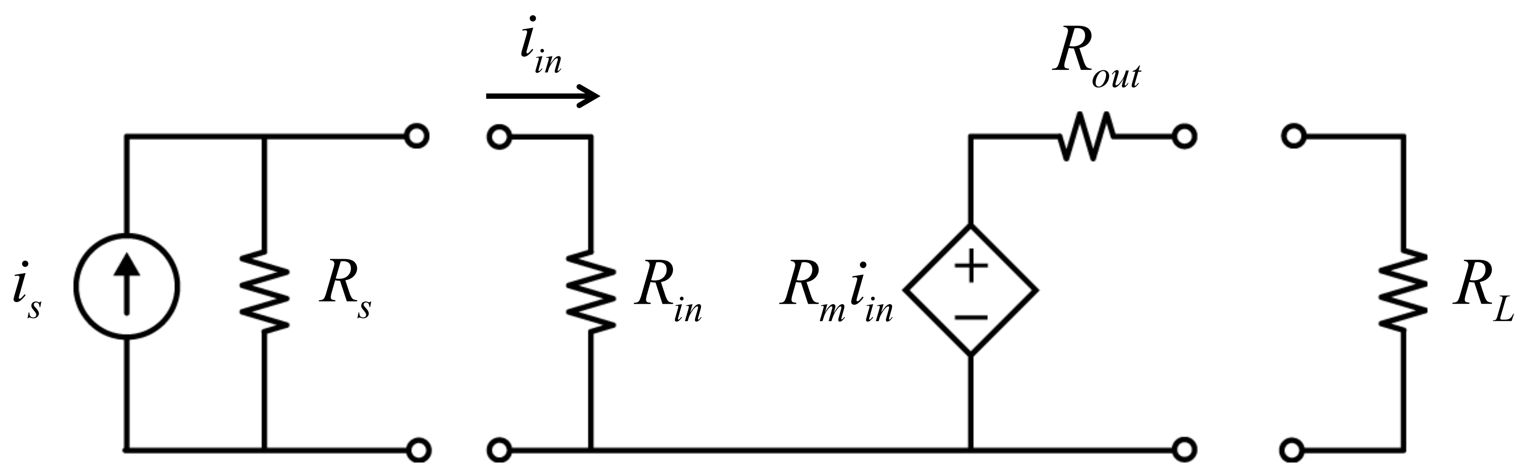


Current Amplifier

Two-Port Small-Signal Amplifiers



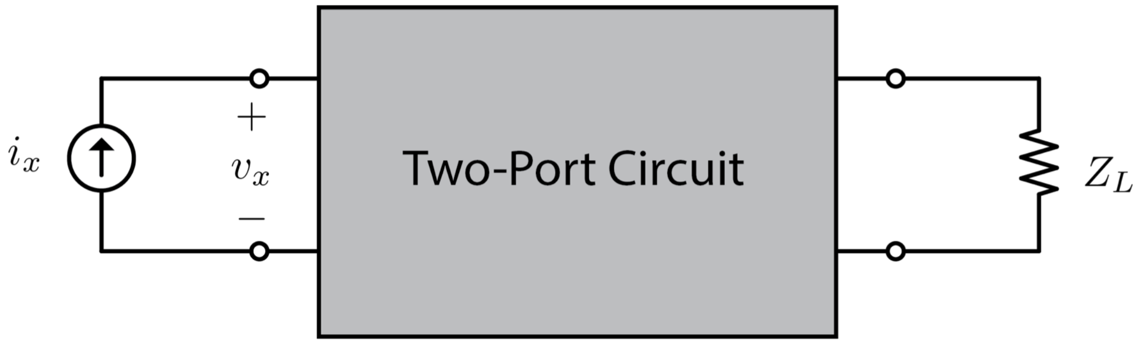
Transconductance Amplifier



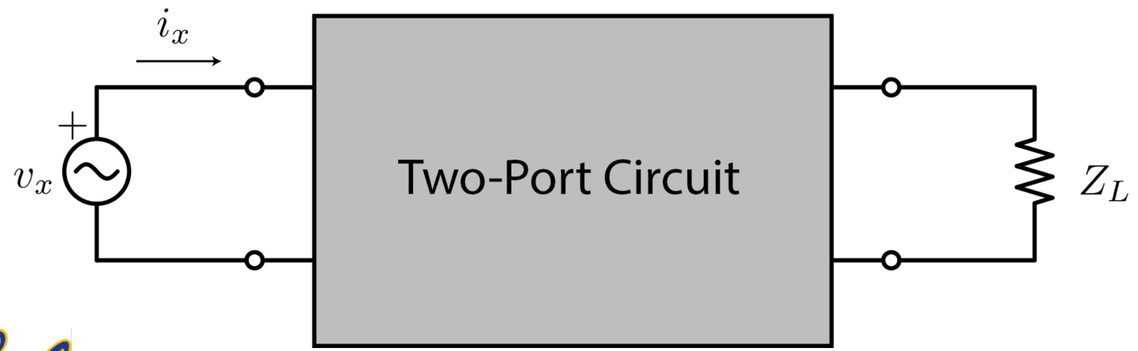
Transresistance Amplifier

Input Impedance Zin

- **Looks like a Thevenin resistance measurement, but note that the output port has the load resistance attached**



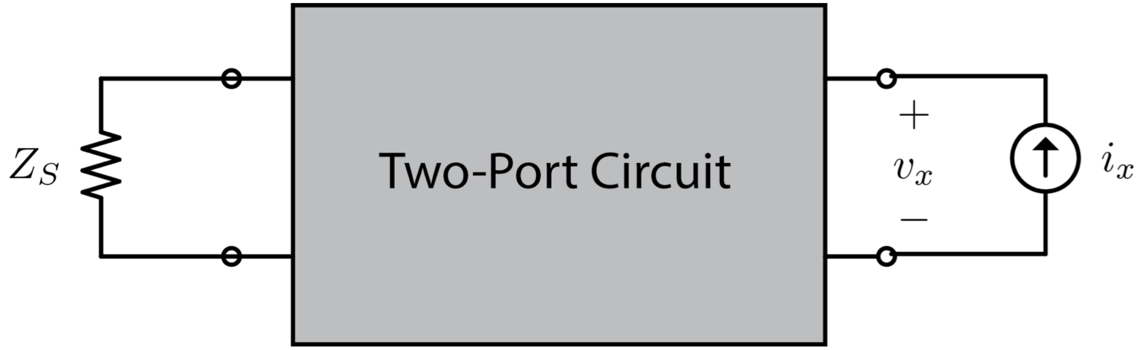
$$Z_{in} = \left.\frac{v_x}{i_x}\right|_{Z_S\,removed,\; Z_L\,attached}$$

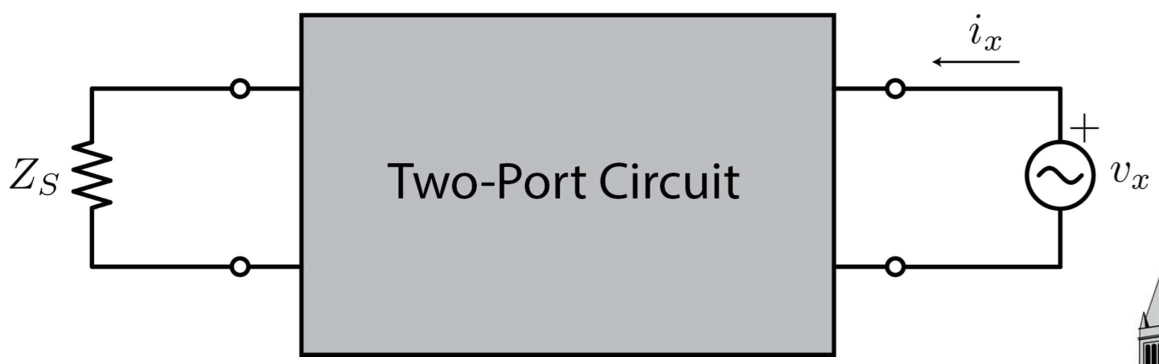


Output Impedance Z_{out}

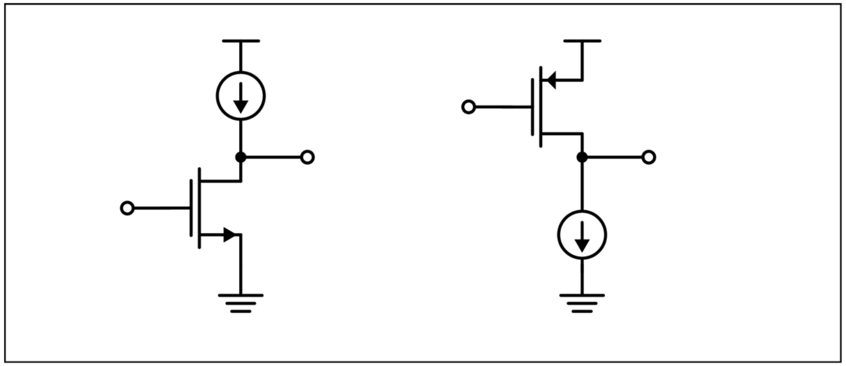
- **Looks like a Thevenin resistance measurement, but note that the input port has the source resistance attached**

$$Z_{out} = \left.\frac{v_x}{i_x}\right|_{Z_L removed,\ Z_S attached}$$

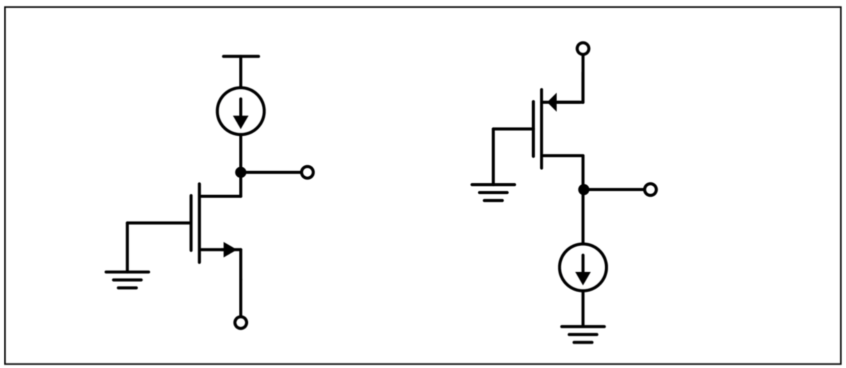




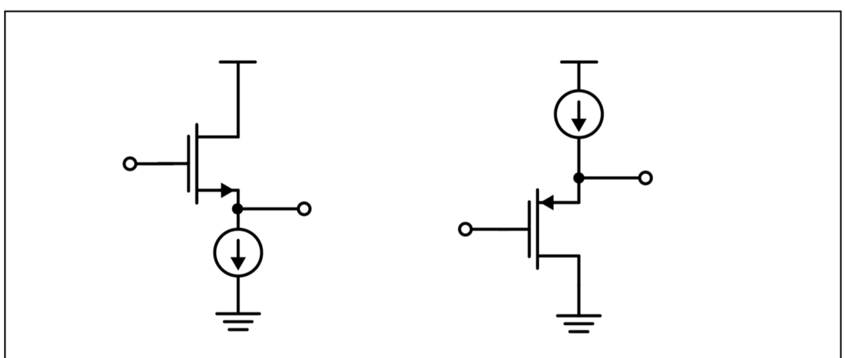
Single-Stage Amplifier Types



Common Source (CS)



Common Gate (CG)

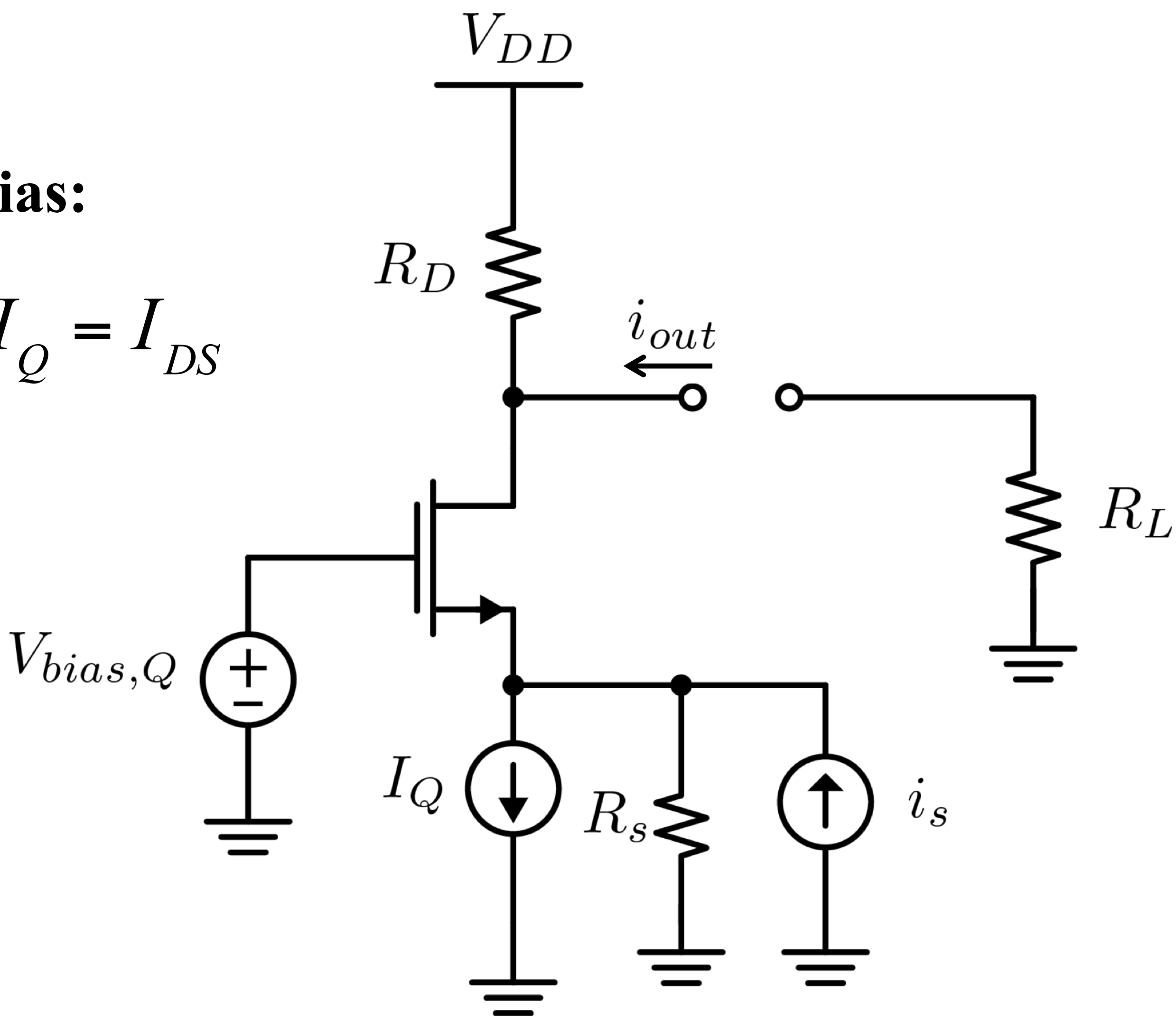


Common Drain (CD)

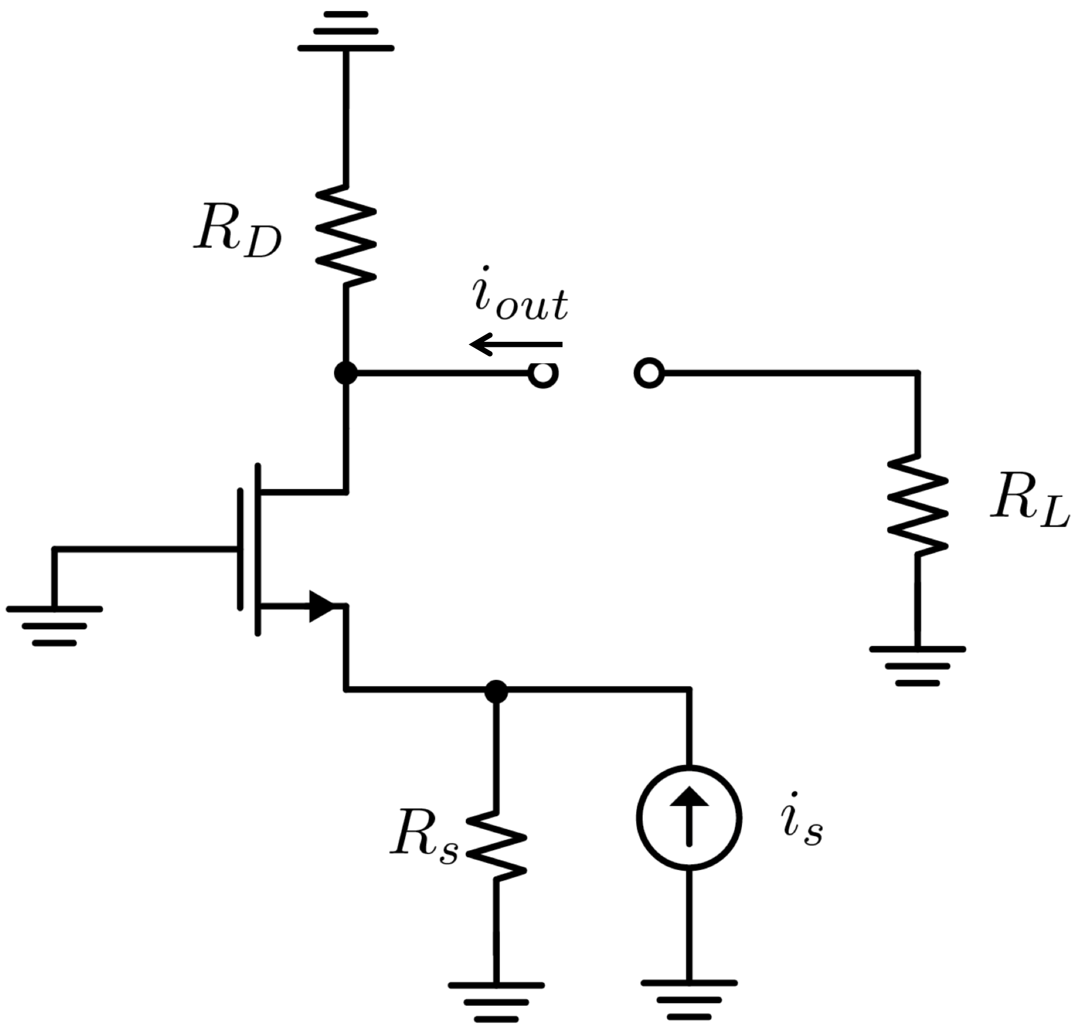
Common Gate (CG) Amplifier

DC bias:

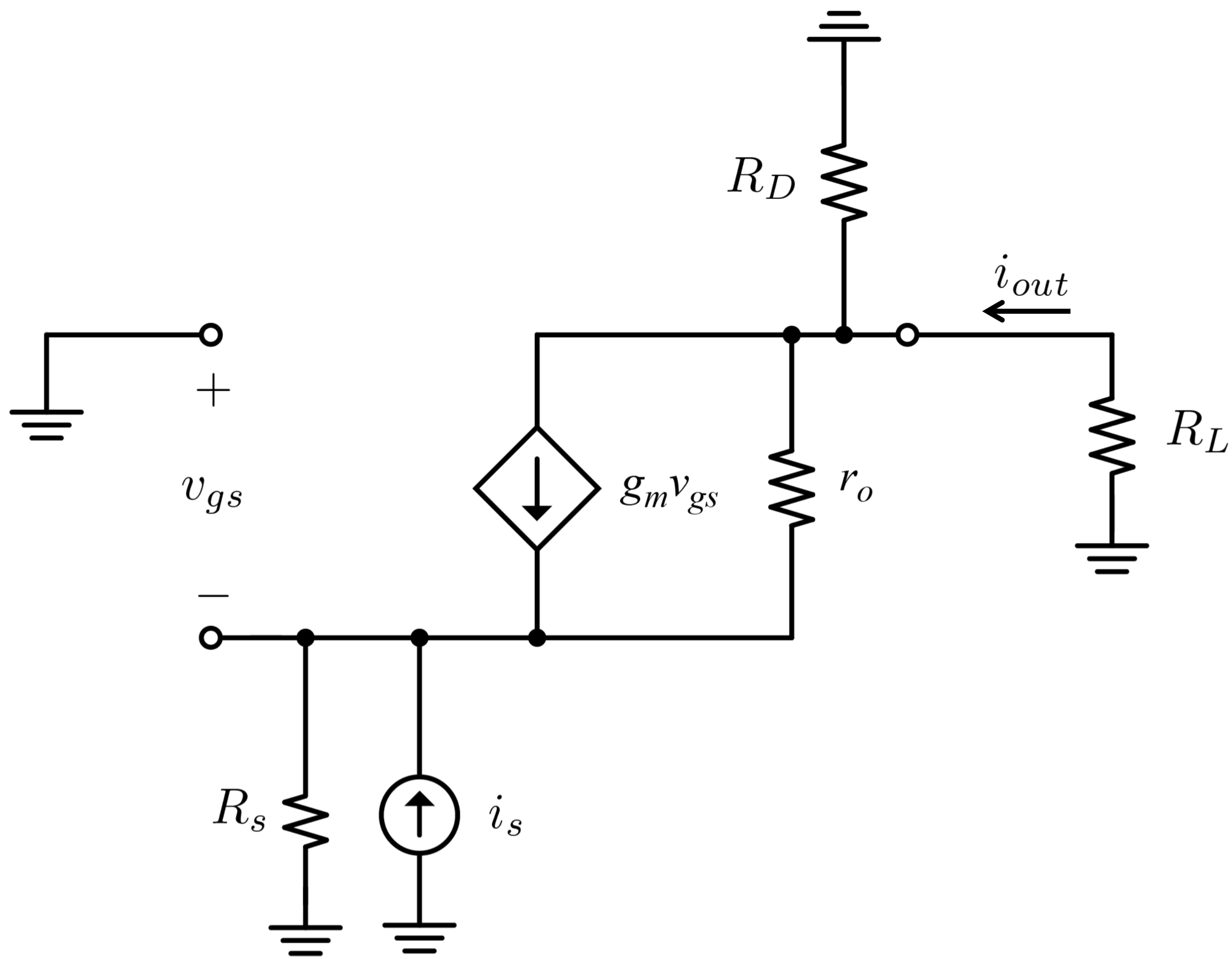
$$I_{SUP} = I_Q = I_{DS}$$



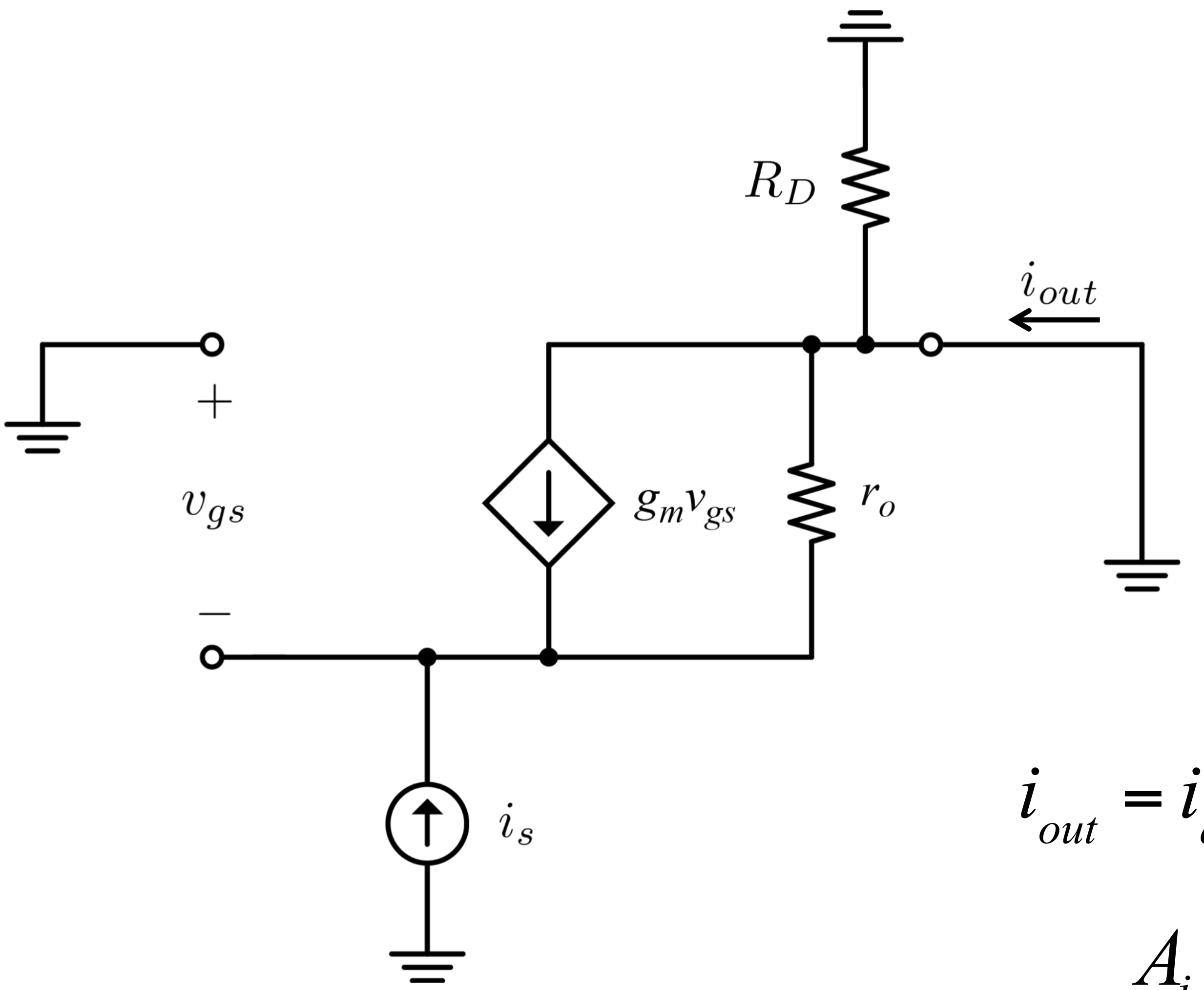
Common Gate AC Model



Common Gate Small Signal



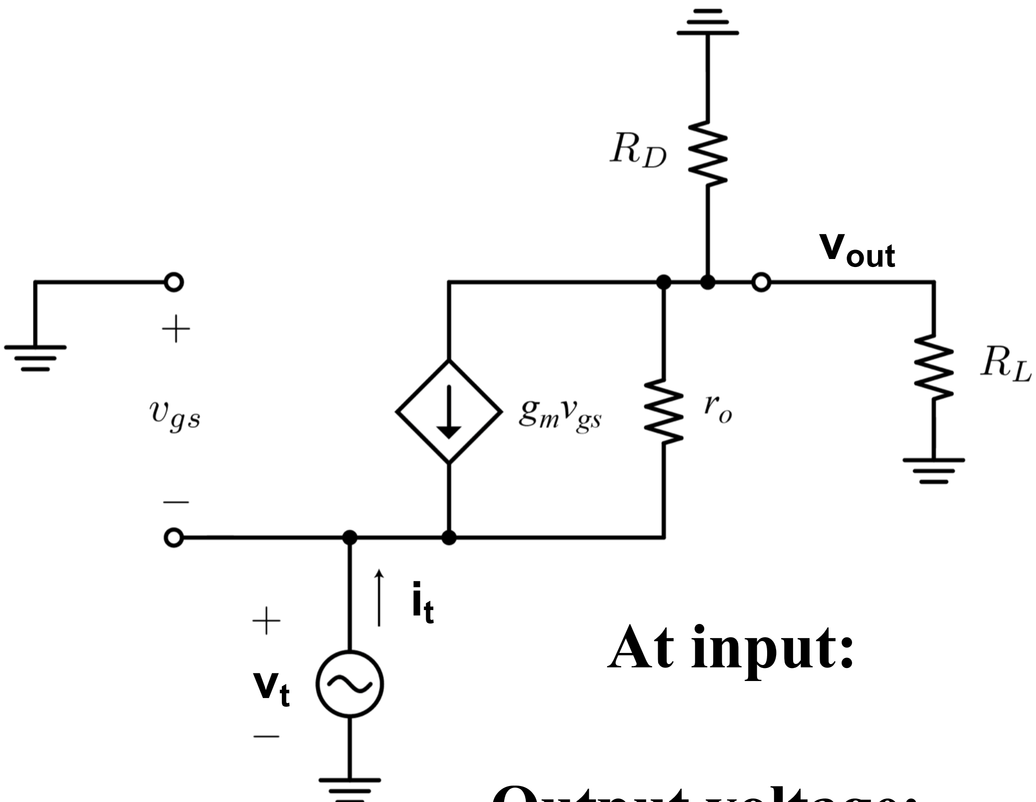
CG as a Current Amplifier: Find A_i



$$i_{out} = i_d = -i_s$$

$$A_i = -1$$

CG Input Resistance



At input: $$i_t = -g_m v_{gs} + \left(\frac{v_t - v_{out}}{r_o} \right)$$

Output voltage: $$v_{out} = -i_d (R_D \parallel R_L) = i_t (R_D \parallel R_L)$$

$$i_t = g_m v_t + \left(\frac{v_t - (R_D \parallel R_L) i_t}{r_o} \right)$$

Approximations…

- **We have this messy result**

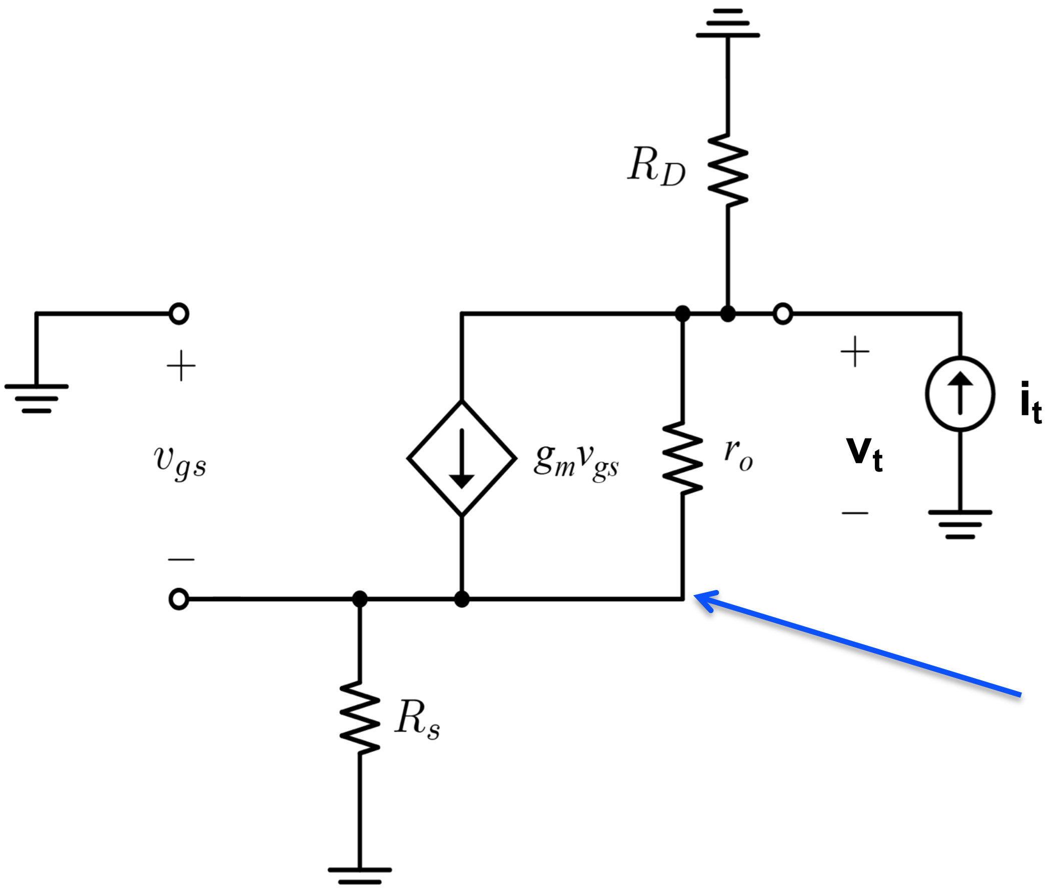
$$\frac{1}{R_{in}} = \frac{i_t}{v_t} = \frac{g_m + \frac{1}{r_o}}{1 + \frac{R_D \| R_L}{r_o}}$$

- **But we don't need that much precision. Let's start approximating:**

$$g_m >> \frac{1}{r_o} \qquad R_D \| R_L \approx R_L \qquad \frac{R_L}{r_o} \approx 0$$

$$R_{in} = \frac{1}{g_m}$$

CG Output Resistance



$$\frac{v_s}{R_S} - g_m v_{gs} + \frac{v_s - v_t}{r_o} = 0$$

$$v_s\left(\frac{1}{R_S} + g_m + \frac{1}{r_o}\right) = \frac{v_t}{r_o}$$

CG Output Resistance

Substituting $v_s = i_t R_S$

$$i_t R_S \left(\frac{1}{R_S} + g_m + \frac{1}{r_o} \right) = \frac{v_t}{r_o}$$

The output resistance is $(v_t / i_t) || R_D$

$$R_{out} = R_D \,||\, \left(R_S \left(\frac{r_o}{R_S} + g_m r_o + 1 \right) \right)$$

$$R_{out} = R_D \,||\, \left(r_o + g_m r_o R_S + R_S \right)$$

Approximating the CG R_{out}

The exact result is complicated, so let's try to make it simpler:

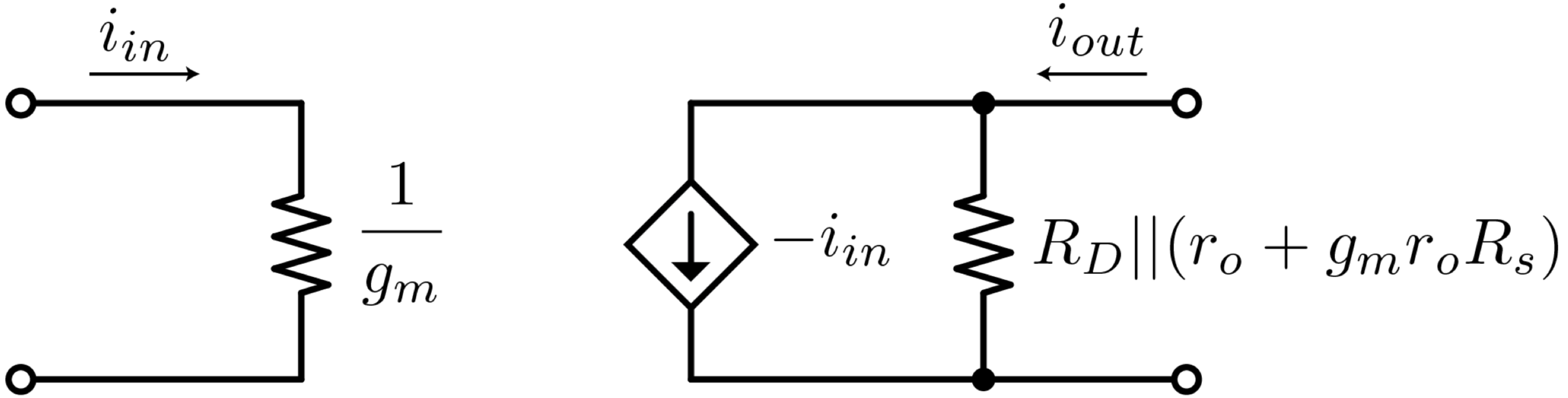
$$g_m \approx 500\mu S \qquad r_o \approx 200k\Omega$$

$$R_{out} \cong R_D \,||\, [r_o + g_m r_o R_S + R_S]$$

Assuming the source resistance is less than r_o,

$$R_{out} \approx R_D \,||\, [r_o + g_m r_o R_S] = R_D \,||\, [r_o(1 + g_m R_S)]$$

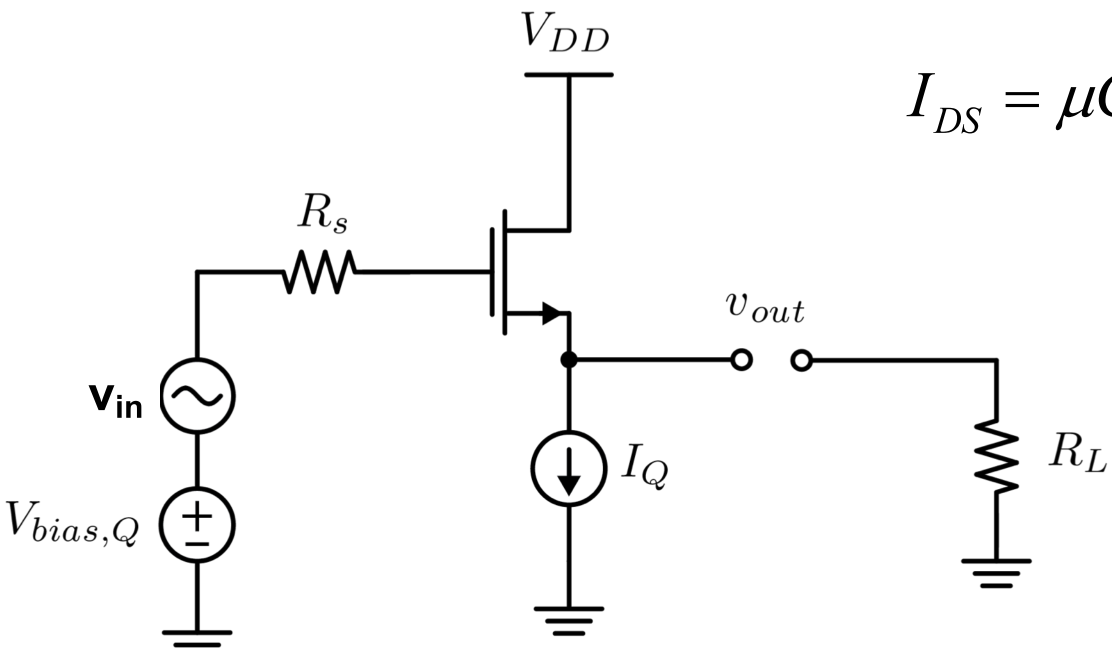
CG Two-Port Model



- **Function: a current buffer**
  - **Low Input Impedance**
  - **High Output Impedance**

Common Gate as a “V Amplifier”

Common-Drain Amplifier

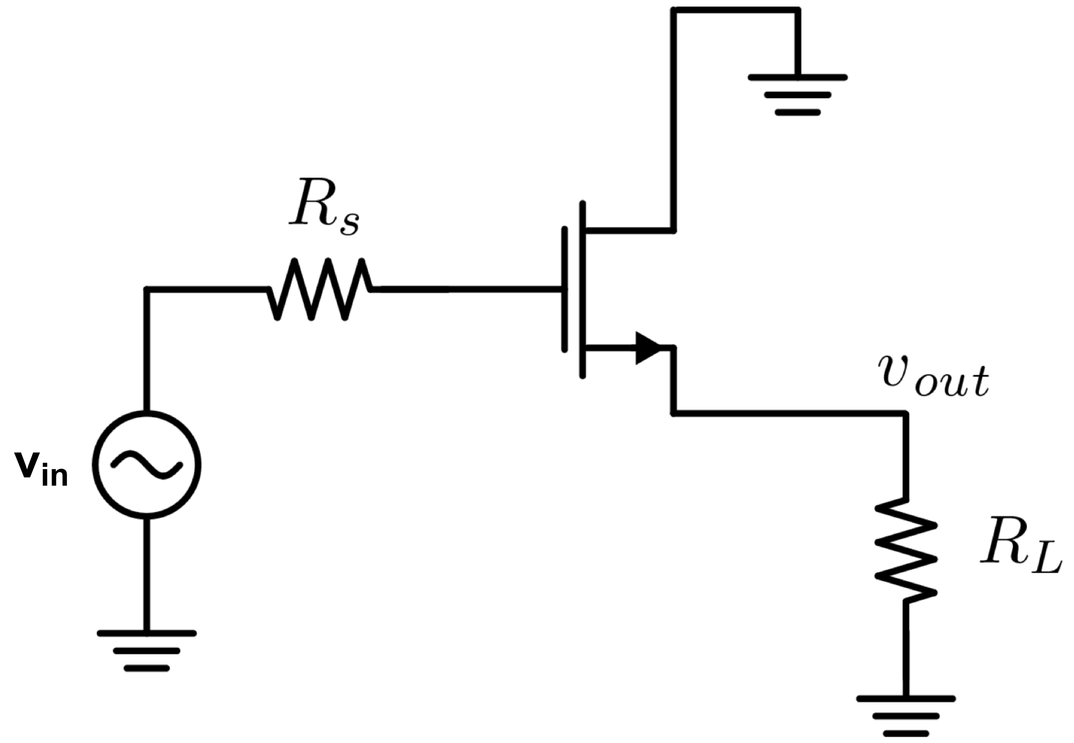


$$I_{DS} = \mu C_{ox} \frac{W}{L} \frac{1}{2} (V_{GS} - V_T)^2$$

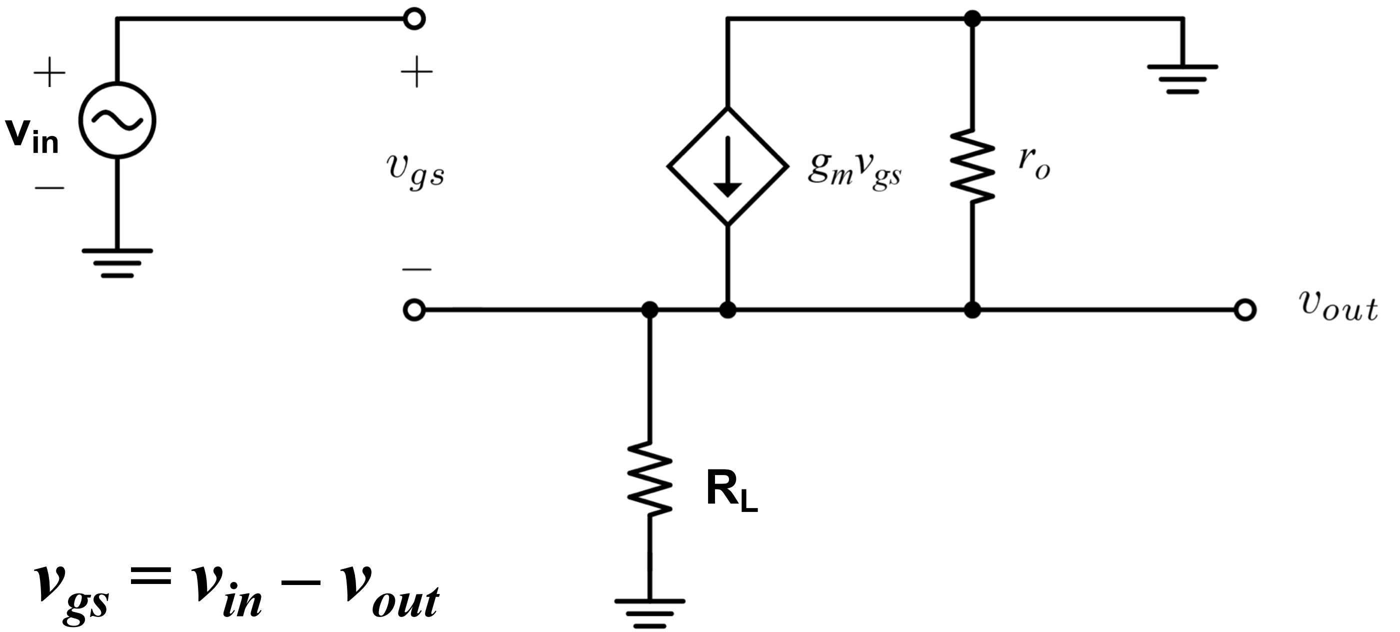
$$V_{GS} = V_T + \sqrt{\frac{2 I_{DS}}{\mu C_{ox} \frac{W}{L}}}$$

Weak I_{DS} dependence

Common Drain AC Schematic



CD Voltage Gain



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

$$\frac{v_{out}}{R_L \parallel r_o} = g_m v_{gs}$$

$$\frac{v_{out}}{R_L \parallel r_o} = g_m \left(v_{in} - v_{out} \right)$$

CD Voltage Gain (Cont.)

KCL at source node:

$$\frac{v_{out}}{R_L \| r_o} = g_m\left(v_{in} - v_{out}\right)$$

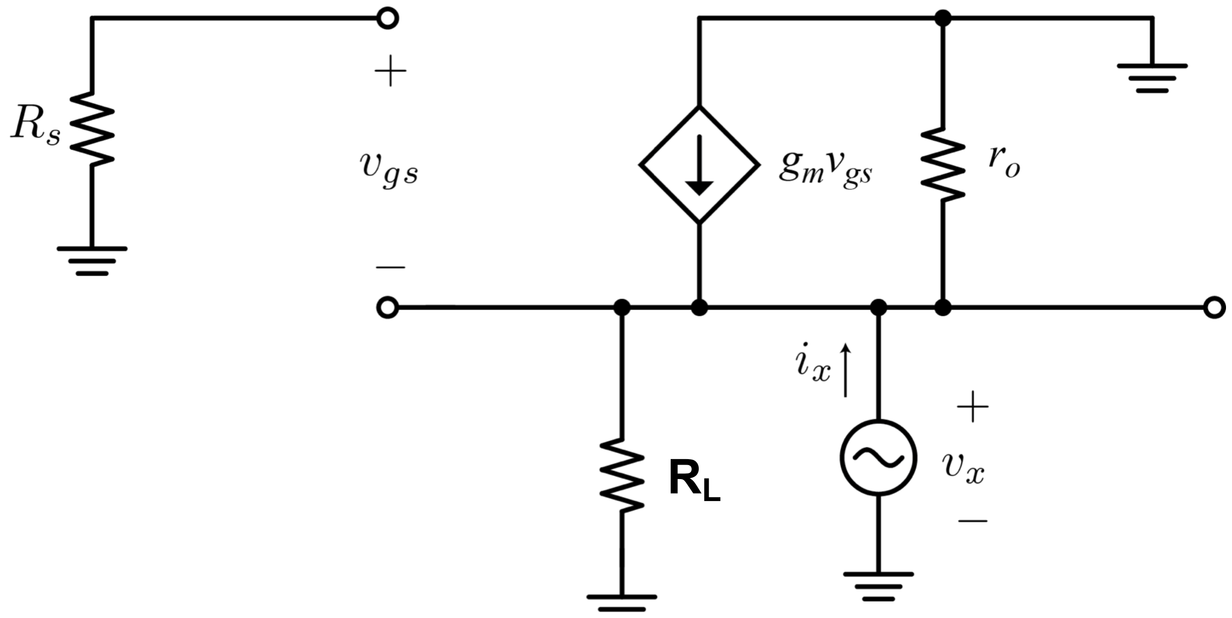
$$\left(\frac{1}{R_L \| r_o} + g_m\right)v_{out} = g_m v_{in}$$

Voltage gain:

$$\frac{v_{out}}{v_{in}} = \frac{g_m}{\dfrac{1}{R_L \| r_o} + g_m}$$

$$\frac{v_{out}}{v_{in}} \approx \frac{g_m}{1/R_L + g_m} \approx 1$$

CD Output Resistance

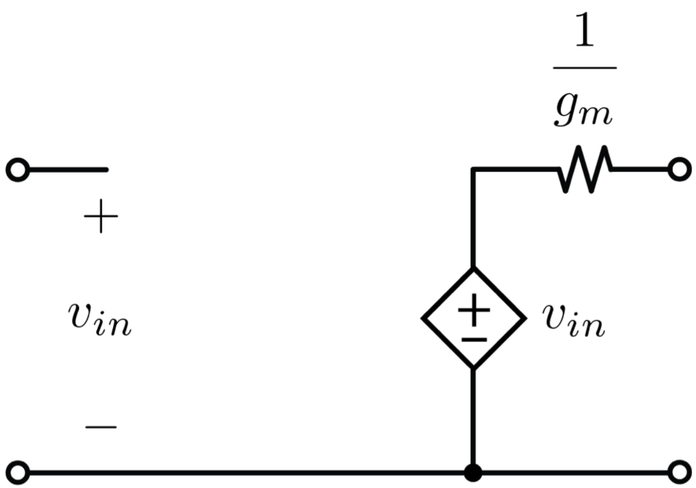


Sum currents at output (source) node:

$$i_x = g_m v_x \qquad R_{out} = r_o \,\|\, R_L \,\|\, \frac{v_x}{i_x} \qquad R_{out} \approx \frac{1}{g_m}$$

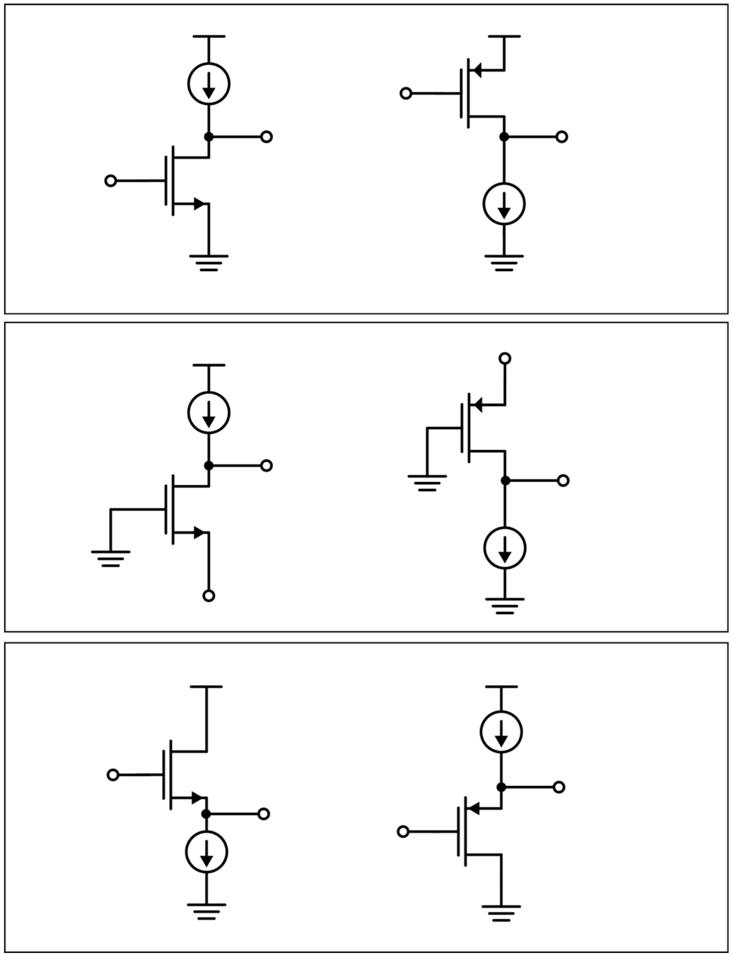
CD Output Resistance (Cont.)

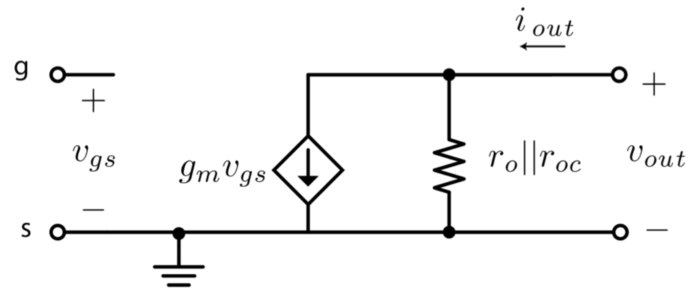
$$r_o || R_L << \frac{1}{g_m} \quad \Longrightarrow \quad \text{Ignore } r_o || R_L$$



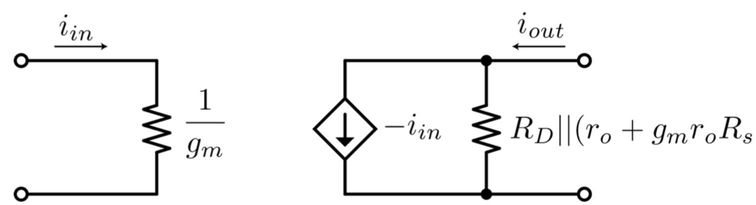
- **Function: a voltage buffer**
  - **High Input Impedance**
  - **Low Output Impedance**

Transistor Amplifiers → Gm/V/I

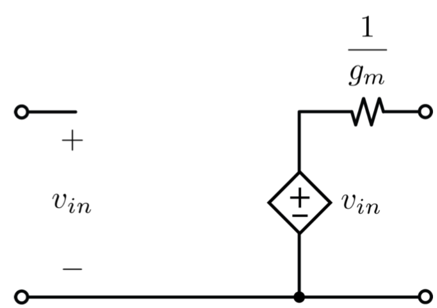




Gm Amplifier
Common Source



I-Buffer
Common Gate



V-Buffer
Source Follower