“1-T”

Single-Stage Amplifiers

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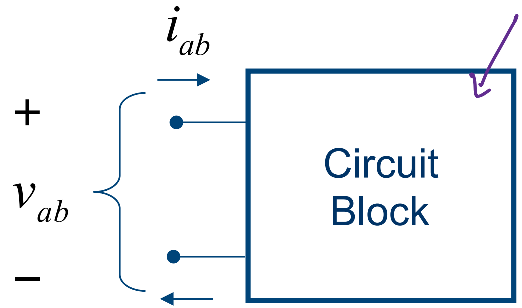
Announcements

- HW8 due on Friday

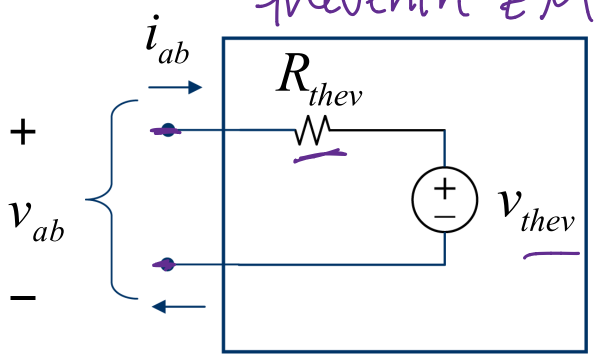
– PICK UP EXAM

One-Port Models (EECS 16A)

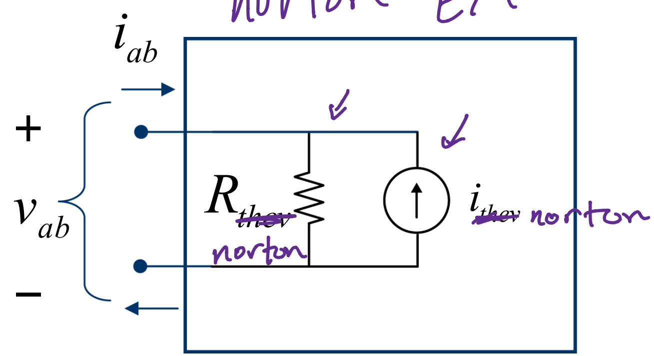
- A terminal pair across which a voltage and associated current are defined



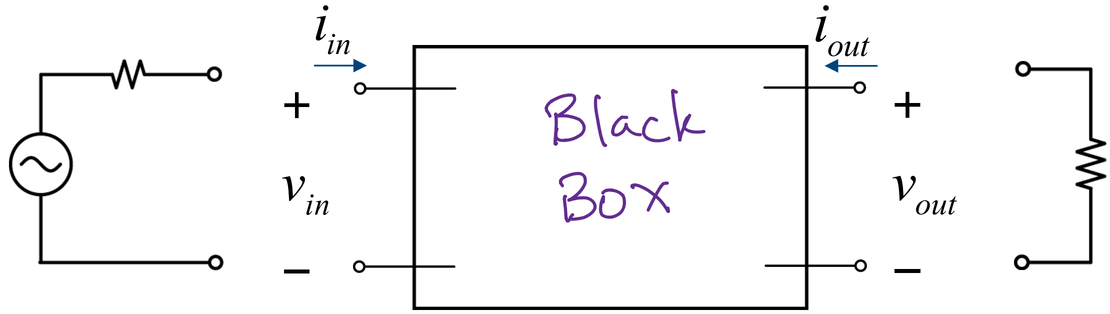
thevenin EM



norton EM



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)

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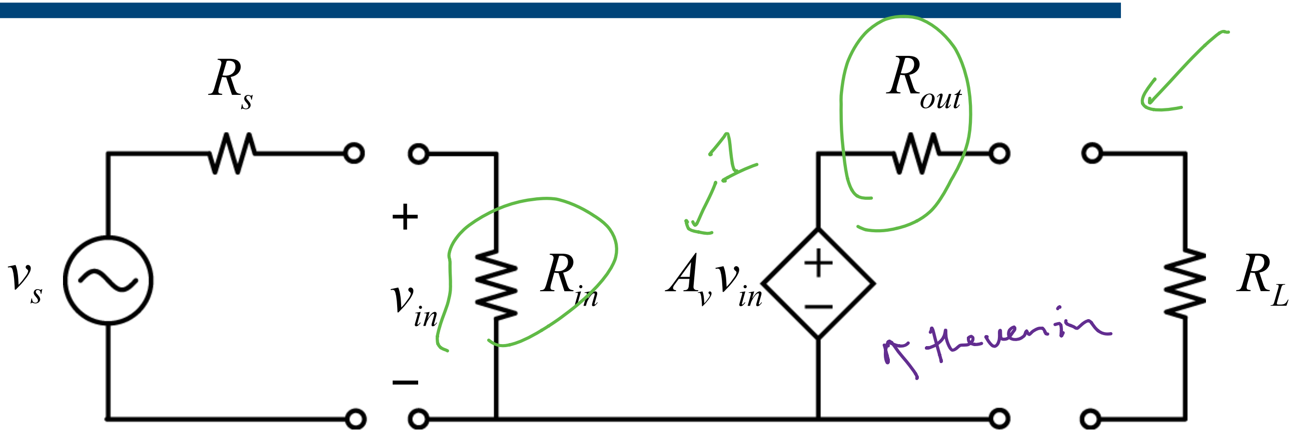
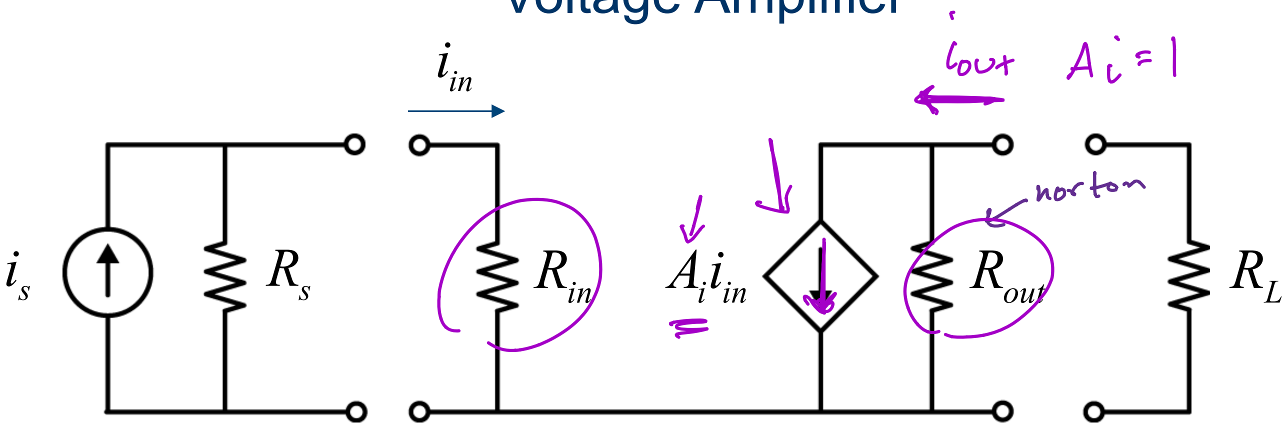
Two-Port Small-Signal Amplifiers



Voltage Amplifier



Current Amplifier

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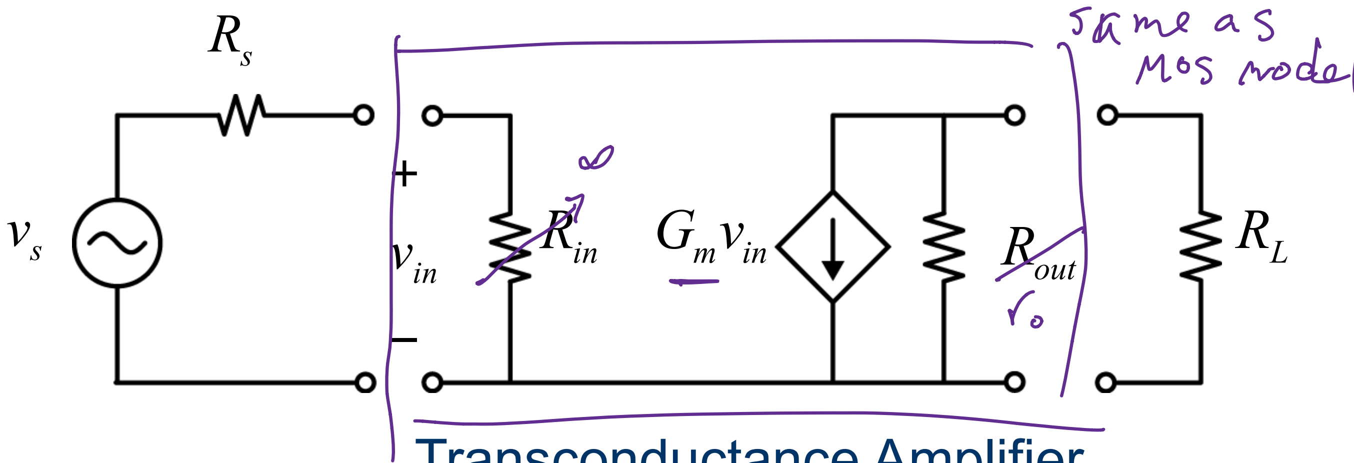
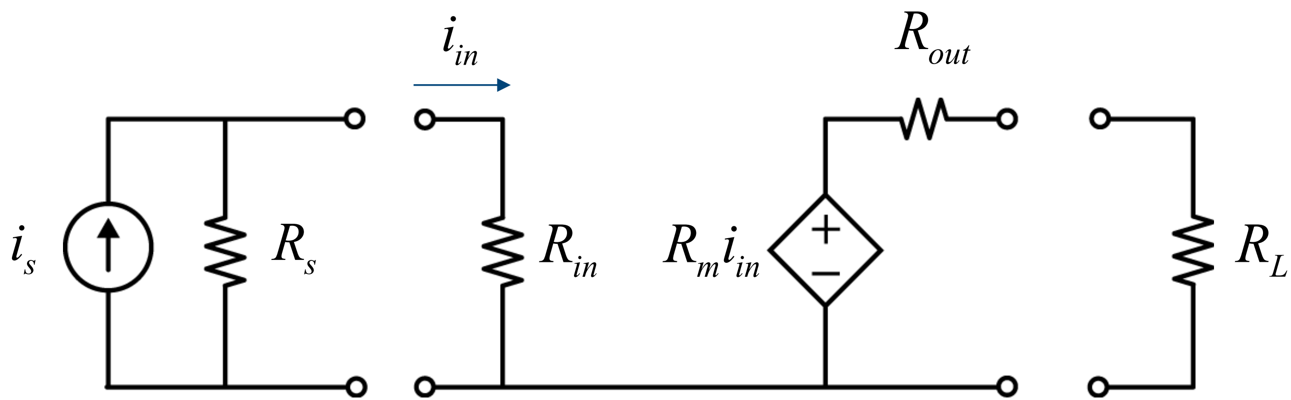
Two-Port Small-Signal Amplifiers



Transconductance Amplifier



Transresistance Amplifier

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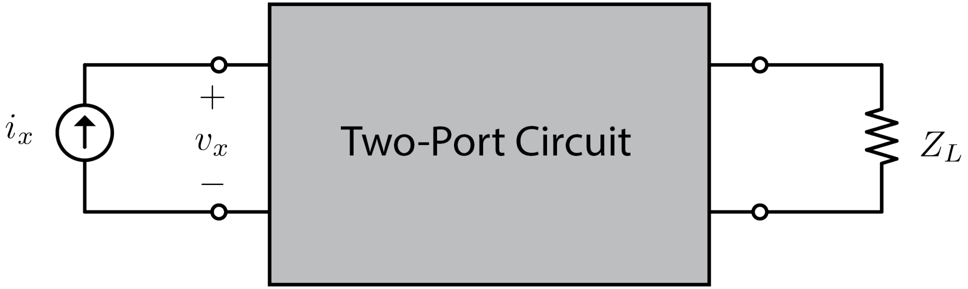
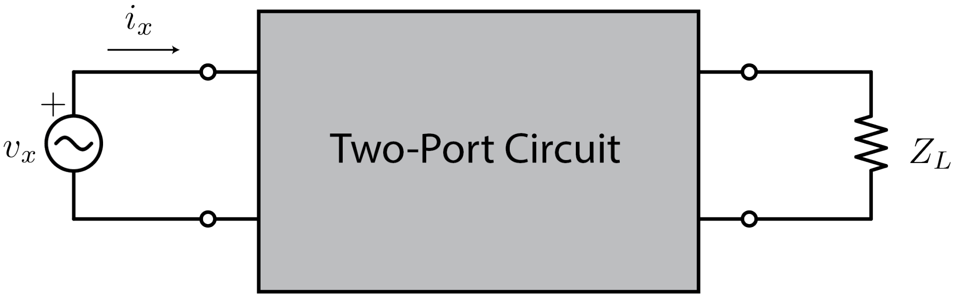
Input Impedance Z_{in}

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



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



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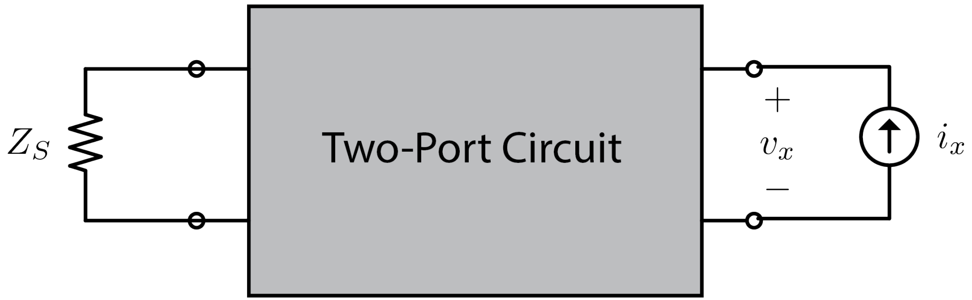
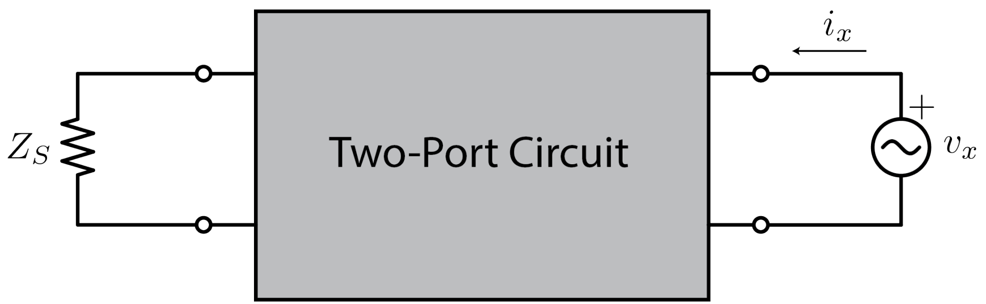
Output Impedance Z_{out}

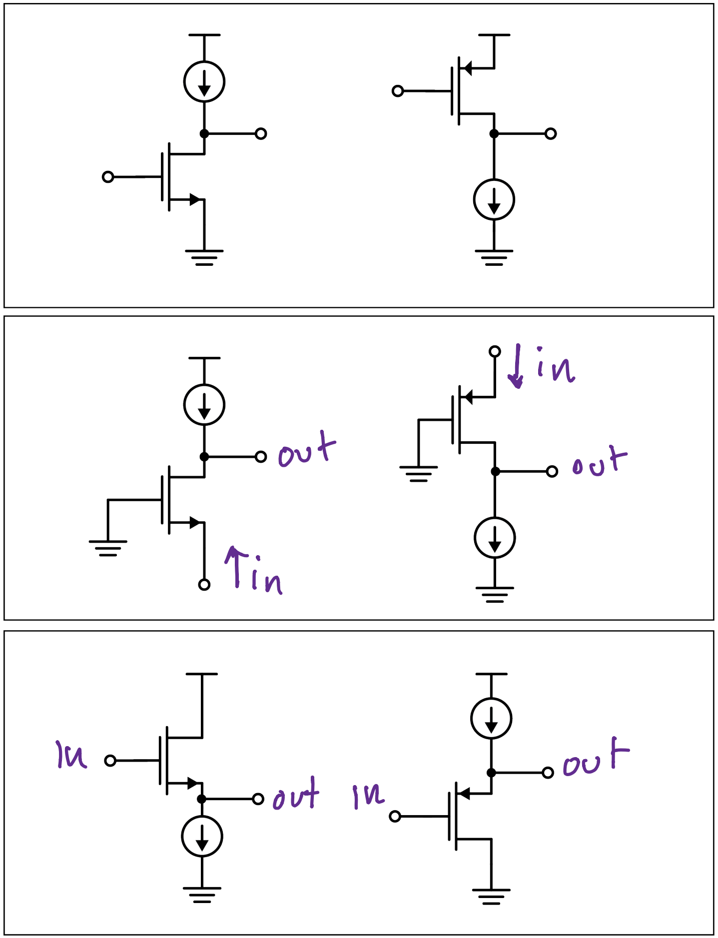
Looks like a Thevenin resistance measurement, but note that the *input* port has the *source* resistance attached

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





Single-Stage Amplifier Types



Common Source (CS)

Common Gate (CG)

Common Drain (CD)

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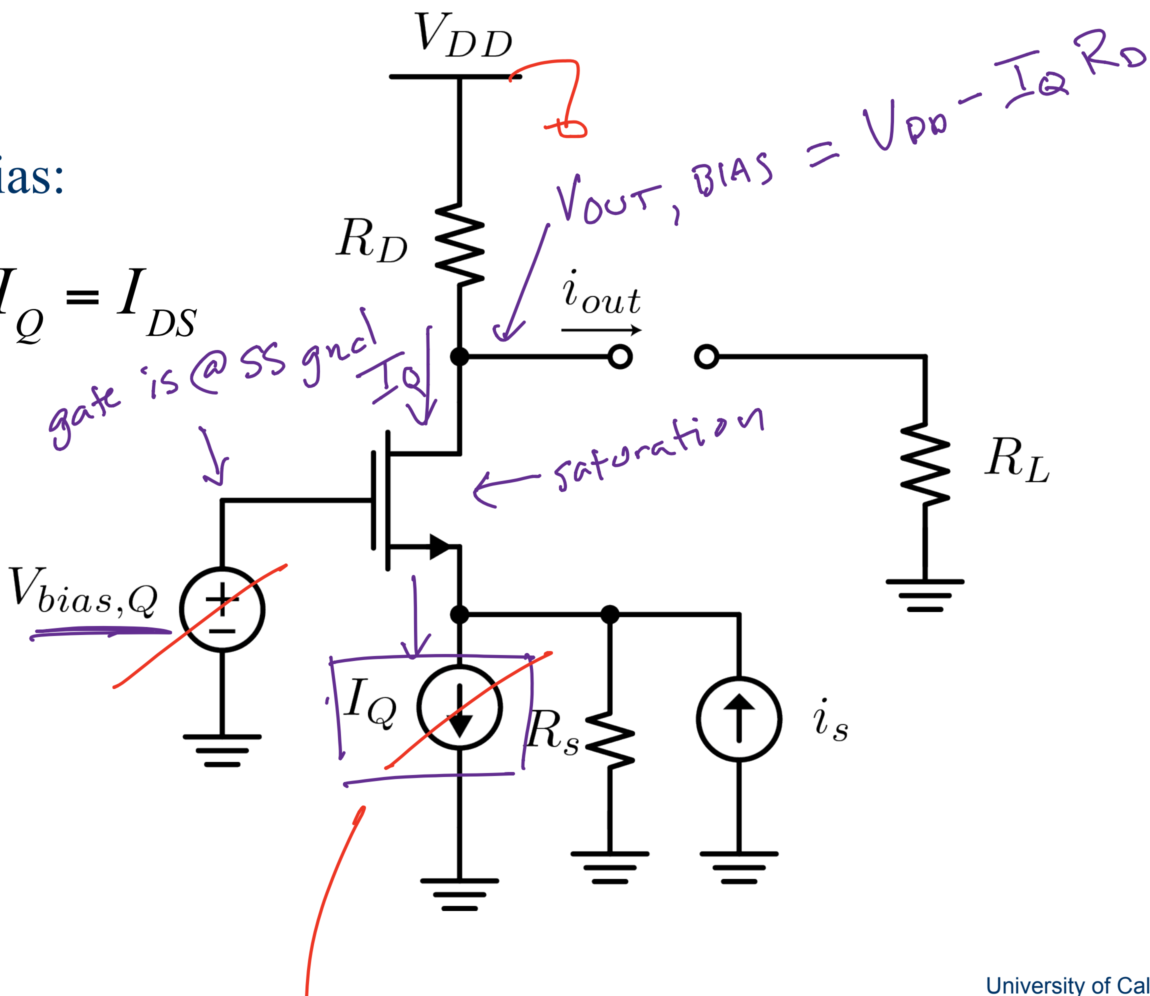
Common Gate (CG) Amplifier

DC bias:

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



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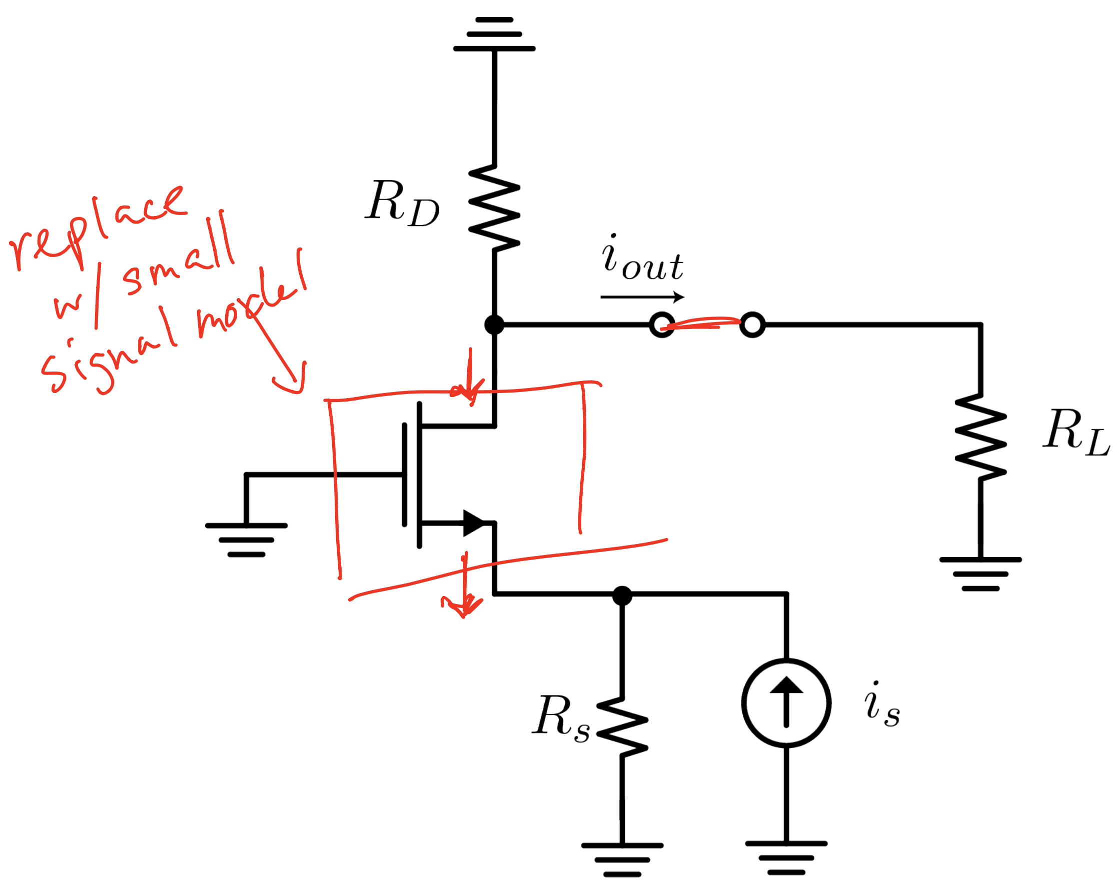
Common Gate AC Model



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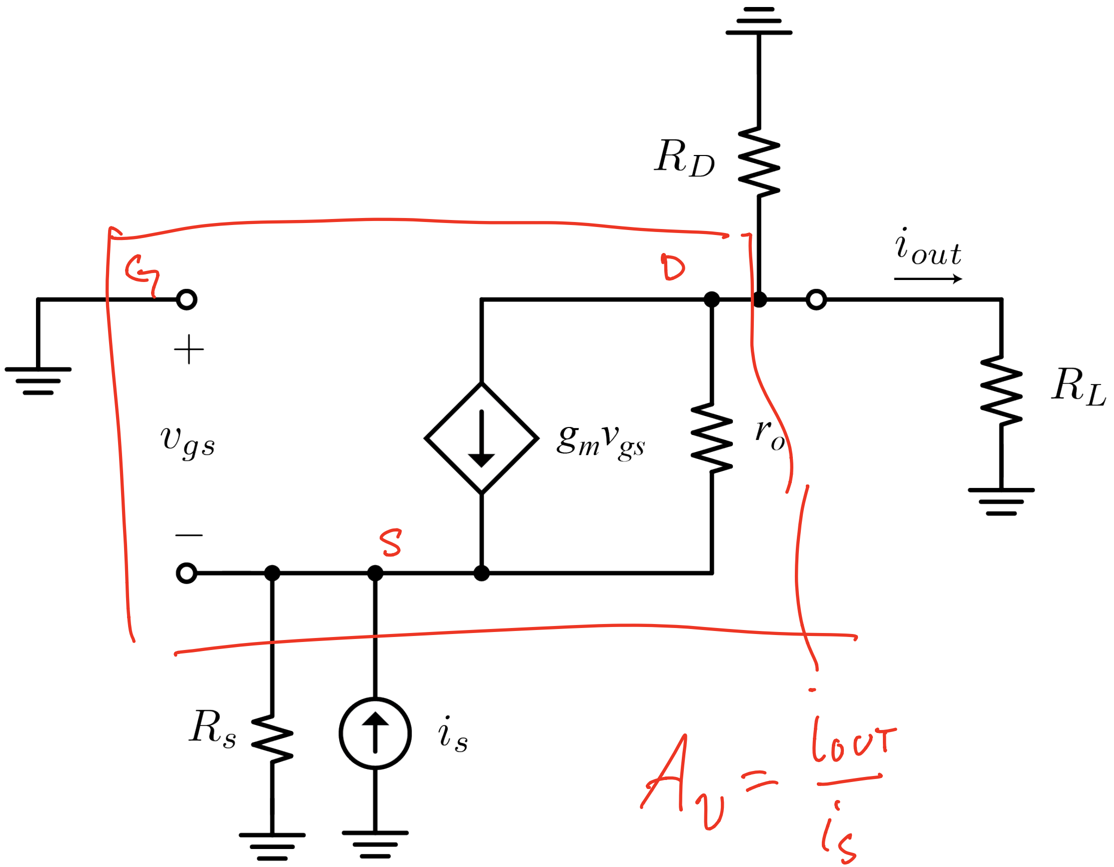
Common Gate Small Signal



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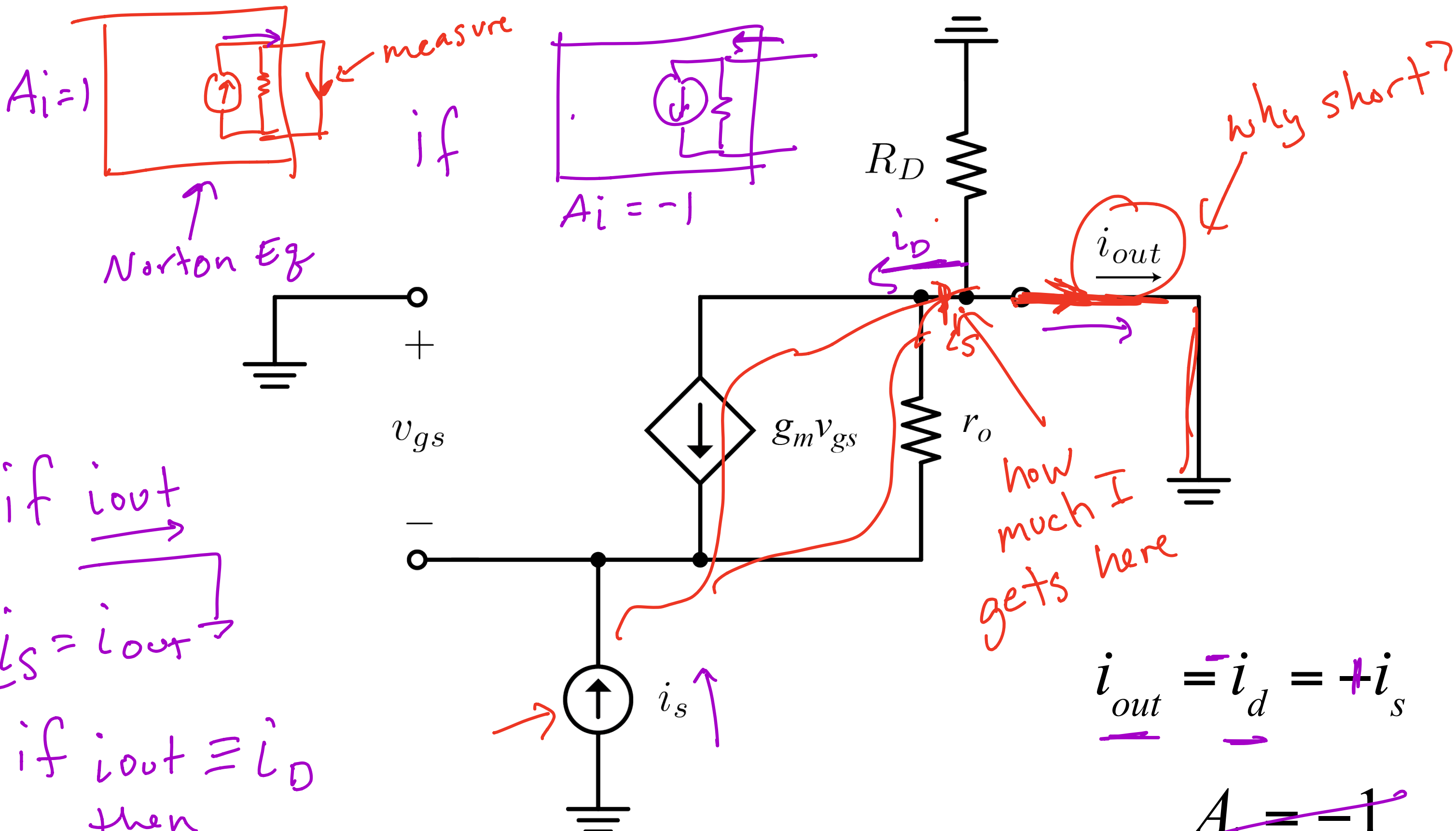
CG as a Current Amplifier: Find A_i



if i_{out} →
$i_s = i_{out}$

if $i_{out} \equiv i_D$
then
$i_s = -i_{out}$

$i_{out} = \cancel{-}i_d = \cancel{+}i_s$

$\cancel{A_i = -1}$

$A_i = 1$

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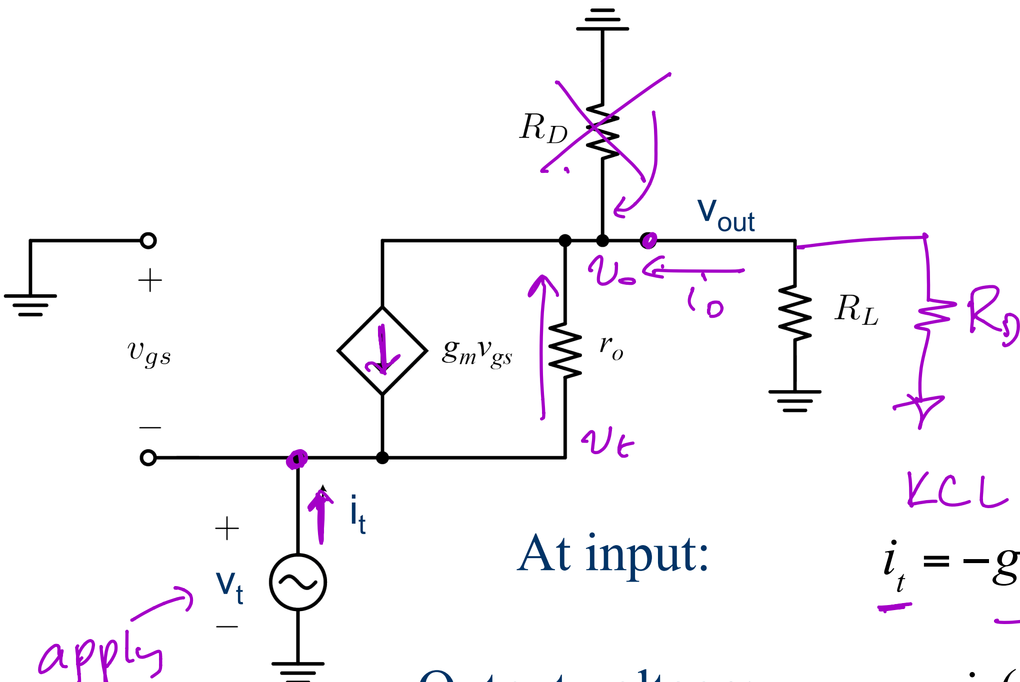
CG Input Resistance



$i_D = -i_t$

apply test votage (v_t)

measure i_t

KCL

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

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

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

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Approximations…

- We have this messy result

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

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

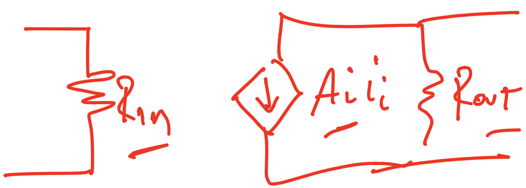
- But we don't need that much precision. Let's start approximating:

give you this information

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

r_o is large

smaller



$$\boxed{R_{in} \approx \frac{1}{g_m}}$$

← small resistance

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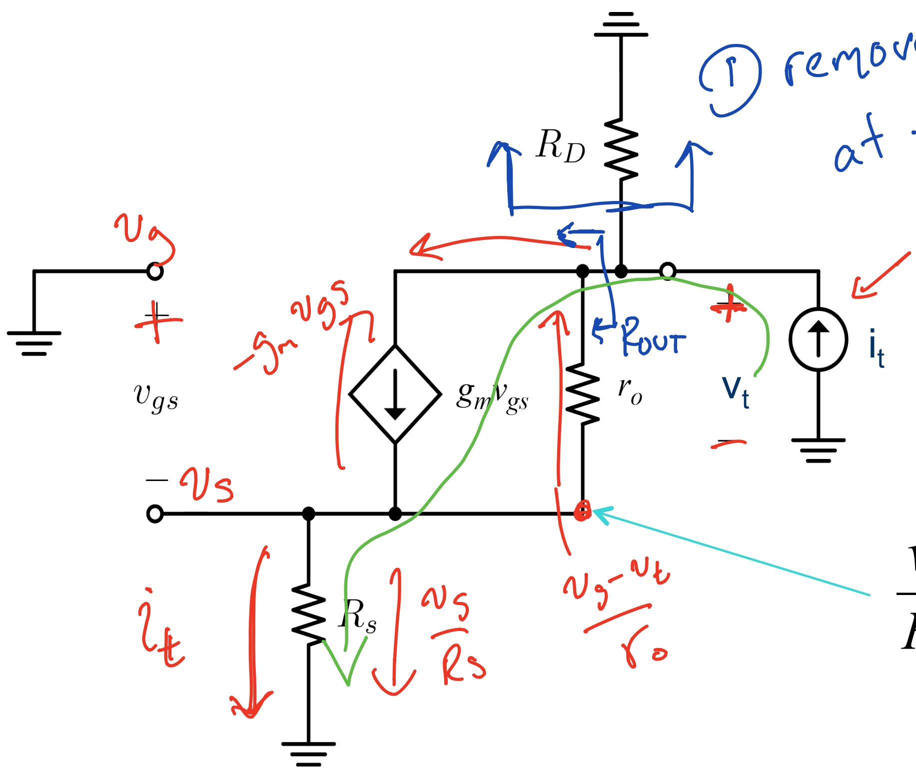
CG Output Resistance



① remove R_D at the end we know $R_D \parallel$ "R_{OUT}"

KCL

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

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

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CG Output Resistance

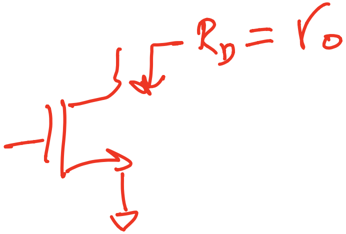
Substituting $v_s = i_t R_S$

$$R_t = \frac{v_t}{i_t}$$

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

Bring R_D back in

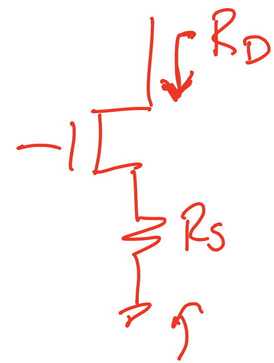
The output resistance is $(v_t / i_t) \| R_D$



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

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

resistance is large



source degeneration

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Approximating the CG R_{out}

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

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

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

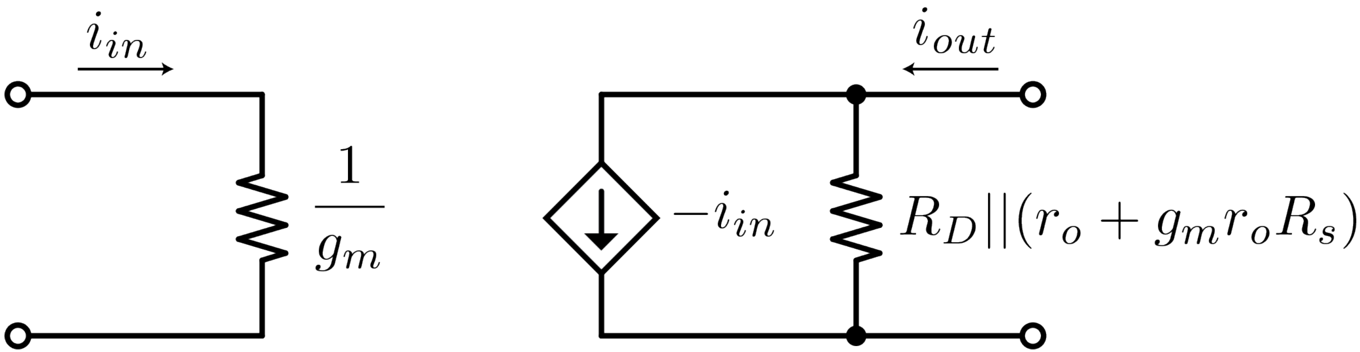
$R_S \ll r_o$

Assuming the source resistance is less than r_o,

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

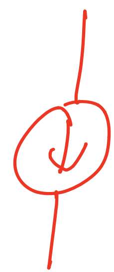
good approximation

CG Two-Port Model



Function: a current buffer

- Low Input Impedance
- High Output Impedance



resistance $= \infty$

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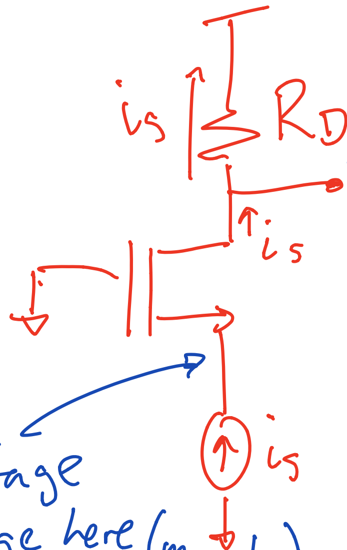
Common Gate as a "V Amplifier"

large voltage swing but input is isolated



$v_o = i_s R_D$

low Zin means voltage doesn't change here (much)

$$A = \frac{v_o}{i_s} = R_D$$

isolates output

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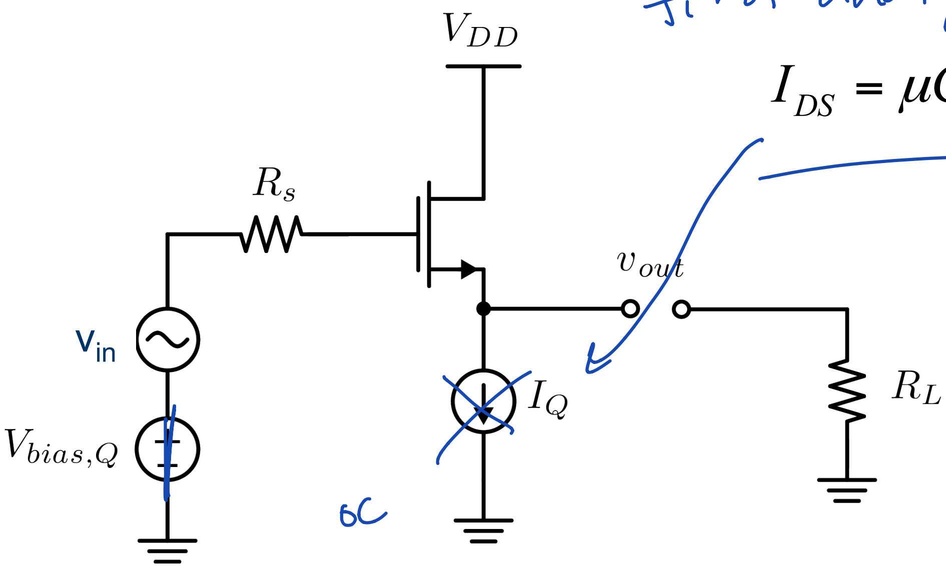
Common-Drain Amplifier

first analyze DC

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

saturation



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

Weak I_{DS} dependence

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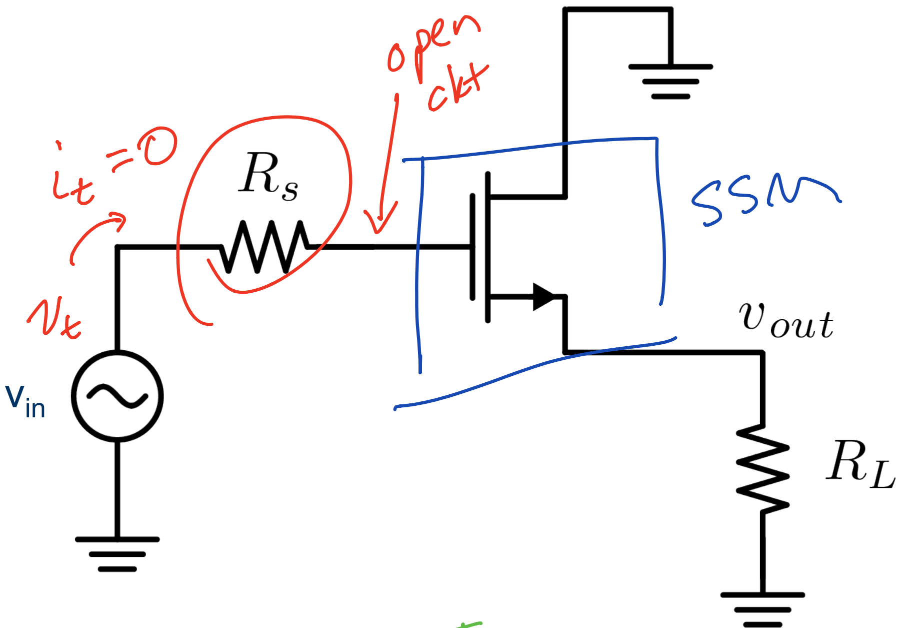
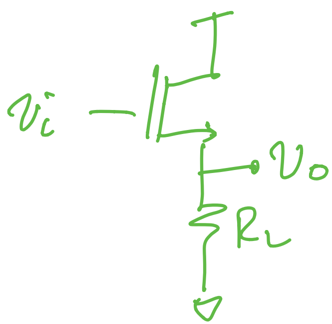
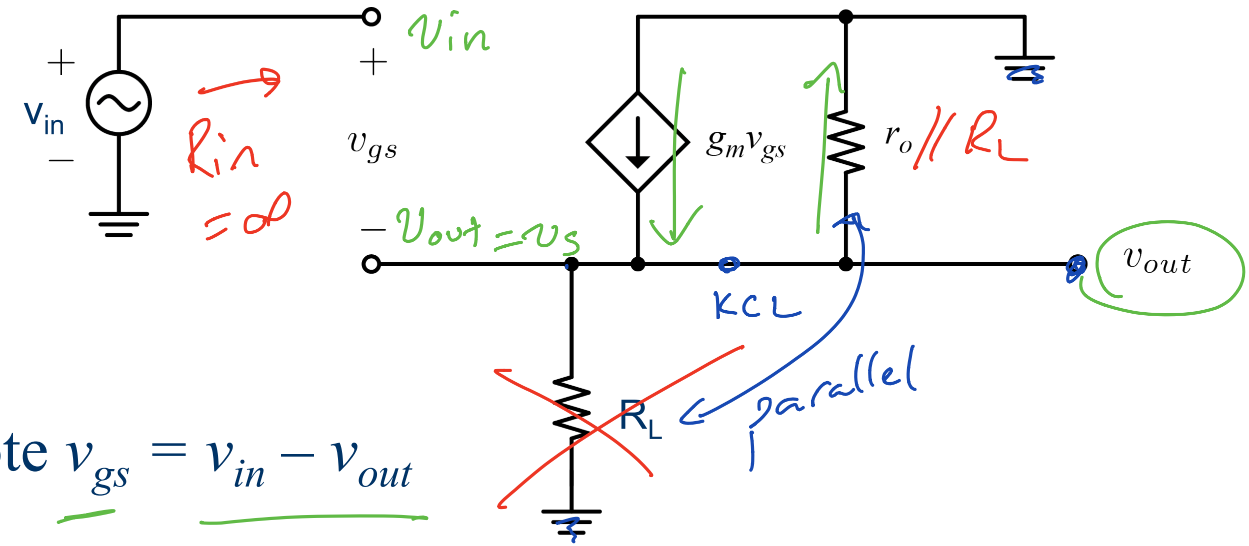
Common Drain AC Schematic





voltage buffer

CD Voltage Gain



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

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

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

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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:

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

$r_o \to$ large

$R_L \| r_o \approx R_L$

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

want R_L large

$g_m > \frac{1}{R_L} \leftarrow$ if large

$\sim 0.97 \to$ always < 1

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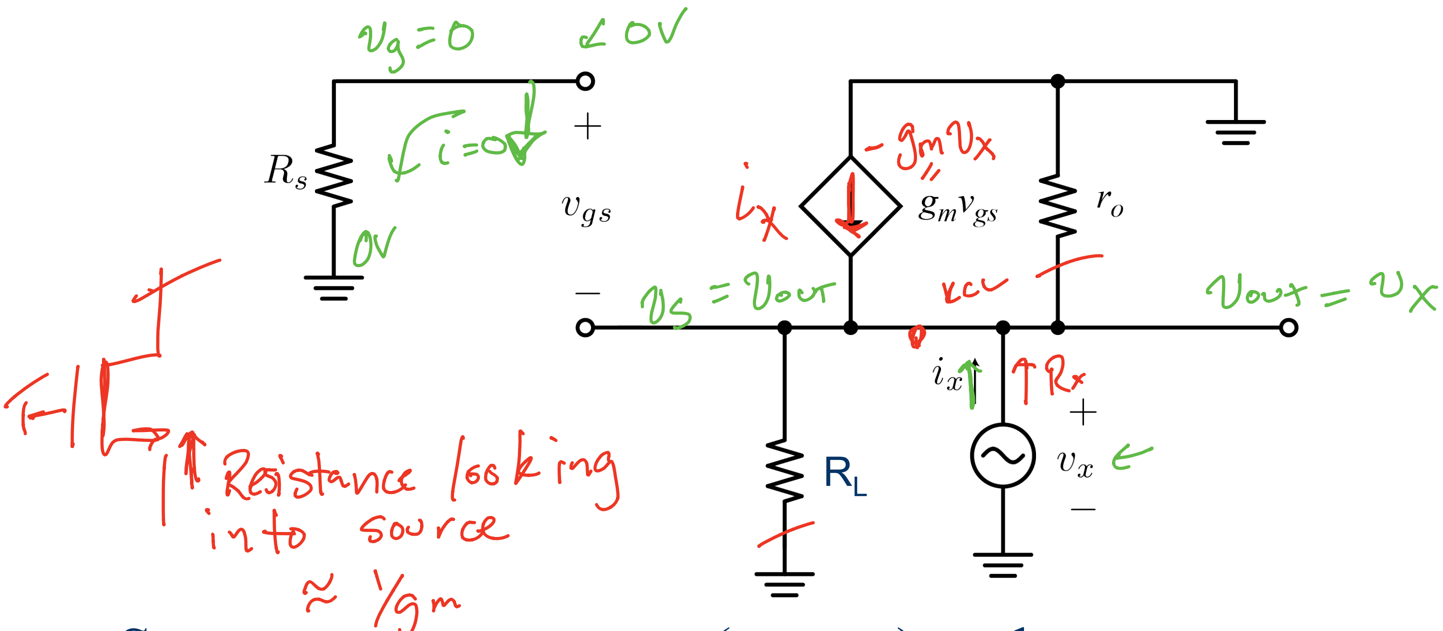
CD Output Resistance



Sum currents at output (source) node:

$$i_x = g_m v_x$$

$$\frac{v_x}{i_x} = \frac{1}{g_m}$$

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

$$R_{out} \approx \frac{1}{g_m}$$

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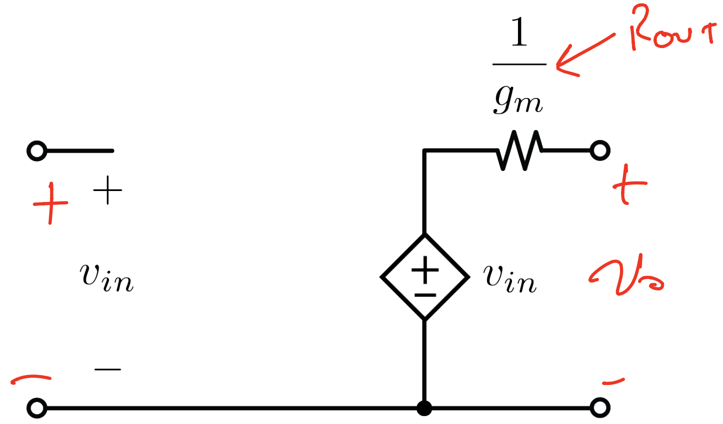
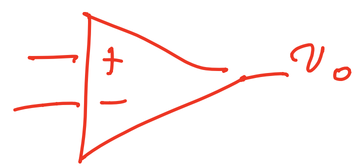
CD Output Resistance (Cont.)

$r_o \,||\, R_L$ is much larger than the inverses of the transconductances → ignore





Function: a voltage buffer

- High Input Impedance
- Low Output Impedance

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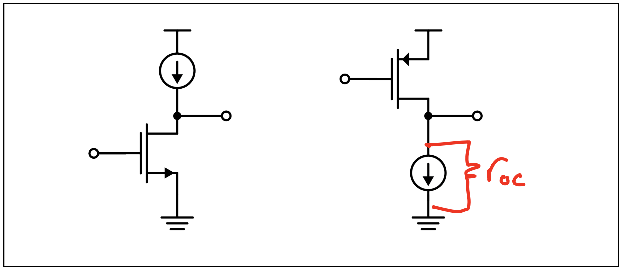
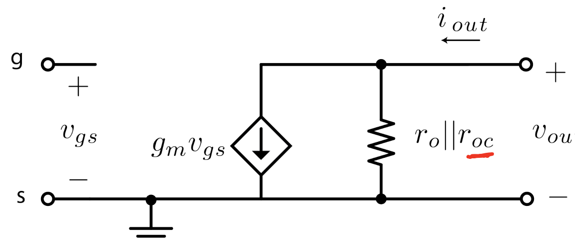
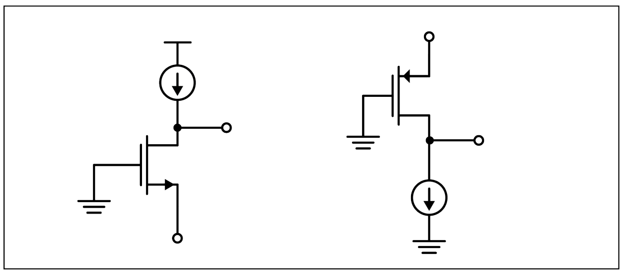
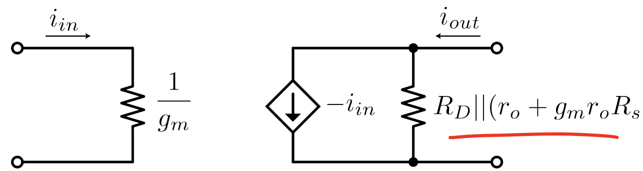
Transistor Amplifiers → Gm/V/I



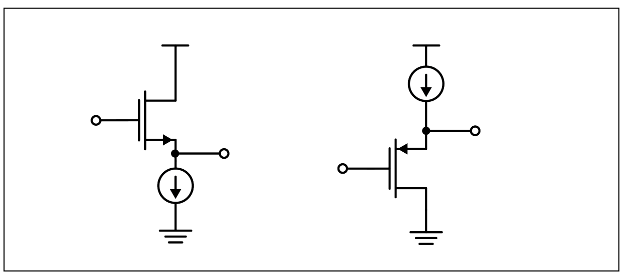


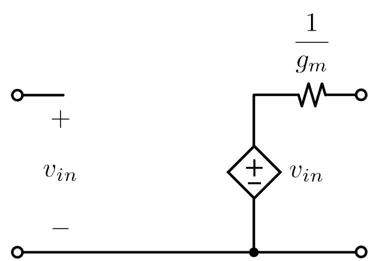
Gm Amplifier
Common Source



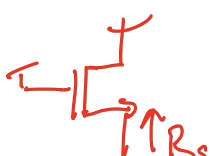


I-Buffer
Common Gate

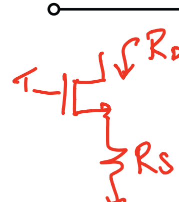




V-Buffer
Source Follower

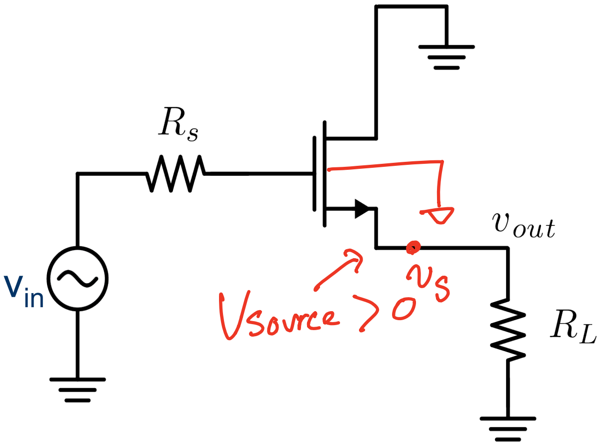


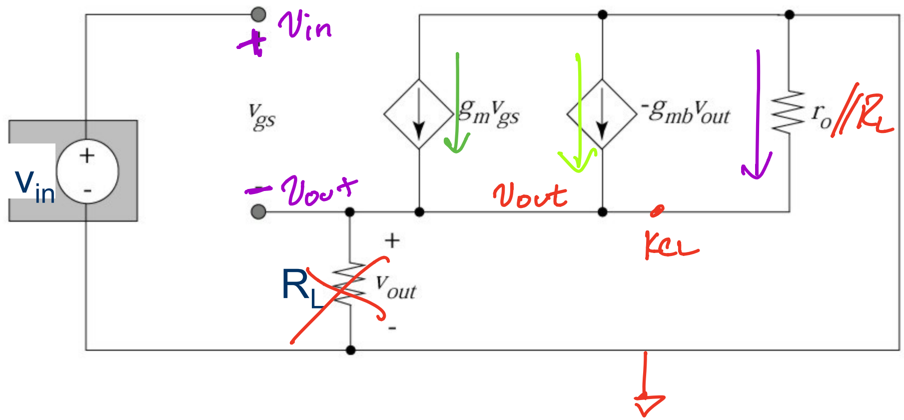
$R_s \approx 1/g_m$



$r_o + R_s + g_m r_o R_s$
$\approx r_o(1 + g_m R_s)$

Body Effect





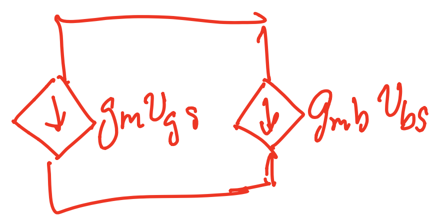
If the backgate is tied to ground you cannot ignore the body effect. How does this effect the gain?

SSM

$$\cancel{\frac{v_{out}}{R_L \| r_o}} = g_m v_{gs} - g_{mb} v_{out} - \frac{v_{out}}{R_L // r_o} = 0$$

$$\frac{v_{out}}{v_{in}} = ?$$

$$\frac{v_{out}}{R_L // r_o} + g_{mb} v_{out} = g_m v_{gs}$$



$v_{bs} = v_b - v_s$
$= 0 - v_{out}$

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

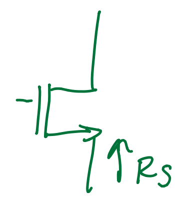
$$\frac{v_{out}}{R_L \| r_o} + g_{mb} v_{out} + g_m v_{out} = g_m v_{in}$$

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

$$\frac{v_{out}}{v_{in}} = \frac{g_m}{\underbrace{\frac{1}{R_L \| r_o}}_{\text{small}} + g_{mb} + g_m}$$

approximations

$$\frac{v_{out}}{v_{in}} \approx \frac{g_m}{g_{mb} + g_m}$$



$$\frac{1}{g_m}$$

$$\sim \frac{1}{g_m + g_{mb}}$$