Lecture 24 - Frequency Response of Amplifiers (II)

Other Amplifier Stages

May 10, 2001

Contents:

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

Reading assignment:

Howe and Sodini, Ch. 10, §§10.5-10.6

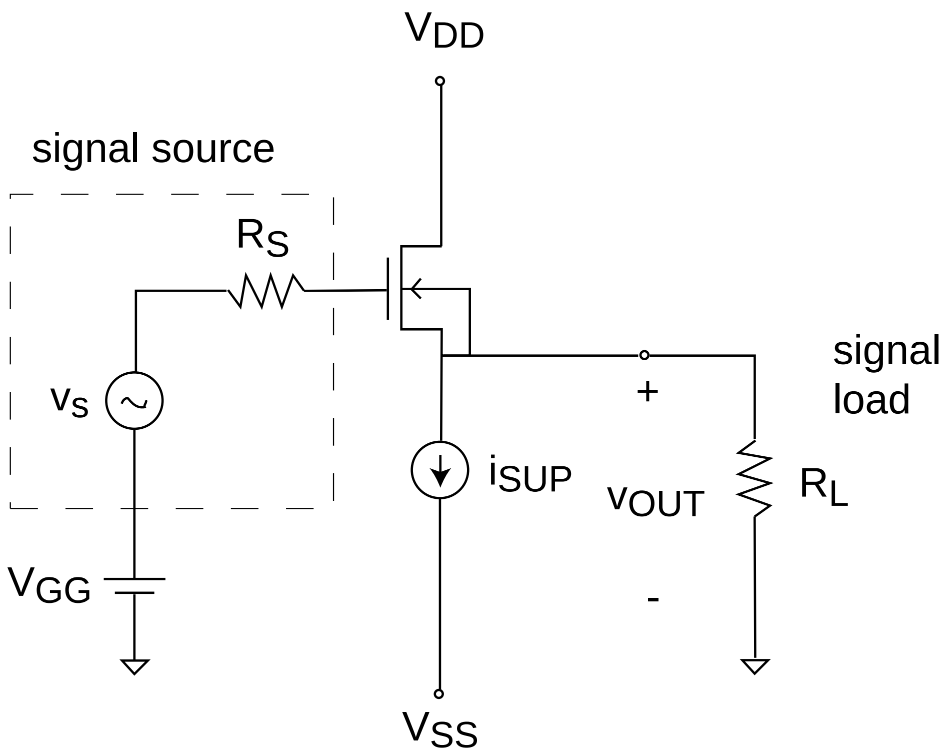
Announcement:

Final exam: May 24, 9 AM-12 noon, Walker; open book, calculator required; entire subject under examination but emphasis on lectures #18-26.

Key questions

- Do all amplifier stages suffer from the Miller effect?
- Is there something unique about the common-gate and common drain stages in terms of frequency response?

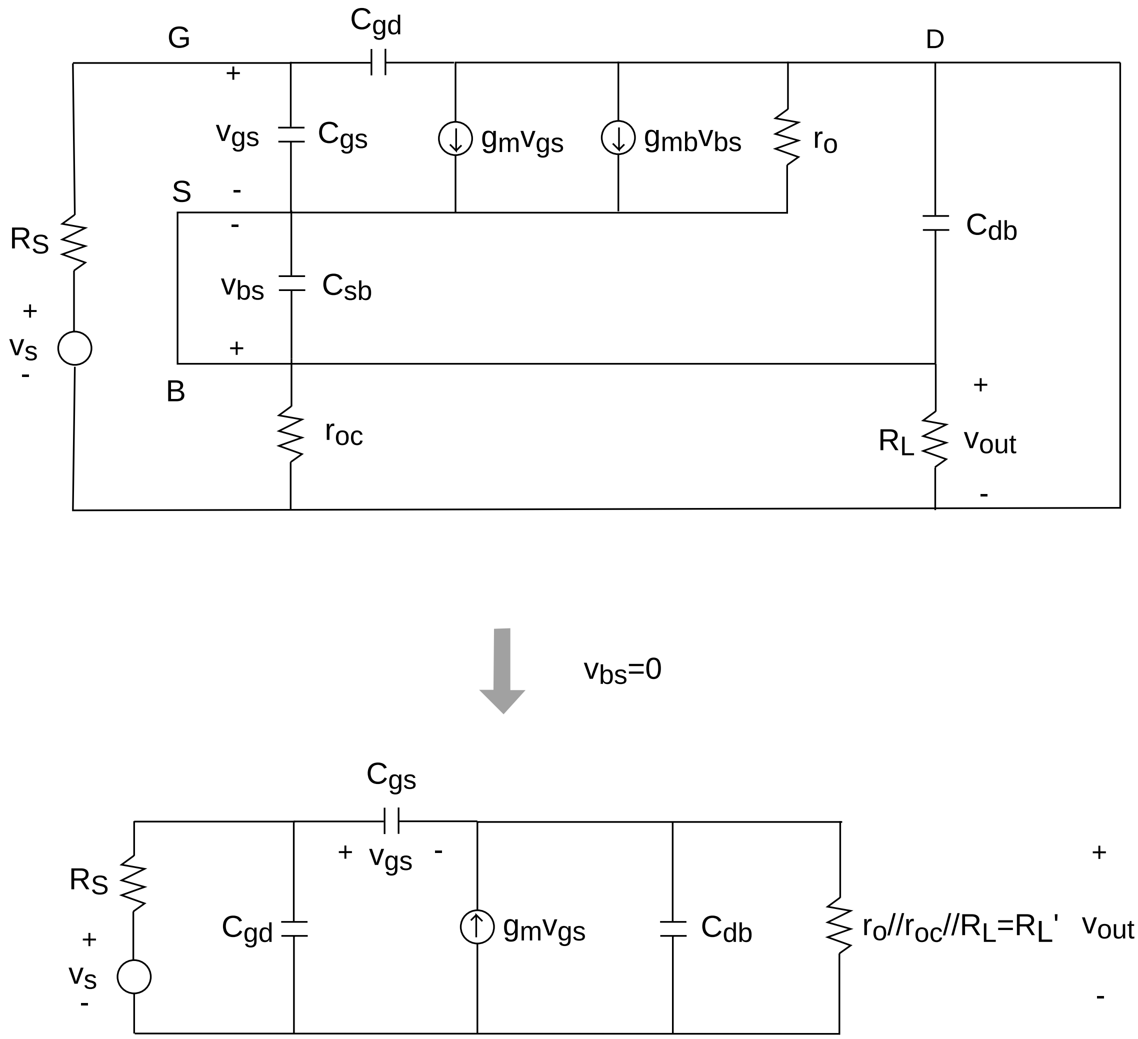
1. Frequency response of common-drain amplifier



Features:

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

High-frequency small-signal model:



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

Compute bandwidth by open-circuit time constant technique:

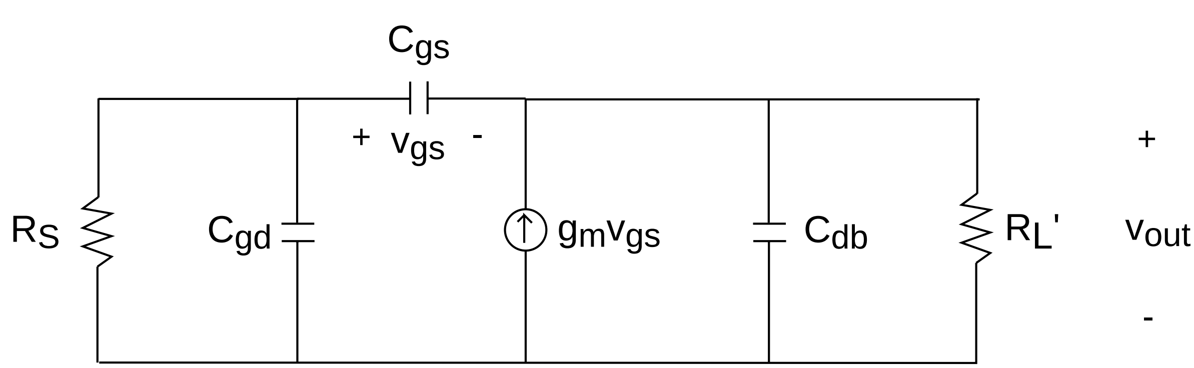
1. shut-off all independent sources,
2. compute Thevenin resistance R_{Ti} seen by each C_i with all other C's open,
3. compute open-circuit time constant for C_i as

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

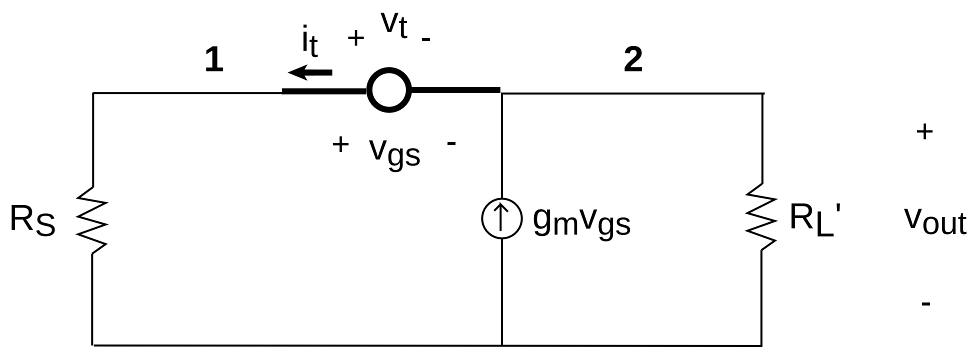
4. conservative estimate of bandwidth:

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

□ 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

$$v_{gs} = v_t$$

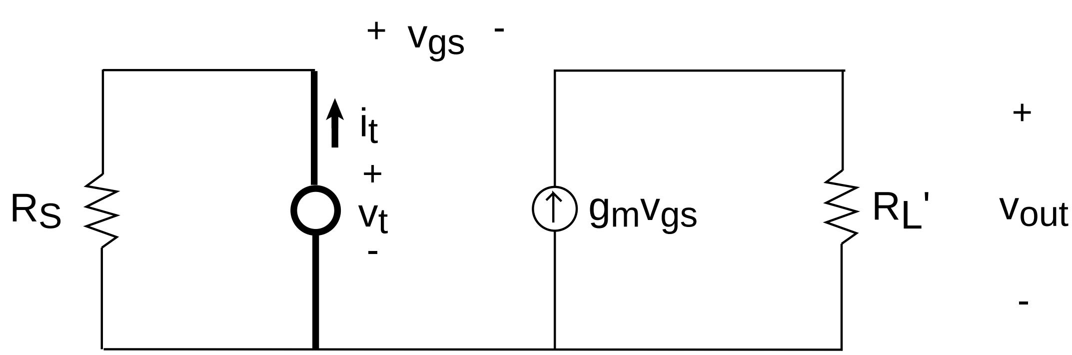
Solve for v_{out} in **1** and plug into **2**:

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

Time constant:

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

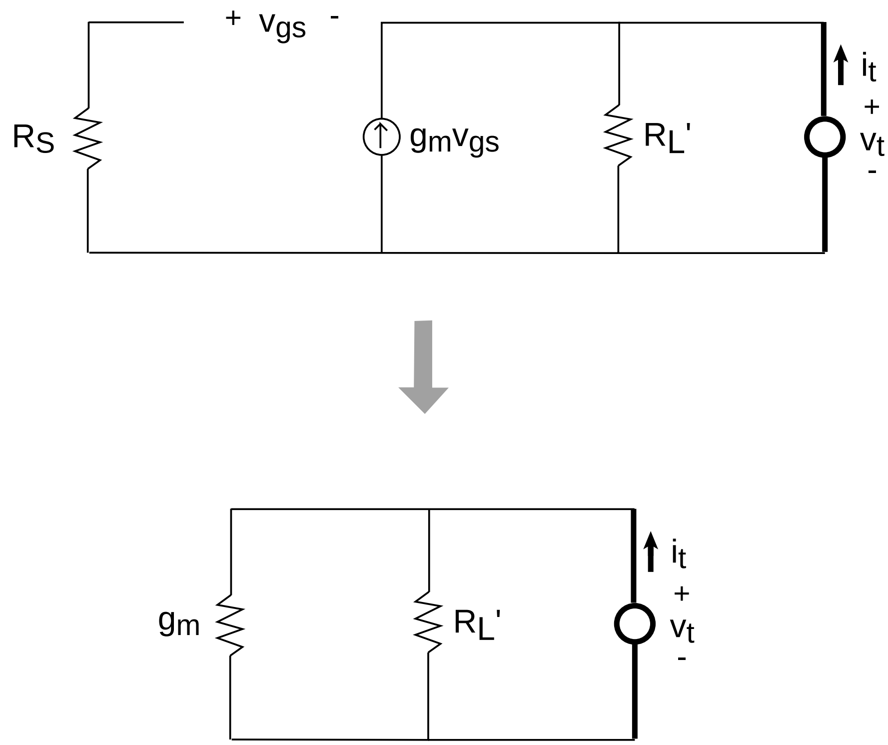
□ Time constant associated with C_{gd}:



$$R_{Tgd} = R_S$$

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

□ Time constant associated with C_{db}:



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

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

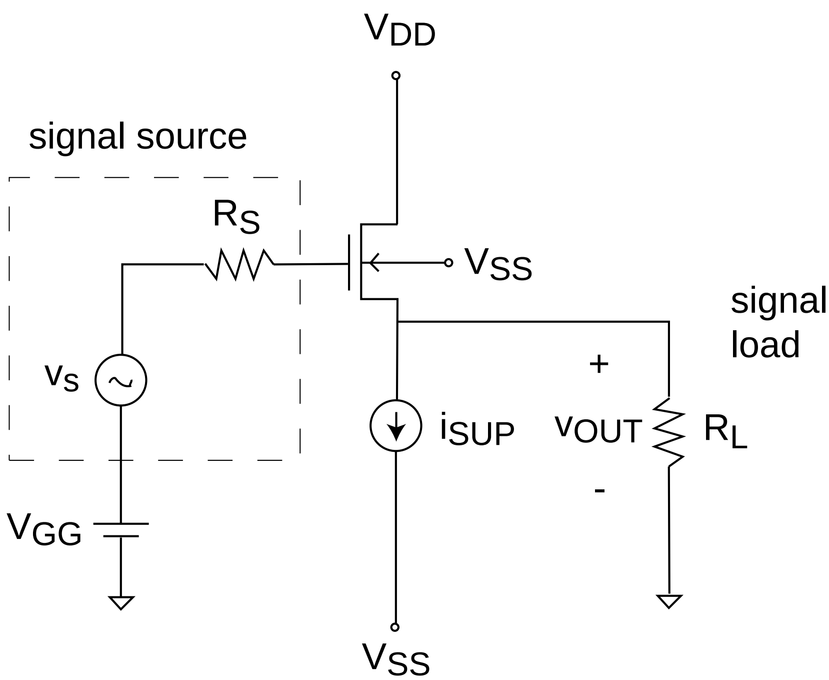
Notice:

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

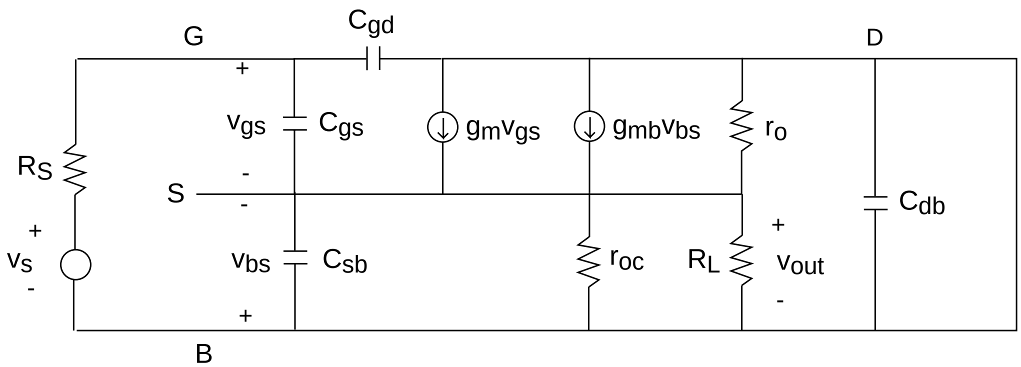
□ Bandwidth:

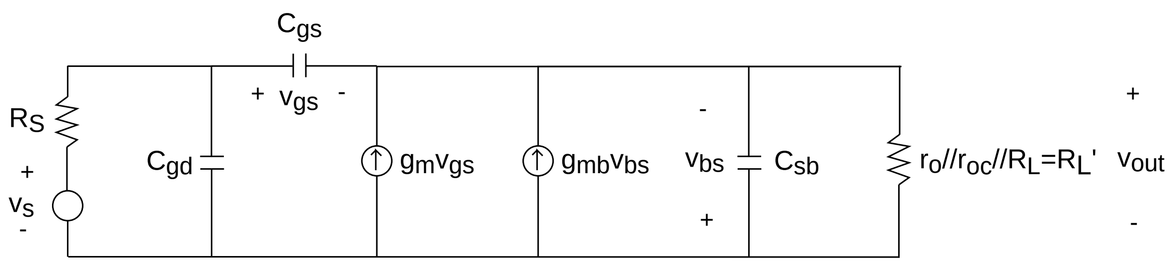
$$\omega_H \simeq \frac{1}{\tau_{gs} + \tau_{gd} + \tau_{db}} = \frac{1}{C_{gs}\frac{R_S+R'_L}{1+g_m R'_L} + C_{gd}R_S + C_{db}\frac{R'_L}{1+g_m R'_L}}$$

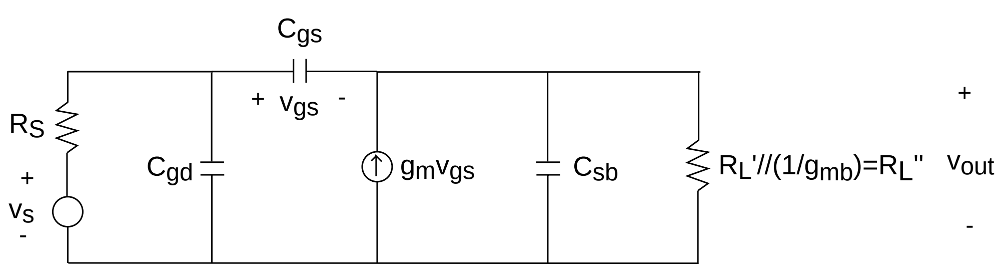
□ If back is not connected to source:



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

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

- 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?

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

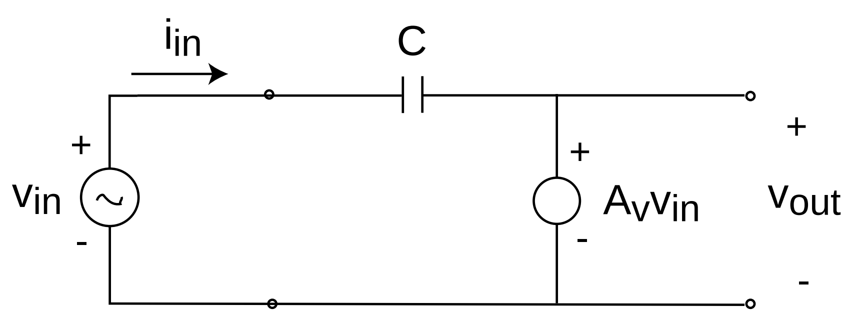
Miller analysis of C_{gs}:

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

agrees with above result.

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

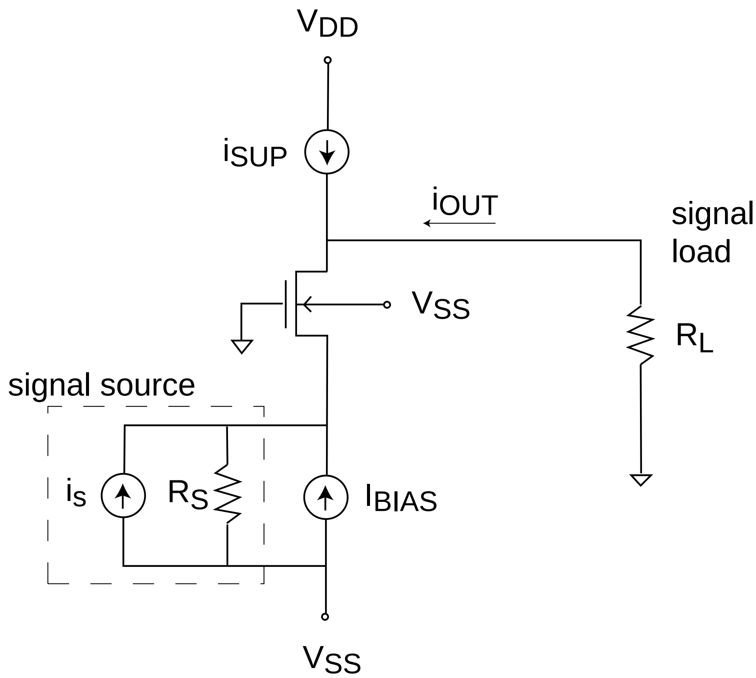
See in circuit:



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

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

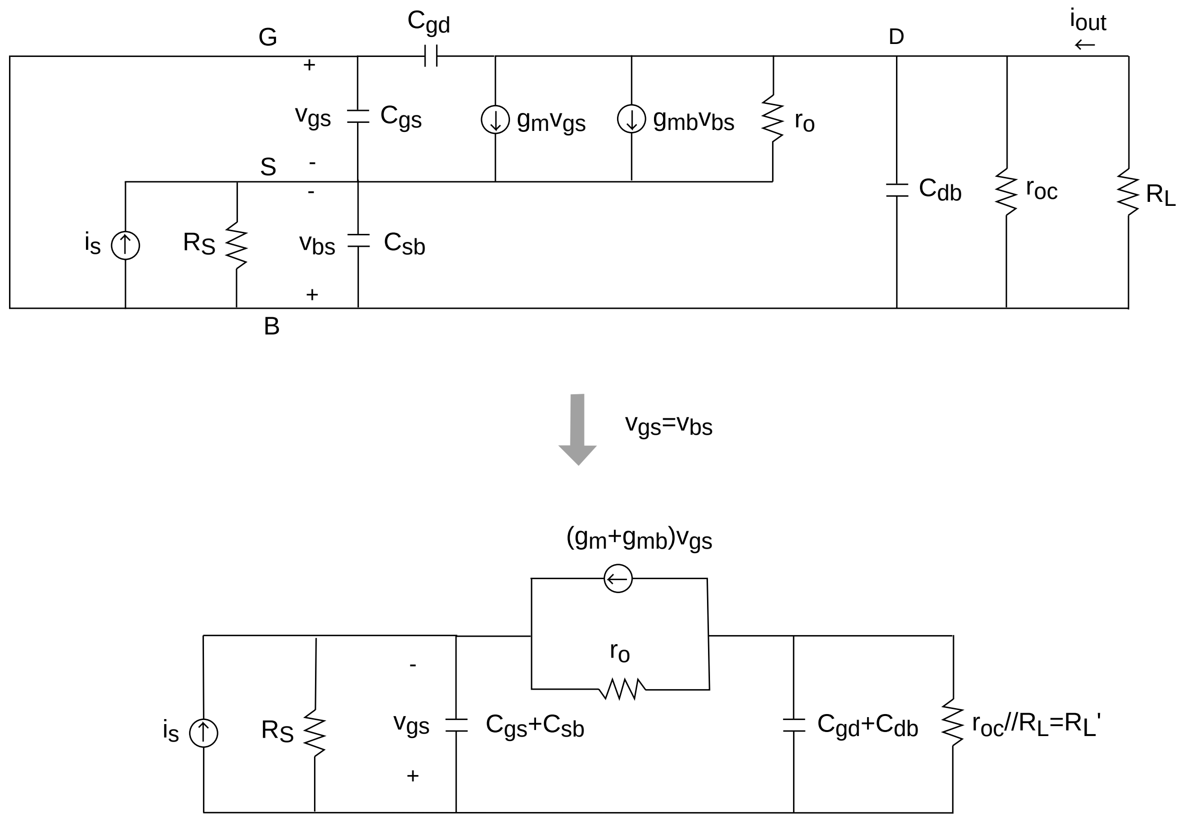
2. Frequency response of common-gate amplifier



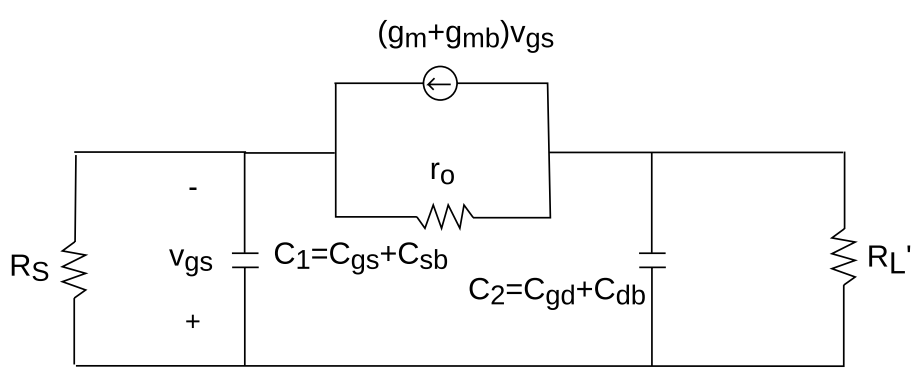
Features:

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

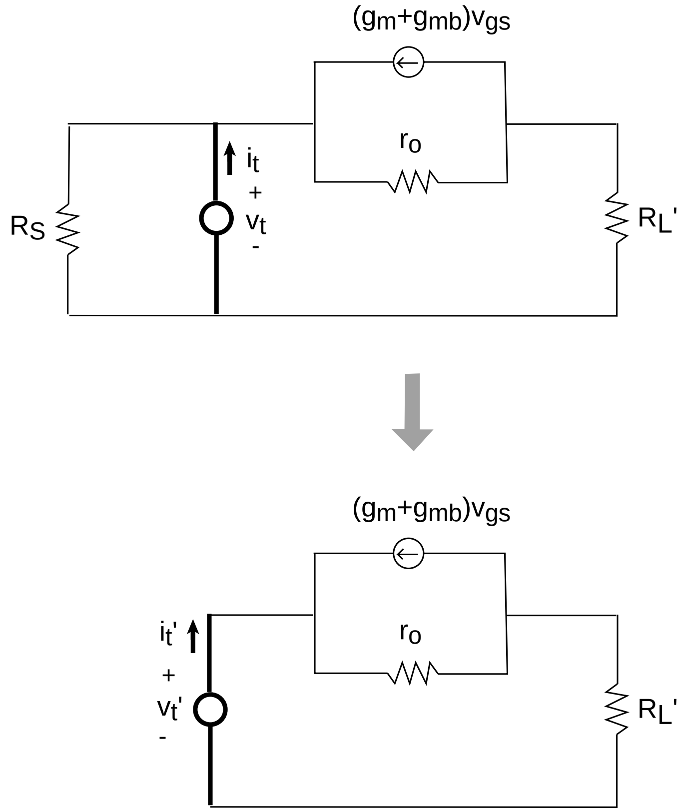
Small-signal equivalent circuit model:



☐ Frequency analysis: first, open i_s:



□ Time constant associated with C_1:



Don't need to solve:

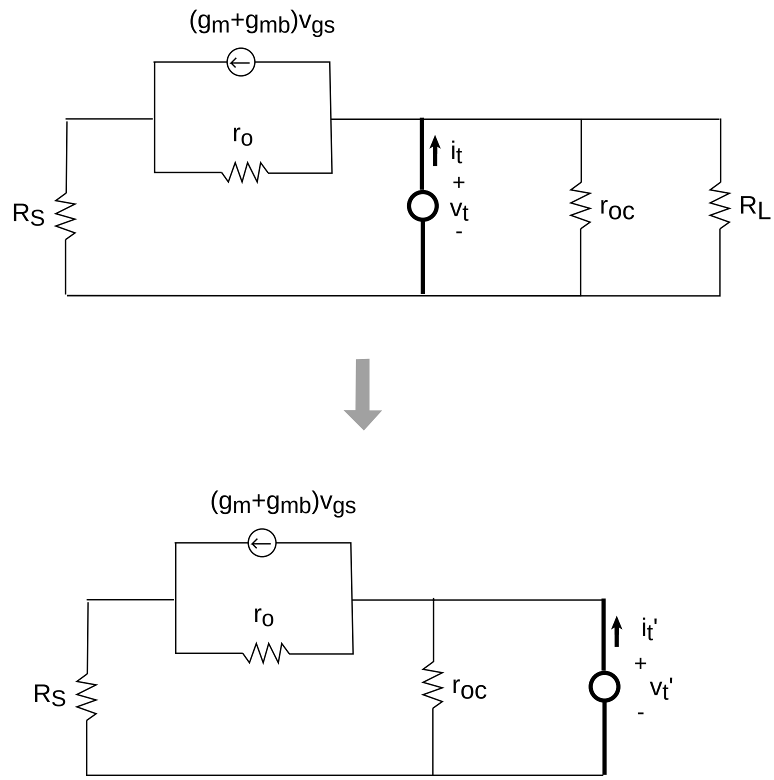
- test probe is in parallel with R_S,
- test probe looks into input of amplifier $\Rightarrow$ sees R_{in}!

$$R_{T1} = R_S // R_{in}$$

And:

$$\tau_1 = (C_{gs} + C_{sb})(R_S // R_{in})$$

□ Time constant associated with C_2:



Again, don't need to solve:

- test probe is in parallel with R_L,
- test probe looks into output of amplifier ⇒ sees R_{out}!

$$R_{T2} = R_L // R_{out}$$

And:

$$\tau_2 = (C_{gd} + C_{db})(R_L // R_{out})$$

□ Bandwidth:

$$\omega_H \simeq \frac{1}{(C_{gs}+C_{sb})(R_S//R_{in})+(C_{gd}+C_{db})(R_L//R_{out})}$$

No capacitor in Miller position → no Miller-like term.

Simplify:

- In a current amplifier, $R_S \gg R_{in}$:

$$R_{T1} = R_S//R_{in} \simeq R_{in} \simeq \frac{1}{g_m+g_{mb}} \simeq \frac{1}{g_m}$$

- At output:

$$R_{T2} = R_L//R_{out} = R_L//r_{oc}//\{r_o[1+R_S(g_m+g_{mb}+\frac{1}{r_o})]$$

or

$$R_{T2} \simeq R_L//r_{oc}//[r_o(1+g_mR_S)] \simeq R_L$$

Then:

$$\omega_H \simeq \frac{1}{(C_{gs}+C_{sb})\frac{1}{g_m}+(C_{gd}+C_{db})R_L}$$

If R_L is not too high, bandwidth can be rather high (and approach ω_T).

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
- Common-gate amplifier:
  - no capacitor in Miller position $\Rightarrow$ no Miller effect
  - if R_L is not too high, CG amp has high bandwidth
- $R_S,\ R_L$ affect bandwidth of amplifier