Lecture 20 - Transistor Amplifiers (II)

Other Amplifier Stages

April 24, 2003

Contents:

1. Common-source amplifier (*cont.*)
2. Common-drain amplifier
3. Common-gate amplifier

Reading assignment:

Howe and Sodini, Ch. 8, §§8.7-8.9

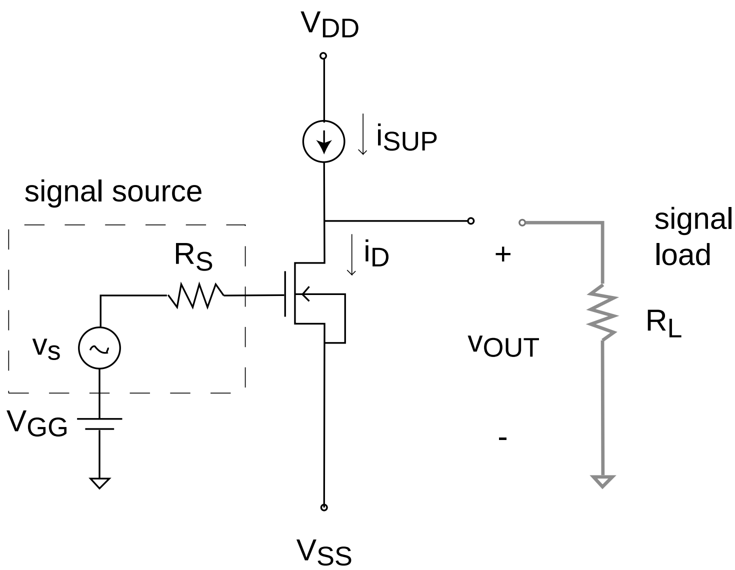
Announcement:

Extra office hours for design problem: Thursday 4/24, 2-3 PM, and Tuesday 4/29, 1-2 PM in 38-370 Athena Cluster

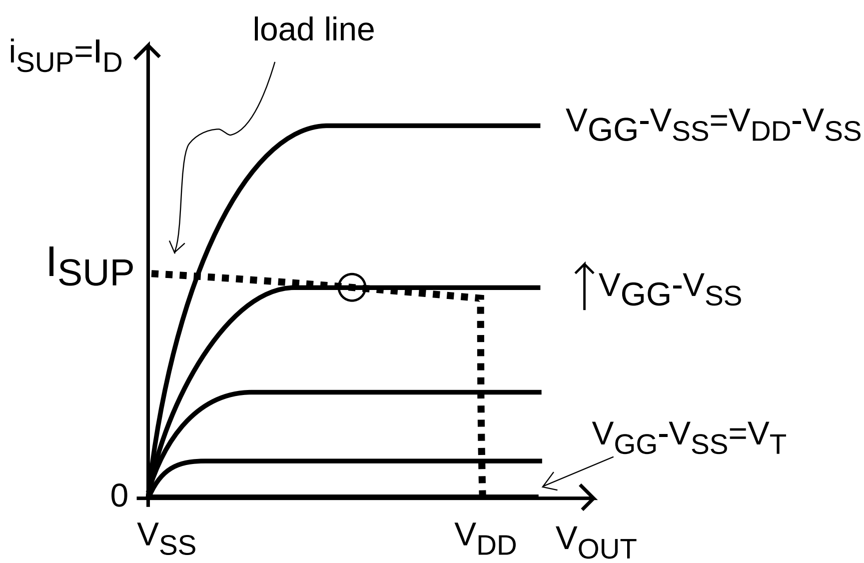
Key questions

- What other amplifier stages can one build with a single MOSFET and a current source?
- What is the uniqueness of these other stages?

1. Common-source amplifier with current-source supply



Loadline view:



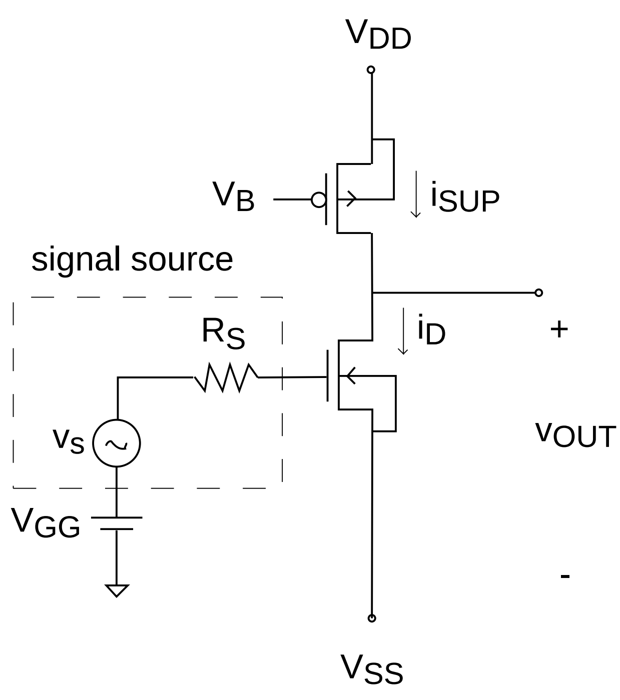
Current source characterized by high output resistance: r_{oc}.

Then, unloaded voltage gain of common-source stage:

$$|A_{vo}| = g_m(r_o//r_{oc})$$

significantly higher than amplifier with resistive supply.

Can implement current source supply by means of p-channel MOSFET:



• Relationship between circuit figures of merit and device parameters

Remember:

$$g_m = \sqrt{2\frac{W}{L}\mu_n C_{ox} I_D}$$

$$r_o \simeq \frac{1}{\lambda_n I_D} \propto \frac{L}{I_D}$$

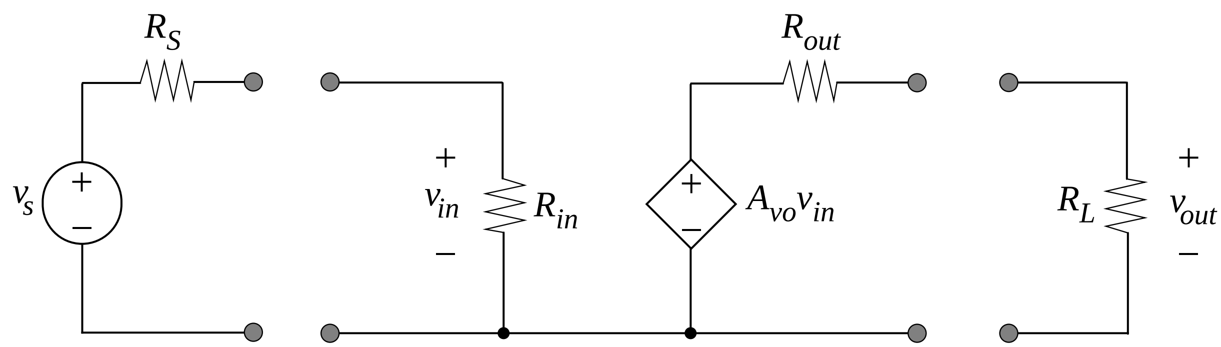
Then:

Device * Parameters	Circuit Parameters		
	$\lvert A_{vo}\rvert$	R_{in}	R_{out}
	$g_m(r_o//r_{oc})$	∞	$r_o//r_{oc}$
$I_{SUP} \uparrow$	$\downarrow$	-	$\downarrow$
$W \uparrow$	$\uparrow$	-	-
$\mu_n C_{ox} \uparrow$	$\uparrow$	-	-
$L \uparrow$	$\uparrow$	-	$\uparrow$

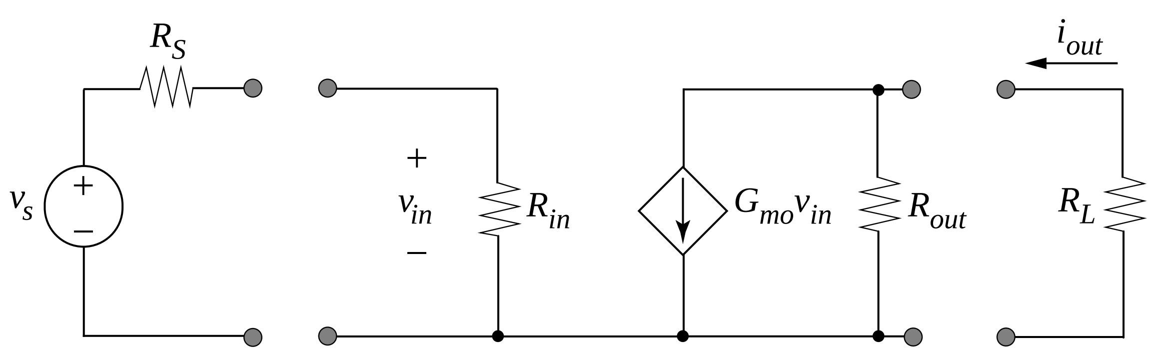
* adjustments are made to V_{GG} so none of the other parameters change

CS amp with current supply source is good voltage amplifier (R_{in} high and $|A_v|$ high), but R_{out} high too $\Rightarrow$ voltage gain degraded if $R_L \ll r_o//r_{oc}$.

Common-source amplifier is acceptable *voltage* amplifier (want high R_{in}, high A_{vo}, low R_{out}):



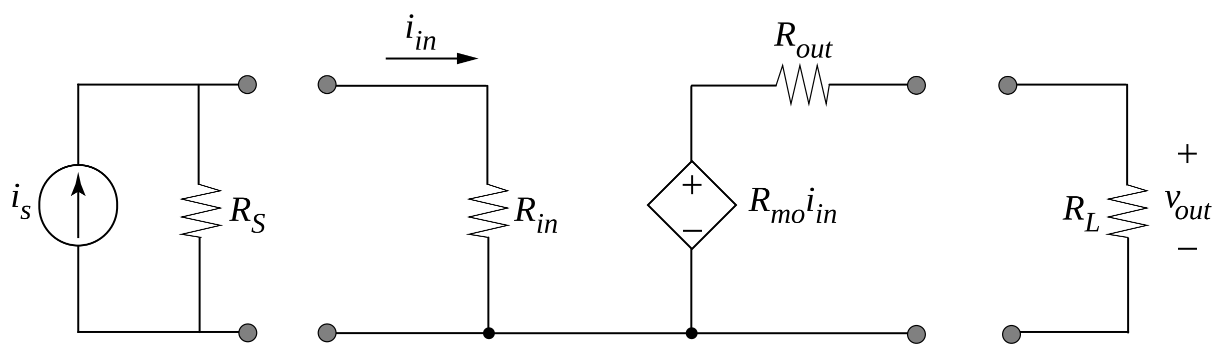
... but excellent *transconductance* amplifier (want high R_{in}, high G_{mo}, high R_{out}):



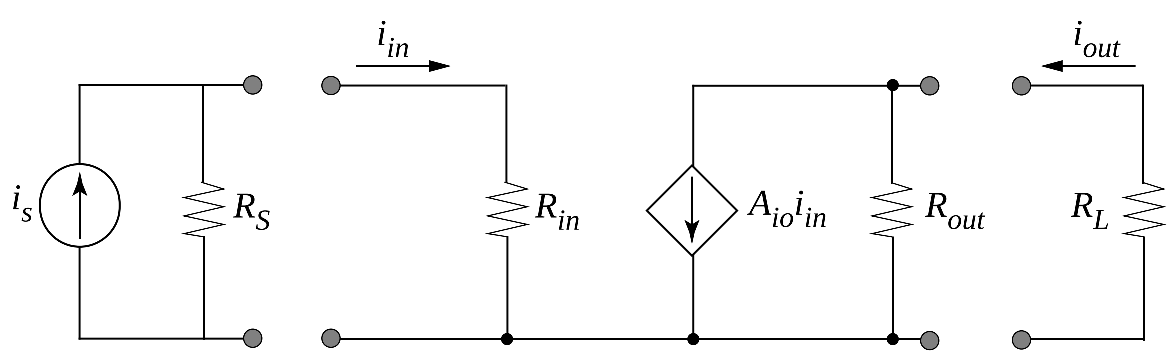
For common-source amplifier:

$$G_{mo} = g_m$$

Common-source amplifier does not work as *transresistance* amplifier (want low R_{in}, high R_{mo}, low R_{out}):

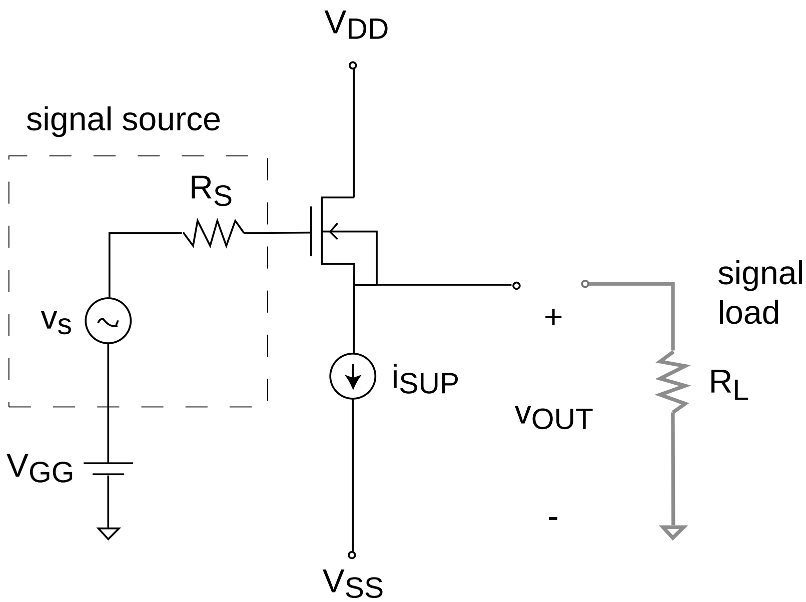


nor as *current* amplifier
(want low R_{in}, high A_{io}, high R_{out}):



Need new amplifier configurations.

2. Common-drain amplifier

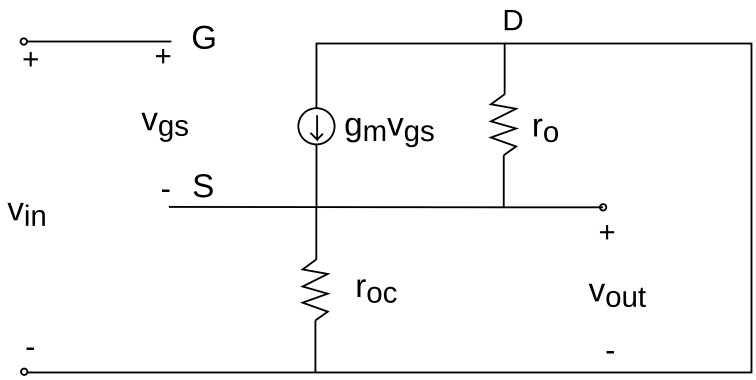


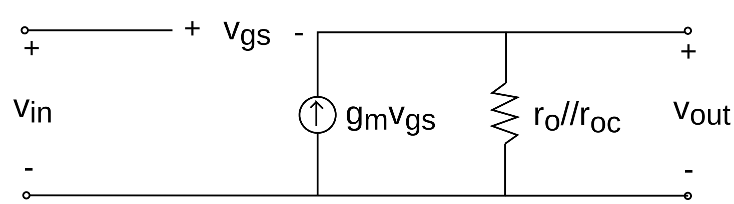
How does it work?

- V_{GG}, I_{SUP}, and W/L selected to bias MOSFET in saturation, obtain desired output bias point, and desired output swing.
- $v_G \uparrow \Rightarrow\ i_D$ can't change $\Rightarrow\ v_{OUT} \uparrow$ (*source follower*)
- to first order, no voltage gain: $v_{out} \simeq v_s$
- but R_{out} small: effective *voltage buffer* stage (good for making voltage amp in combination with common-source stage).

□ *Small-signal analysis*

Unloaded small-signal equivalent circuit model:





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

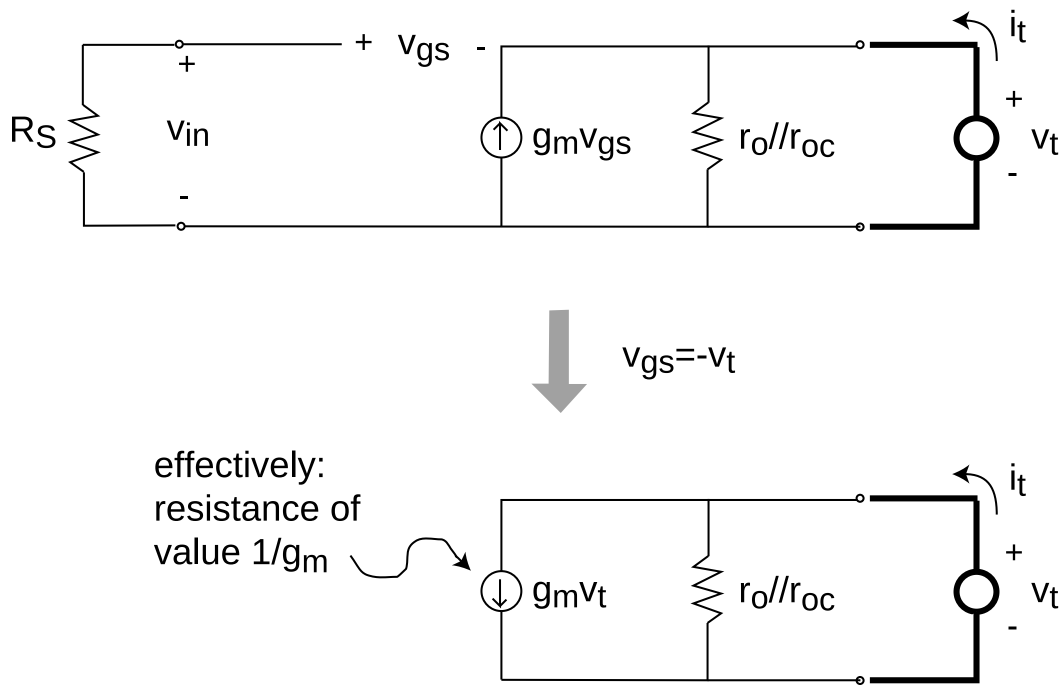
$$v_{out} = g_m v_{gs}(r_o//r_{oc})$$

Then:

$$A_{vo} = \frac{g_m}{g_m + \frac{1}{r_o//r_{oc}}} \simeq 1$$

Input impedance: $R_{in} = \infty$

Output impedance:



$$R_{out} = \frac{1}{g_m + \frac{1}{r_o//r_{oc}}} \simeq \frac{1}{g_m}$$

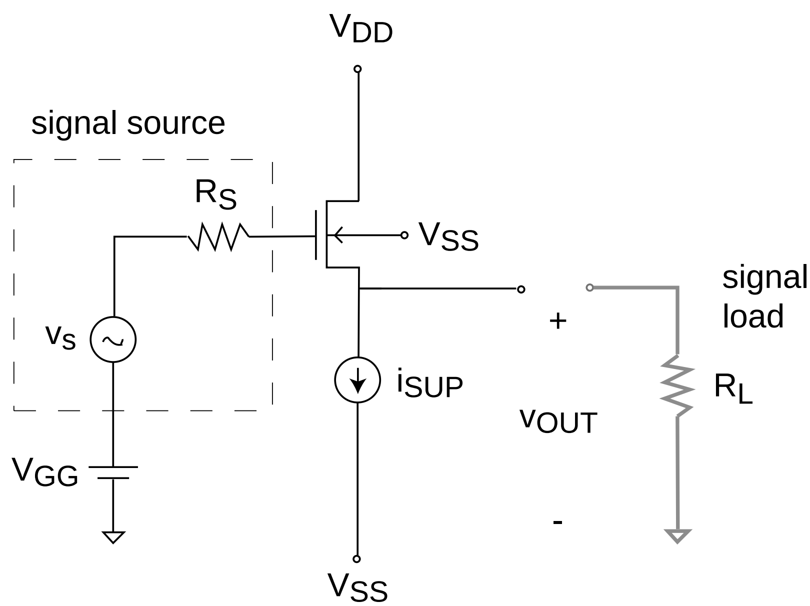
small!

Loaded voltage gain:

$$A_v = A_{vo}\frac{R_L}{R_L + R_{out}} \simeq \frac{R_L}{R_L + \frac{1}{g_m}} \simeq 1$$

□ Effect of back bias:

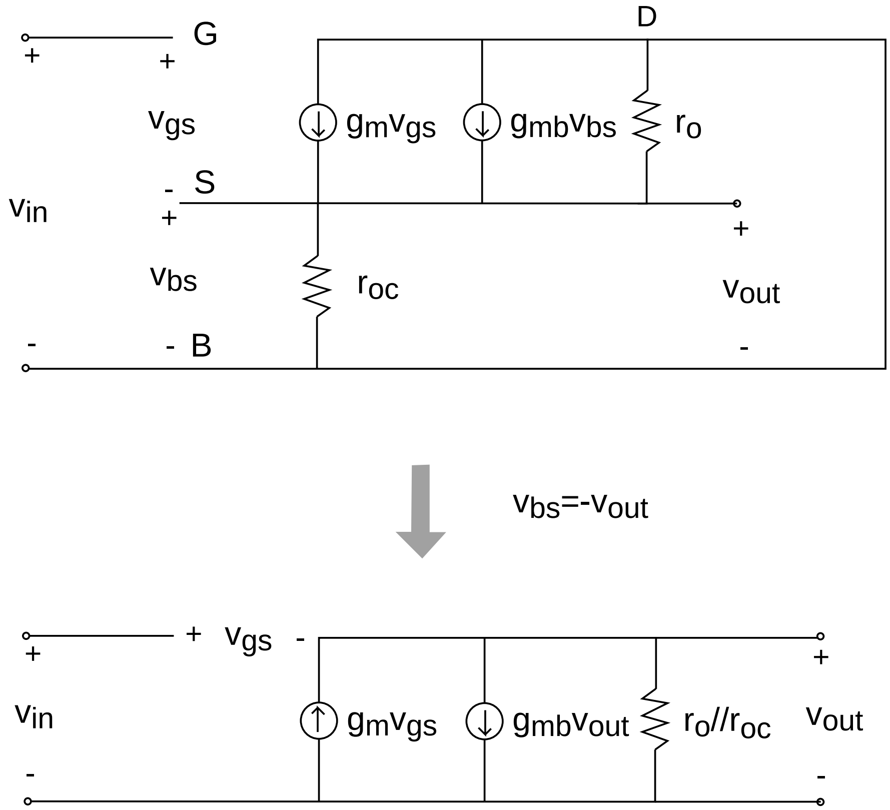
If MOSFET not fabricated on isolated p-well, then body is tied up to wafer substrate (connected to V_{SS}):



Two consequences:

- Bias affected: V_T depends on $V_{BS} = V_{SS} - V_{OUT} \neq 0$
- Small-signal figures of merit affected: signal shows up between B and S ($v_{bs} = -v_{out}$).

Small-signal equivalent circuit model:



$$A_{vo} = \frac{g_m}{g_m + g_{mb} + \frac{1}{r_o//r_{oc}}} \simeq \frac{g_m}{g_m + g_{mb}} < 1$$

Also:

$$R_{out} = \frac{1}{g_m + g_{mb} + \frac{1}{r_o//r_{oc}}} \simeq \frac{1}{g_m + g_{mb}}$$

□ Relationship between circuit figures of merit and device parameters:

$$g_m = \sqrt{2\frac{W}{L}\mu_n C_{ox} I_D}$$

$$g_{mb} = \frac{\gamma}{2\sqrt{-2\phi_p - V_{BS}}} g_m$$

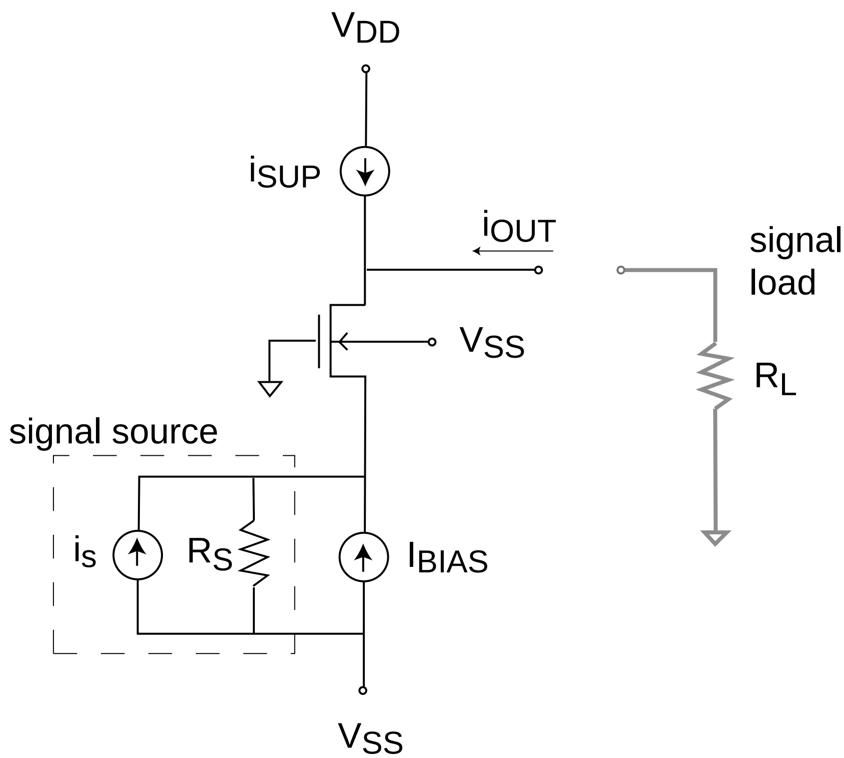
Device * Parameters	Circuit Parameters		
	$\lvert A_{vo}\rvert$	R_{in}	R_{out}
	$\frac{g_m}{g_m+g_{mb}}$	∞	$\frac{1}{g_m+g_{mb}}$
$I_{SUP} \uparrow$	-	-	$\downarrow$
$W \uparrow$	-	-	$\downarrow$
$\mu_n C_{ox} \uparrow$	-	-	$\downarrow$
$L \uparrow$	-	-	$\uparrow$

* adjustments are made to V_{GG} so none of the other parameters change

CD amp useful as a *voltage buffer* to drive small loads (in a multistage amp, other stages will be used to provide voltage gain).

3. Common-gate amplifier

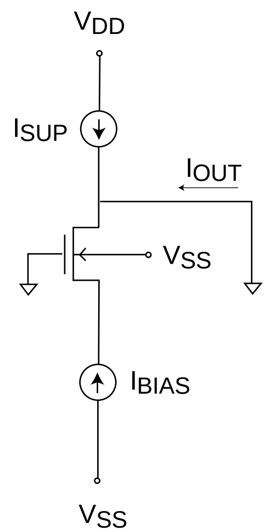
Need to handle current-mode signal sources:



How does it work?

- since source is signal input terminal, body cannot be tied up to source (C_{db} is significant)
- i_{SUP}, I_{BIAS}, and W/L selected to bias MOSFET in saturation, obtain desired output bias point, and desired output swing
- $i_S \uparrow \Rightarrow\ i_D \downarrow \Rightarrow\ i_{OUT} \downarrow$
- no current gain: $i_s = -i_{out}$ (*current buffer*)

□ *Bias*: select I_{SUP}, I_{BIAS}, and W/L to get proper quiescent I_{OUT} and keep MOSFET in saturation.



$$I_{SUP} + I_{OUT} + I_{BIAS} = 0$$

Select bias so that $I_{OUT} = 0 \Rightarrow V_{OUT} = 0$.

Assume MOSFET in saturation (no channel modulation):

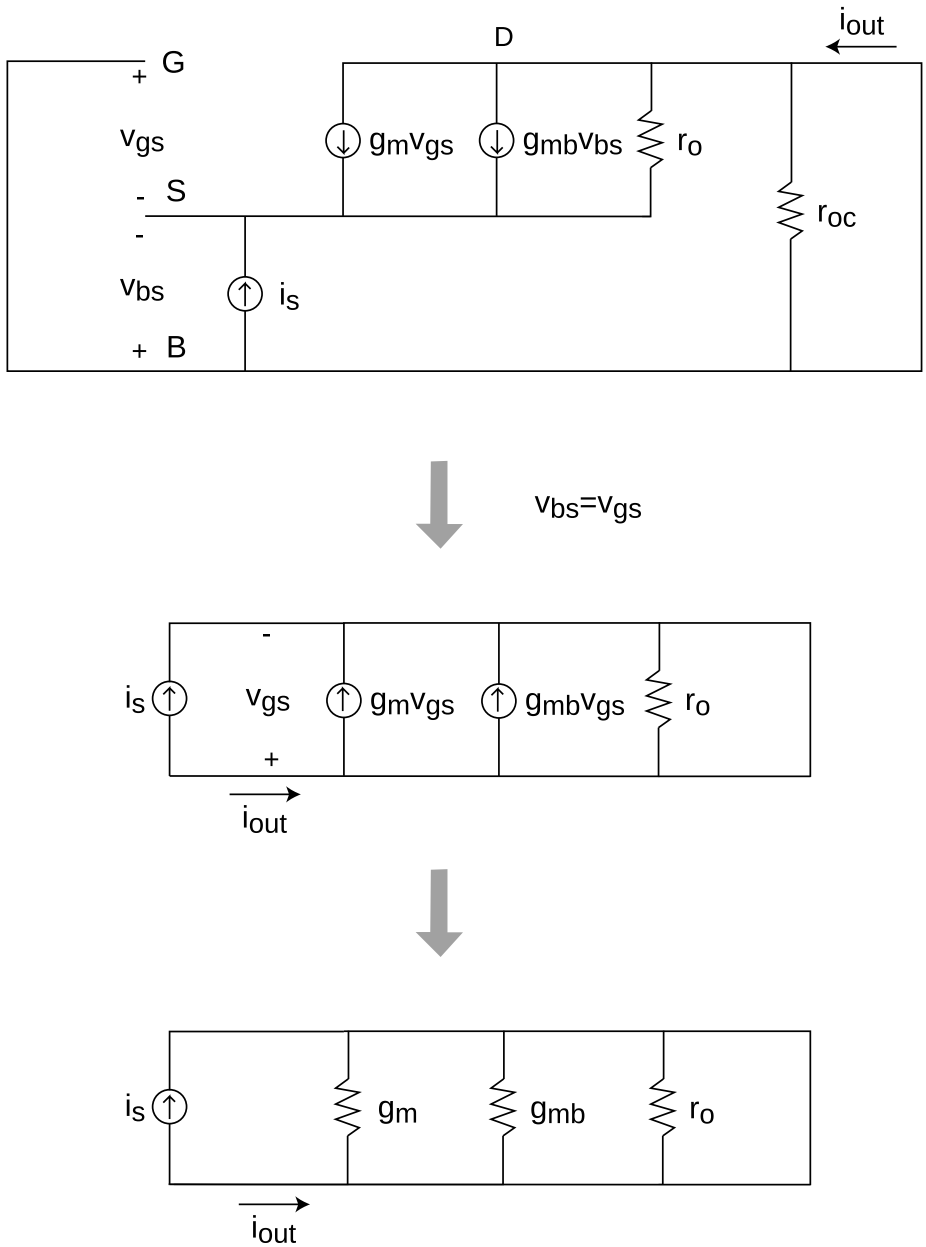
$$I_D = \frac{W}{2L}\mu_n C_{ox}(V_{GS} - V_T)^2 = I_{SUP} = -I_{BIAS}$$

but V_T depends on V_{BS}:

$$V_T = V_{To} + \gamma_n(\sqrt{-2\phi_p - V_{BS}} - \sqrt{-2\phi_p})$$

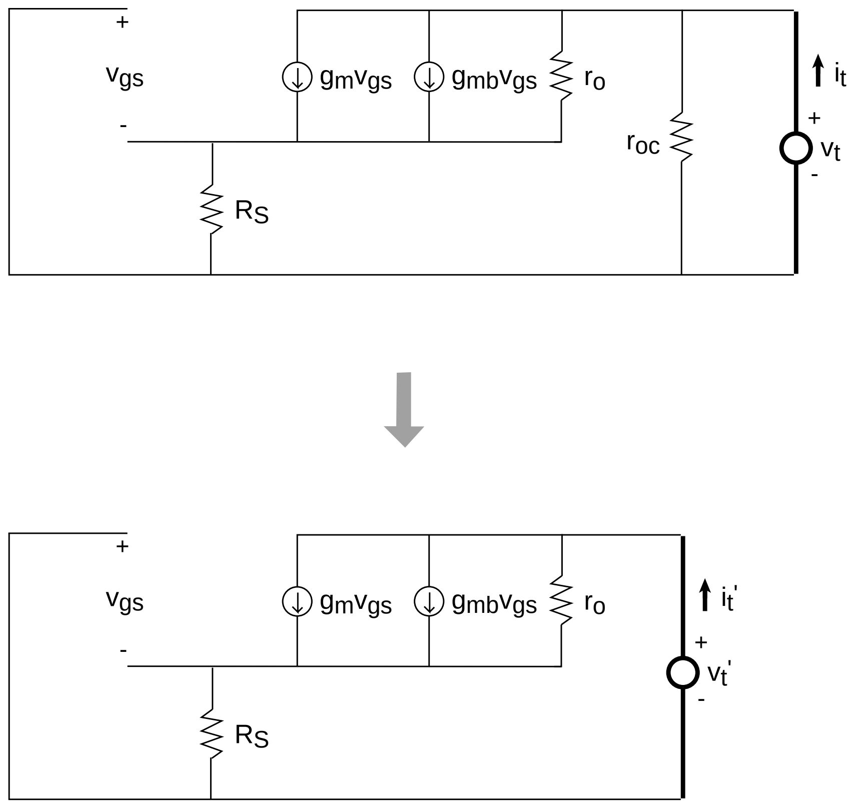
Must solve these two equations iteratively to get V_S.

□ *Small-signal circuit* (unloaded)



i_s

Output resistance:



Do KCL on input node:

$$i_t' - g_m v_{gs} - g_{mb} v_{gs} - \frac{v_t' + v_{gs}}{r_o} = 0$$

Notice also:

$$v_{gs} = -i_t' R_S$$

Then:

$$R_{out} = r_{oc} // \{r_o[1 + R_S(g_m + g_{mb} + \frac{1}{r_o})]\} \simeq r_{oc} // [r_o(1 + g_m R_S)]$$

Very large, because of the feedback effect of R_S.

Summary of MOSFET amplifier stages:

stage	$A_{vo},\ G_{mo},\ A_{io}$	R_{in}	R_{out}	**key function**
common source	$G_{mo} = g_m$	∞	$r_o//r_{oc}$	transconductance amp.
common drain	$A_{vo} \simeq \frac{g_m}{g_m+g_{mb}}$	∞	$\frac{1}{g_m+g_{mb}}$	voltage buffer
common gate	$A_{io} \simeq -1$	$\frac{1}{g_m+g_{mb}}$	$r_{oc}//[r_o(1+g_mR_S)]$	current buffer

In order to design amplifiers with suitable performance, need to combine these stages $\Rightarrow$ *multistage amplifiers*

Key conclusions

Different MOSFET stages designed to accomplish different goals:

- *Common-source stage*:
  - large voltage gain and transconductance, high input resistance, large output resistance
  - excellent transconductance amplifier, reasonable voltage amplifier
- *Common-drain stage*:
  - no voltage gain, but high input resistance and low output resistance
  - good voltage buffer
- *Common-gate stage*:
  - no current gain, but low input resistance and high output resistance
  - good current buffer