

Lecture 25 - Frequency Response of Amplifiers (III)

OTHER AMPLIFIER STAGES

December 8, 2005

Contents:

1. Frequency response of common-drain amplifier
2. Cascode amplifier

Reading assignment:

Howe and Sodini, Ch. 9, §9.3.3; Ch. 10, §§10.5, 10.7

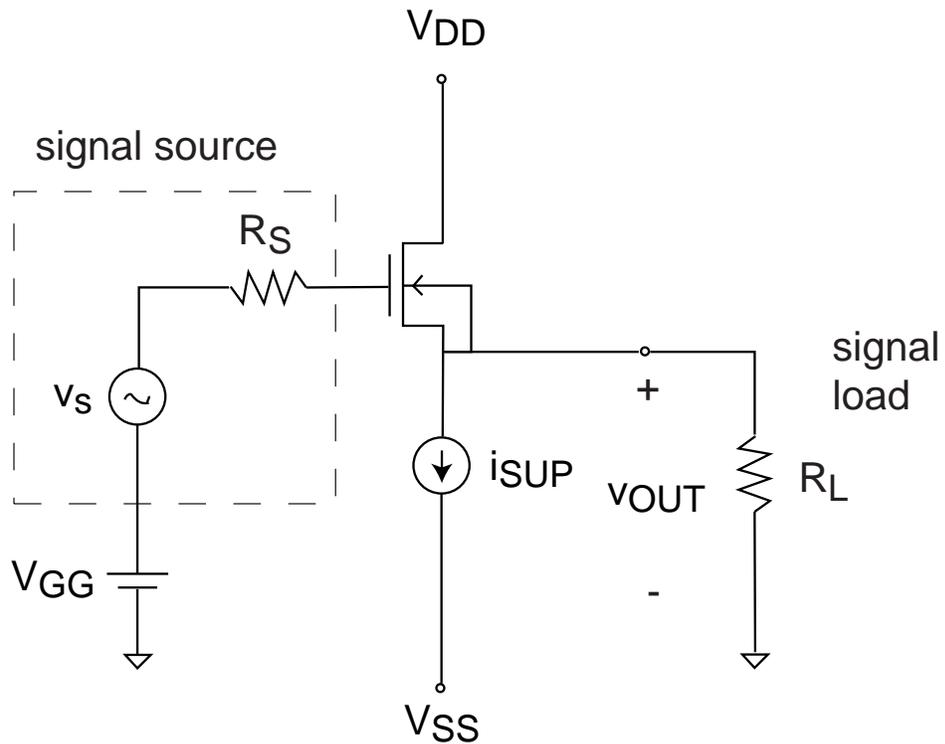
Announcement:

Final exam: December 19, 1:30-4:30 PM, duPont; open book, calculator required; entire subject under examination but emphasis on lectures #19-26.

Key questions

- Do all amplifier stages suffer from the Miller effect?
- Is there something unique about the common drain stage in terms of frequency response?
- Can we make a transconductance amplifier with a large bandwidth?

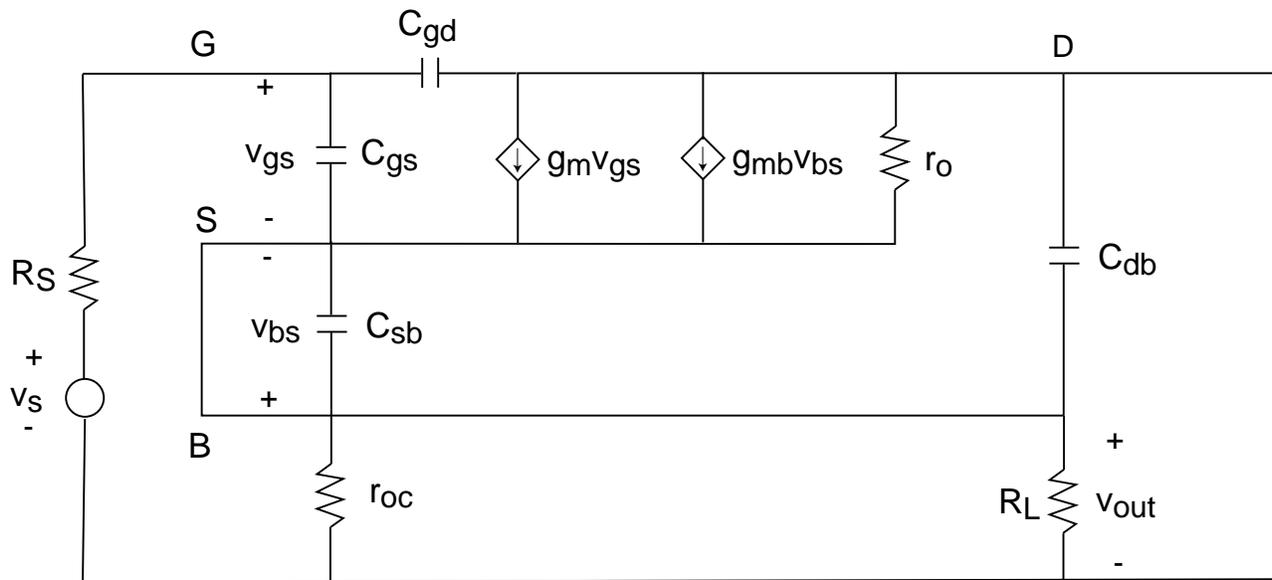
1. Frequency response of common-drain amplifier



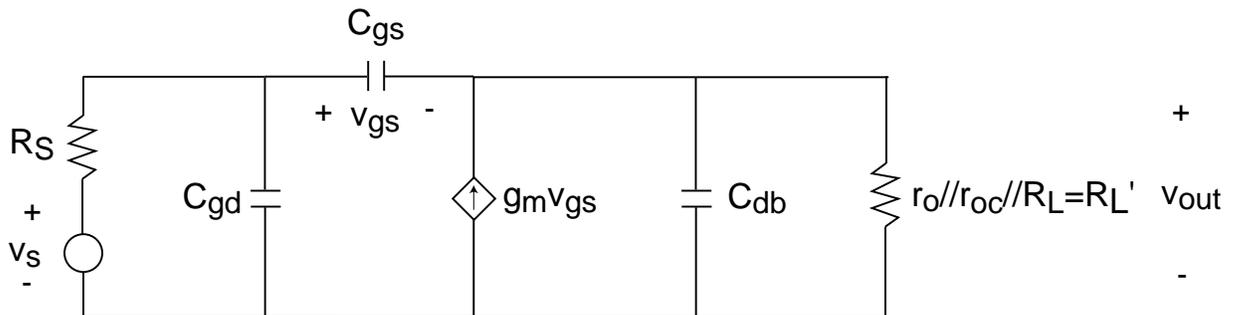
Features:

- voltage gain $\simeq 1$
- high input resistance
- low output resistance
- \Rightarrow good voltage buffer

High-frequency small-signal model:



↓ $v_{bs}=0$



$$A_{v,LF} = \frac{g_m R'_L}{1 + g_m R'_L} \leq 1$$

Compute bandwidth by open-circuit time constant technique:

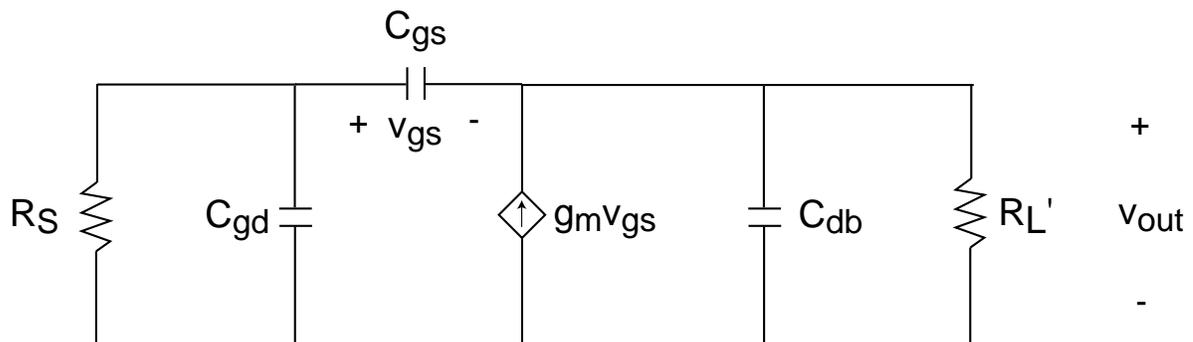
1. shut-off all independent sources,
2. compute Thevenin resistance R_{Ti} seen by each C_i with all other C 's open,
3. compute open-circuit time constant for C_i as

$$\tau_i = R_{Ti}C_i$$

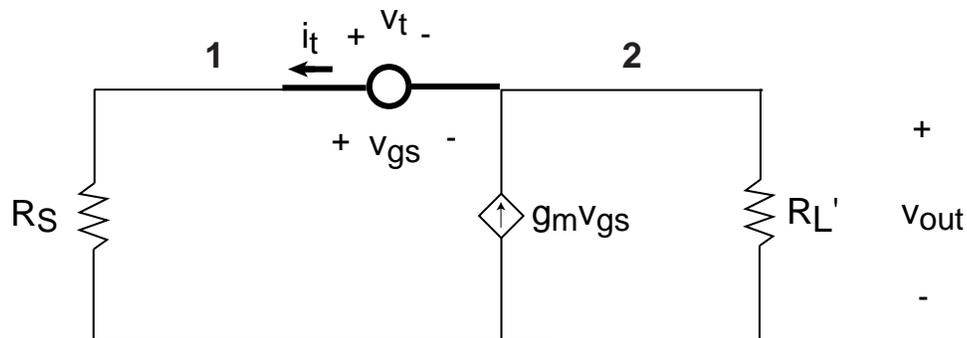
4. conservative estimate of bandwidth:

$$\omega_H \simeq \frac{1}{\sum \tau_i}$$

□ First, short v_s :



□ Time constant associated with C_{gs} :



node **1**:

$$i_t - \frac{v_t + v_{out}}{R_S} = 0$$

node **2**:

$$g_m v_{gs} - i_t - \frac{v_{out}}{R_L'} = 0$$

also

$$v_{gs} = v_t$$

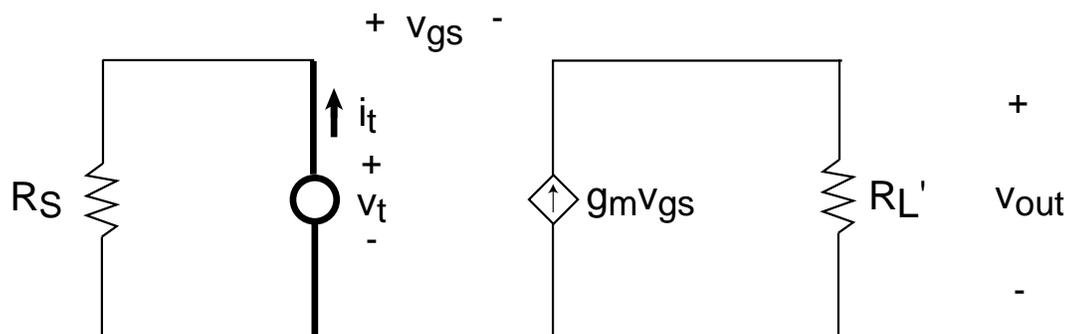
Solve for v_{out} in **1** and plug into **2**:

$$R_{T_{gs}} = \frac{v_t}{i_t} = \frac{R_S + R'_L}{1 + g_m R'_L}$$

Time constant:

$$\tau_{gs} = C_{gs} \frac{R_S + R'_L}{1 + g_m R'_L}$$

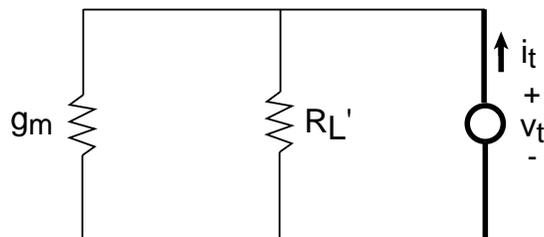
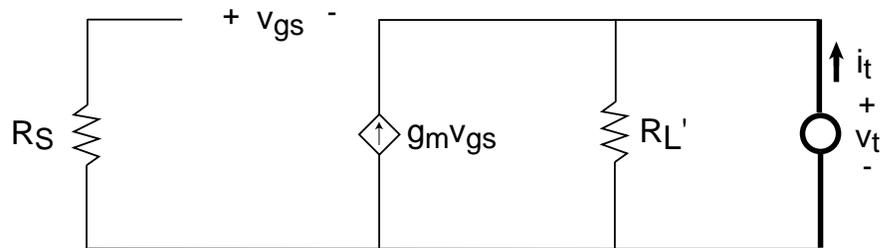
□ Time constant associated with C_{gd} :



$$R_{T_{gd}} = R_S$$

$$\tau_{gd} = C_{gd} R_S$$

□ Time constant associated with C_{db} :



$$R_{Tdb} = \frac{1}{g_m} // R_L' = \frac{R_L'}{1 + g_m R_L'}$$

$$\tau_{db} = C_{db} \frac{R_L'}{1 + g_m R_L'}$$

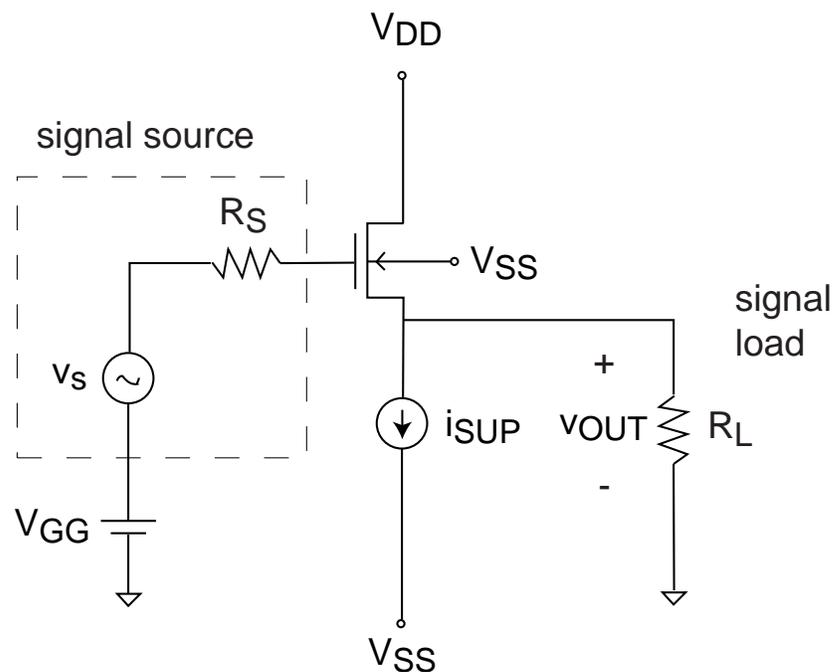
Notice:

$$R_{Tdb} = R_{out} // R_L$$

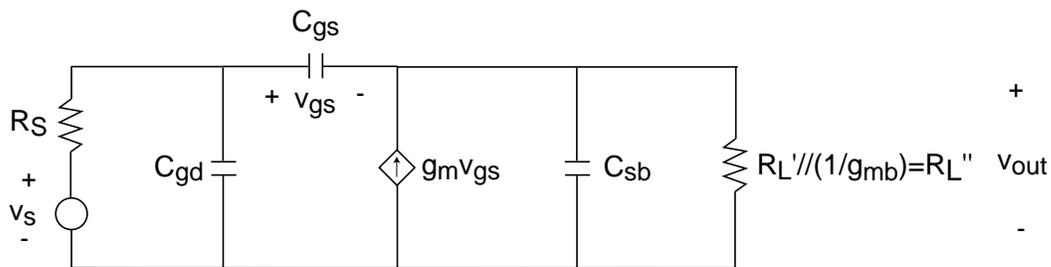
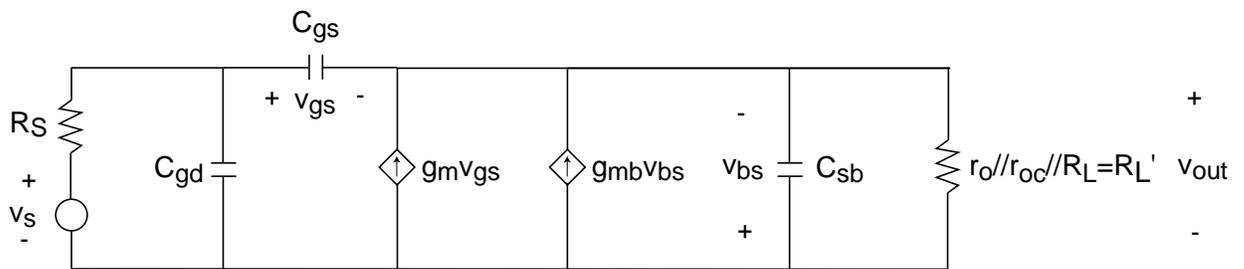
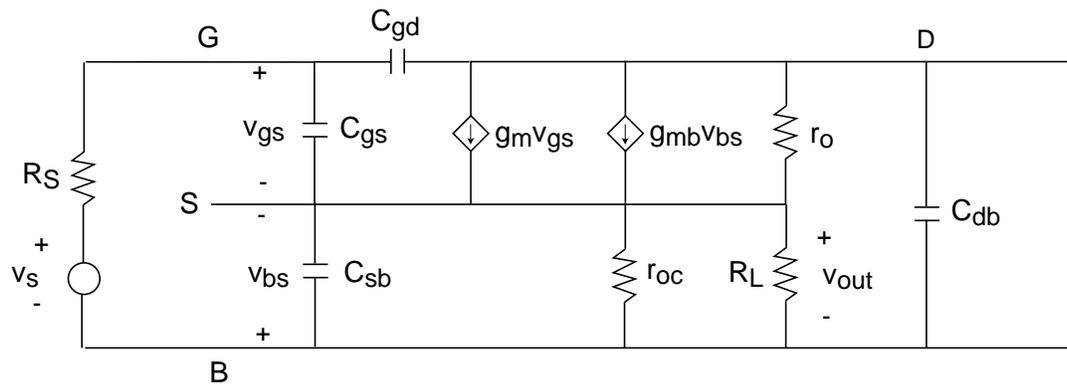
□ Bandwidth:

$$\omega_H \simeq \frac{1}{\tau_{gs} + \tau_{gd} + \tau_{db}} = \frac{1}{C_{gs} \frac{R_S + R'_L}{1 + g_m R'_L} + C_{gd} R_S + C_{db} \frac{R'_L}{1 + g_m R'_L}}$$

□ If back is not connected to source:



Small-signal equivalent circuit:



$$A_{v,LF} = \frac{g_m R_L''}{1 + g_m R_L''}$$

C_{sb} shows up at same location as C_{db} before, then bandwidth is:

$$\omega_H \simeq \frac{1}{C_{gs} \frac{R_S + R_L''}{1 + g_m R_L''} + C_{gd} R_S + C_{sb} \frac{R_L''}{1 + g_m R_L''}}$$

Simplify:

- CD amp is about driving low R_L from high $R_S \Rightarrow R_S \gg R_L''$, and

$$\omega_H \simeq \frac{1}{R_S \left(\frac{C_{gs}}{1 + g_m R_L''} + C_{gd} \right) + C_{sb} \frac{R_L''}{1 + g_m R_L''}}$$

- CD stage operates as voltage buffer with $A_{v,LF} \simeq 1 \Rightarrow g_m R_L'' \gg 1$, and

$$\omega_H \simeq \frac{1}{C_{gd} R_S + \frac{C_{sb}}{g_m}}$$

Since C_{gd} and $1/g_m$ are small, if R_S is not too high, ω_H can be rather high (approach ω_T).

□ What happened to the Miller effect in CD amp?

$$\omega_H \simeq \frac{1}{R_S \left(\frac{C_{gs}}{1 + g_m R_L''} + C_{gd} \right) + C_{sb} \frac{R_L''}{1 + g_m R_L''}}$$

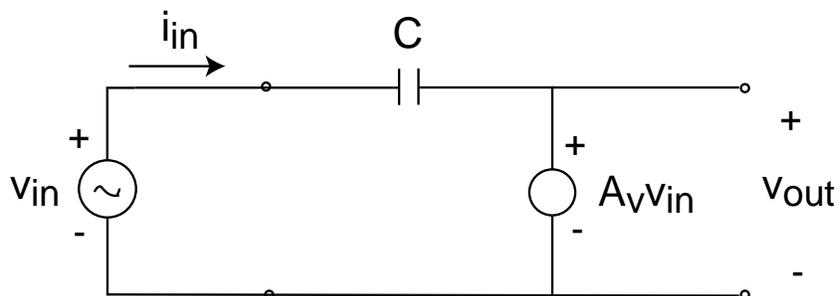
Miller analysis of C_{gs} :

$$C'_{gs} = C_{gs}(1 - A_v) = C_{gs} \left(1 - \frac{g_m R_L''}{1 + g_m R_L''} \right) = C_{gs} \frac{1}{1 + g_m R_L''}$$

agrees with above result.

Note, since $A_v \rightarrow 1$, $C'_{gs} \rightarrow 0$.

See in circuit:



$$C_M = C(1 - A_v)$$

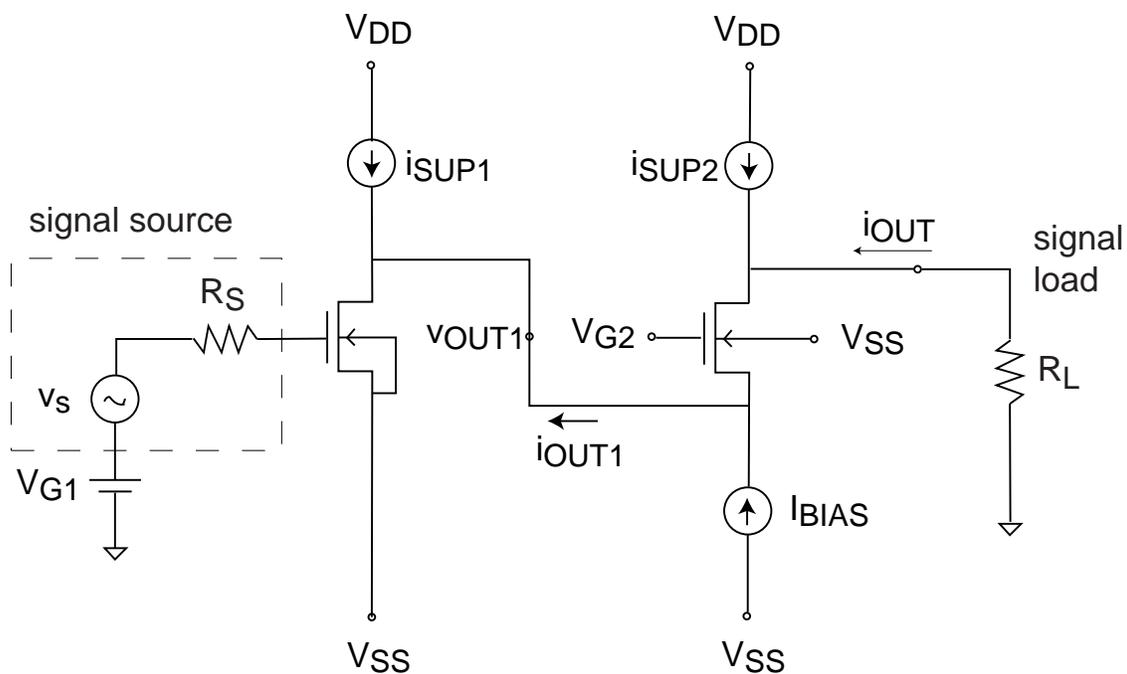
if $A_v \simeq 1 \Rightarrow C_M \simeq 0$: *bootstrapping*

2. Cascode amplifier

Common-source stage: excellent *transconductance amplifier*, but bandwidth hurt by Miller effect.

What's a circuit designer to do?

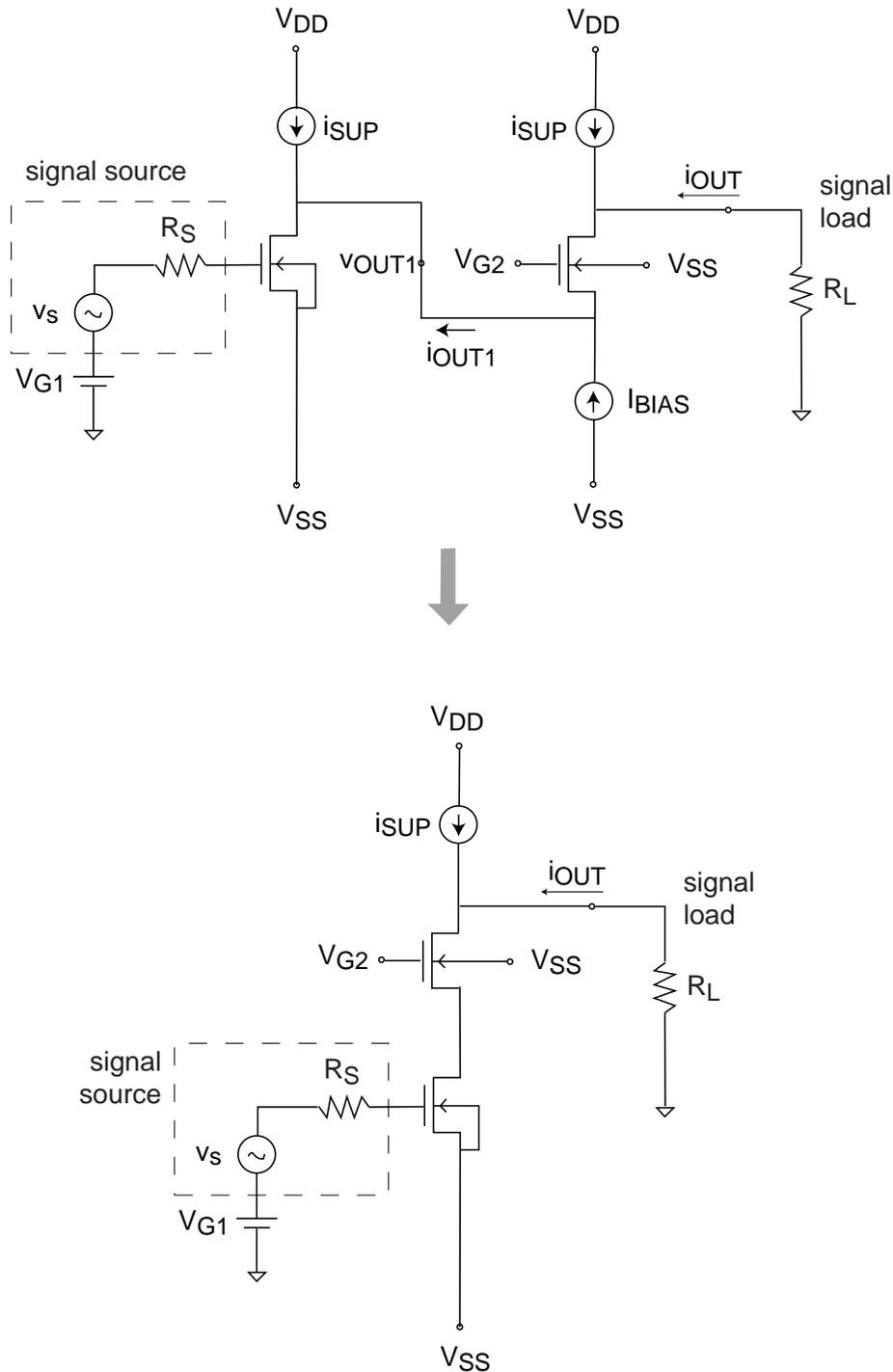
Consider CS-CG stage:

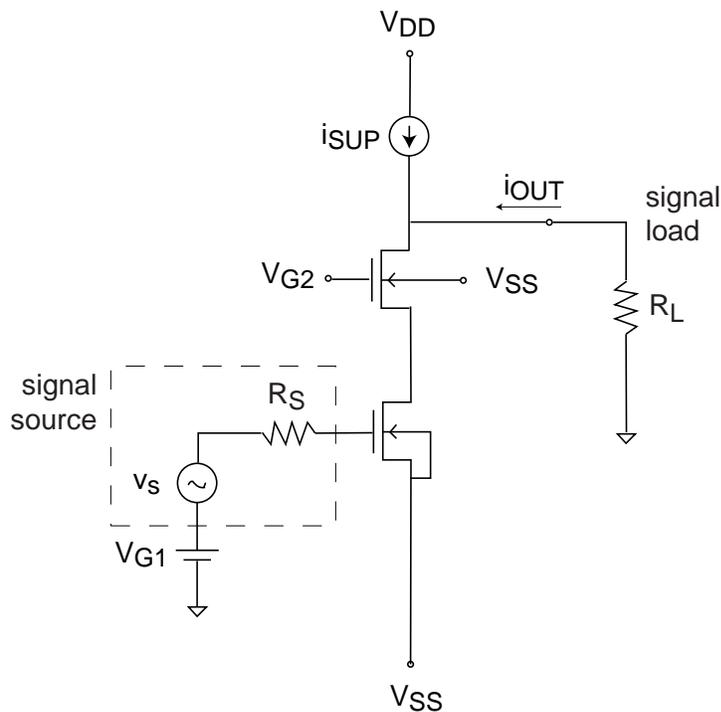


How does this address the problem?

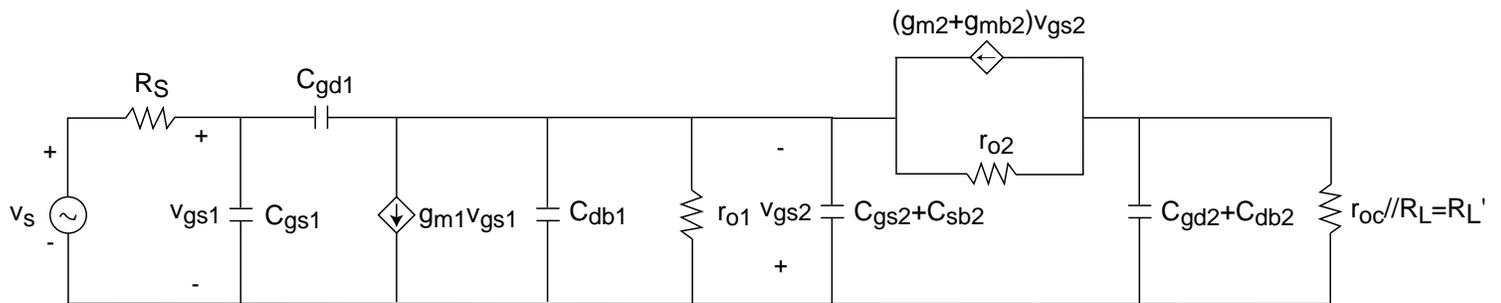
- R_{in2} very small $\Rightarrow i_{OUT1}$ can change a lot with v_{OUT1} changing little \Rightarrow small voltage gain in CS stage \Rightarrow no Miller effect \Rightarrow high bandwidth
- CG stage also has high bandwidth

Before analyzing CS-CG amp, notice that if we make $i_{SUP1} = i_{SUP2} = i_{SUP}$, amplifier drastically simplified:





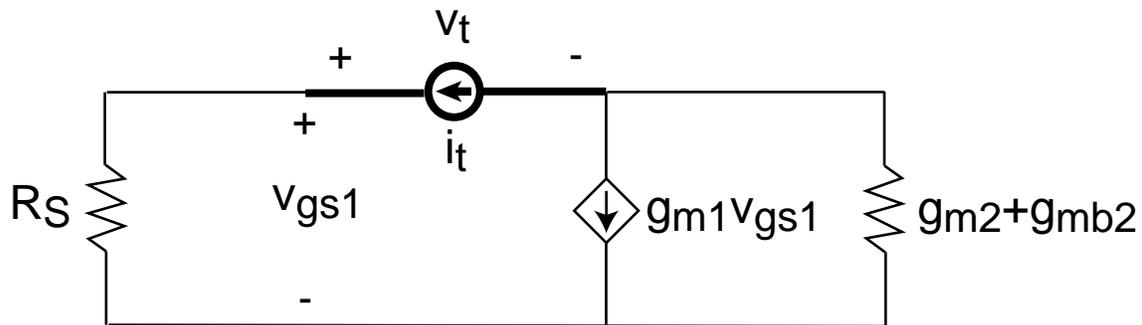
Small-signal equivalent circuit model:



Time constants associated with C_{gs1} and $C_{gd2} + C_{db2}$ have not changed.

Time constant associated with $C_{db1} + C_{gs2} + C_{sb2}$ small (looking into $R_{in2} \simeq 1/g_m$).

Focus on time constant associated with C_{gd1} :



From Lecture 24:

$$\tau_{gd1} = \left[\frac{1}{g_{m2} + g_{mb2}} + R_S \left(1 + \frac{g_{m1}}{g_{m2} + g_{mb2}} \right) \right] C_{gd1}$$

If transistors identical ($g_{m1} = g_{m2}$):

$$\tau_{gd1} \simeq 2R_S C_{gd1}$$

Much smaller than in single stage CS transconductance amp:

$$\tau_{gd} = [R'_{out} + R_S(1 + g_m R'_{out})] C_{gd}$$

Cascode: excellent transconductance amplifier with high bandwidth.

Key conclusions

- Common-drain amplifier:
 - Voltage gain $\simeq 1$, Miller effect nearly completely eliminates impact of C_{gs} (*bootstrapping*)
 - if R_S is not too high, CD amp has high bandwidth
- Cascode amplifier:
 - effective sharing of current source
 - Miller effect minimized by reducing voltage gain of CS stage as a result of low input impedance of CG stage
 - transconductance amplifier with high bandwidth