Lecture 23

Frequency Response of Amplifiers (III)

OTHER AMPLIFIER STAGES

Outline

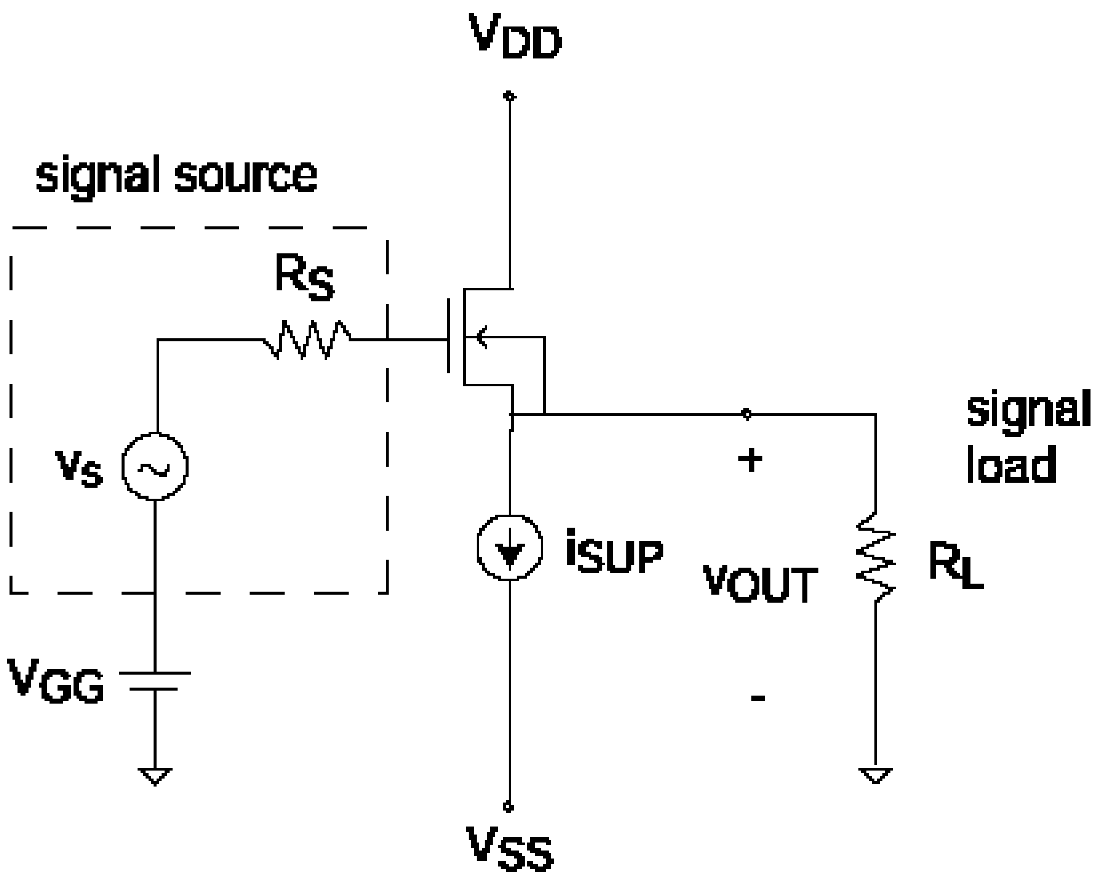
1. Frequency Response of the Common-Drain Amplifier
2. Frequency Response of the Common-Gate Amplifier

Reading Assignment:
Howe and Sodini, Chapter 10, Sections 10-5-10.6

Summary of Key Concepts

- Common-drain amplifier:
  - Voltage gain ≈ 1, ***Miller Effect*** nearly completely eliminates the effect of C_{gs} (***bootstrapping***)
  - If R_S is not too high, CD amplifier has high bandwidth
- Common-gate amplifier
  - No Miller Effect because there is no feedback capacitor
  - If R_L is not too high, CG amplifier has high bandwidth
- R_S, R_L affect bandwidth of amplifiers.

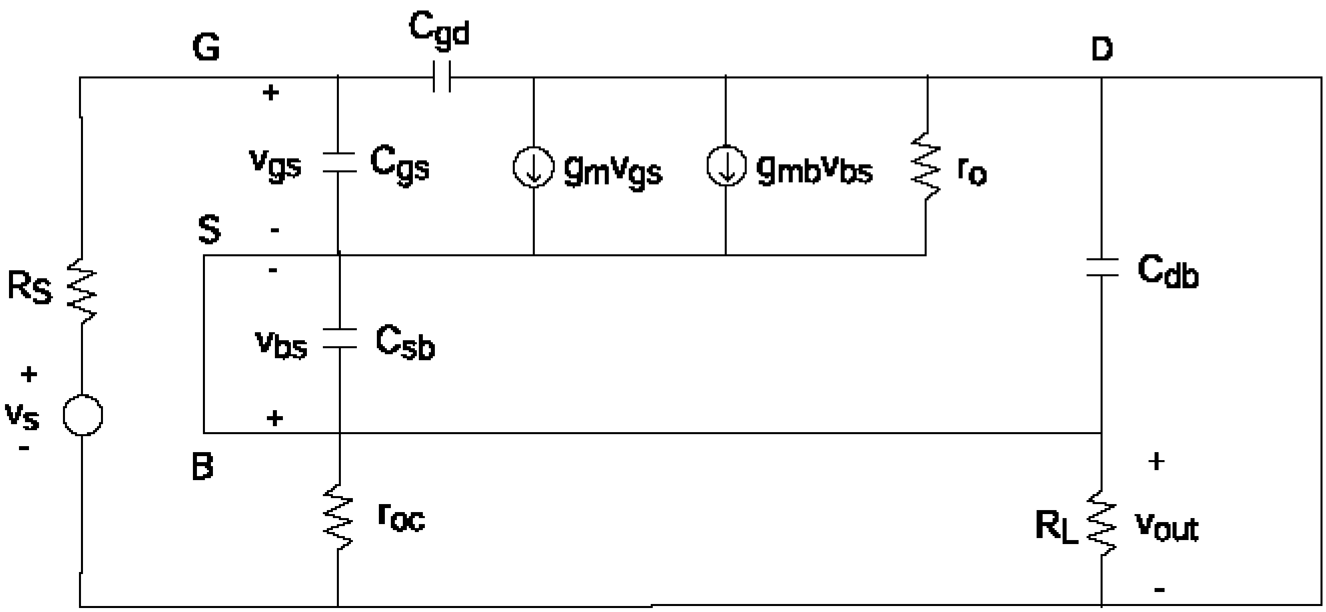
1. Frequency Response of the Common-Drain Amplifier

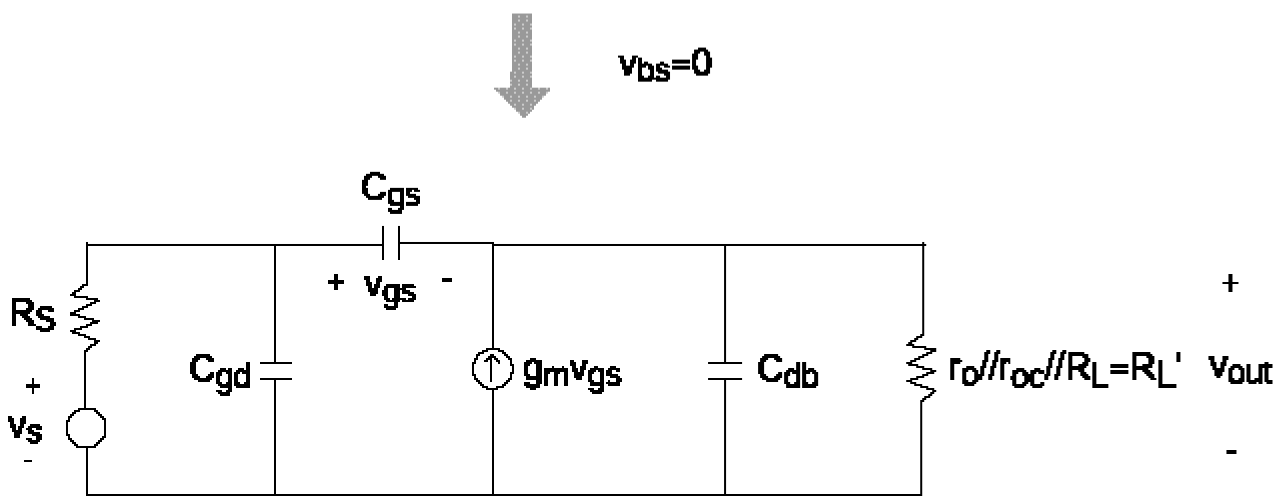


Key features:

- Voltage gain ≈ 1
- High input resistance
- Low output resistance
- ⇒ Good voltage buffer

High-frequency small-signal model





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

Bandwidth

Compute bandwidth by open-circuit time constant technique:

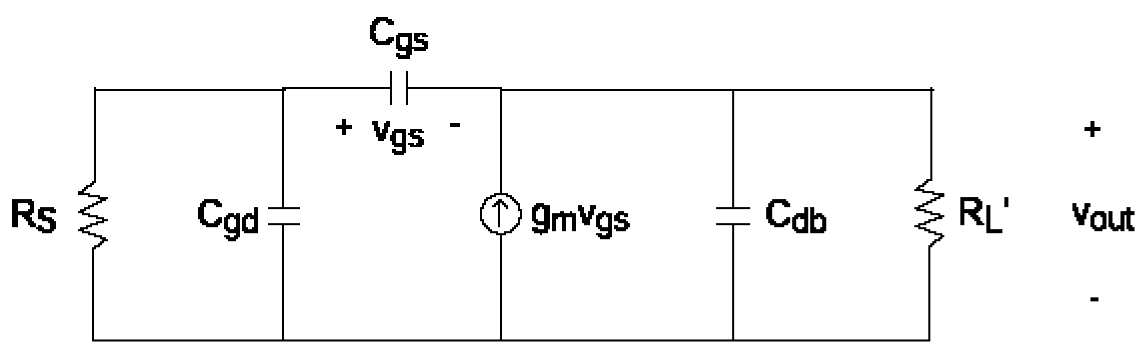
1. Shut-off all independent sources,
2. Compute Thevenin resistance R_{Ti} seen by each capacitor C_i with all other C's open,
3. Compute open-circuit time constant for C_i as

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

4. Conservative estimate of bandwidth is:

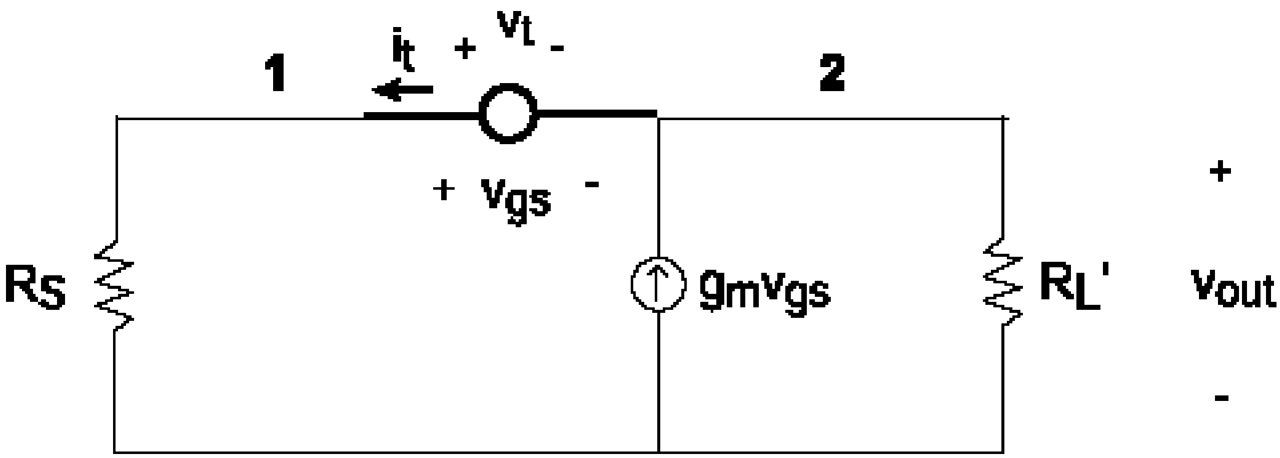
$$\omega_H \approx \frac{1}{\sum_i \tau_i}$$

First, short v_s:



Bnadwidth (contd.)

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**.

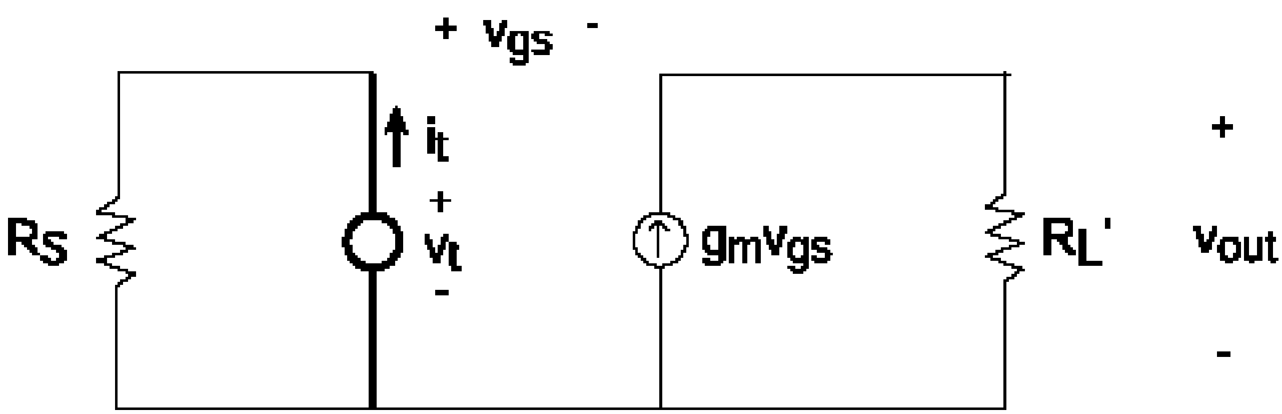
Bandwidth (contd…)

$$R_{Tgs} = \frac{v_t}{i_t} = \frac{R_s + R_L'}{1 + g_m R_L'}$$

Time constant for C_{gs}:

$$\tau_{gs} = C_{gs} \bullet \frac{R_s + R_L'}{1 + g_m R_L'}$$

Time Constant associated with C_{gd}:

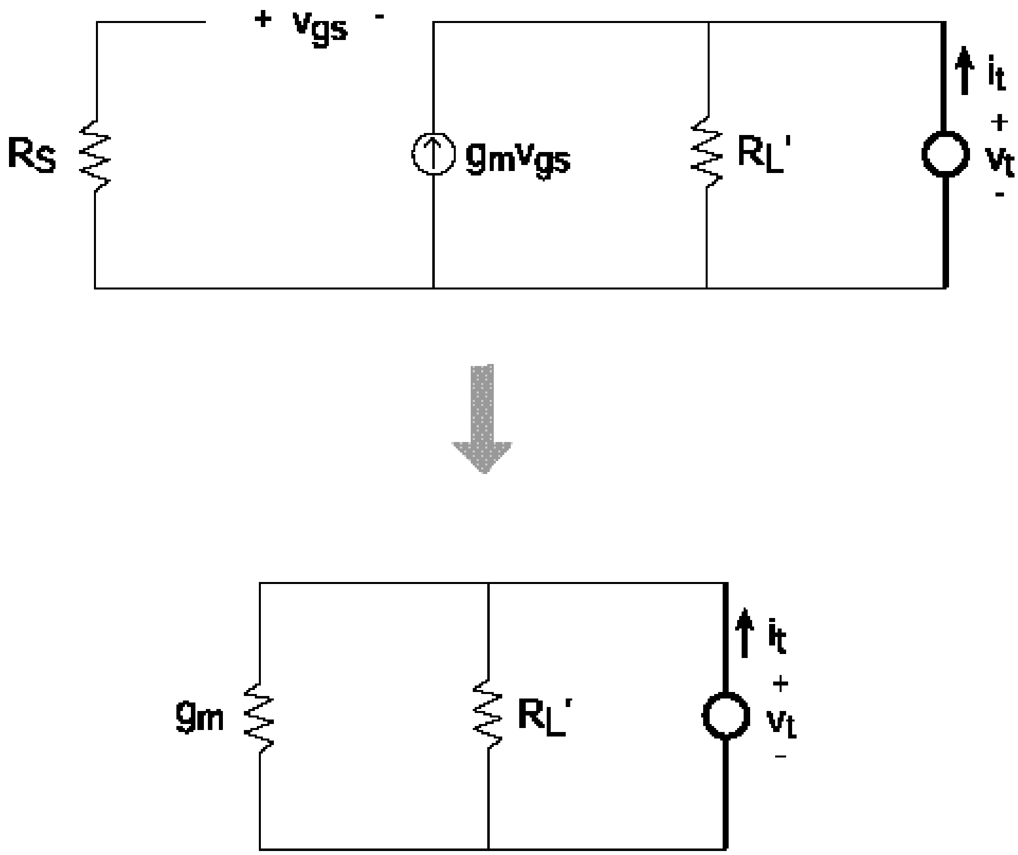


$$R_{Tgd} = R_S$$

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

Bandwidth (contd….):

Time Constant Associated with C_{db}:



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

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

Notice:

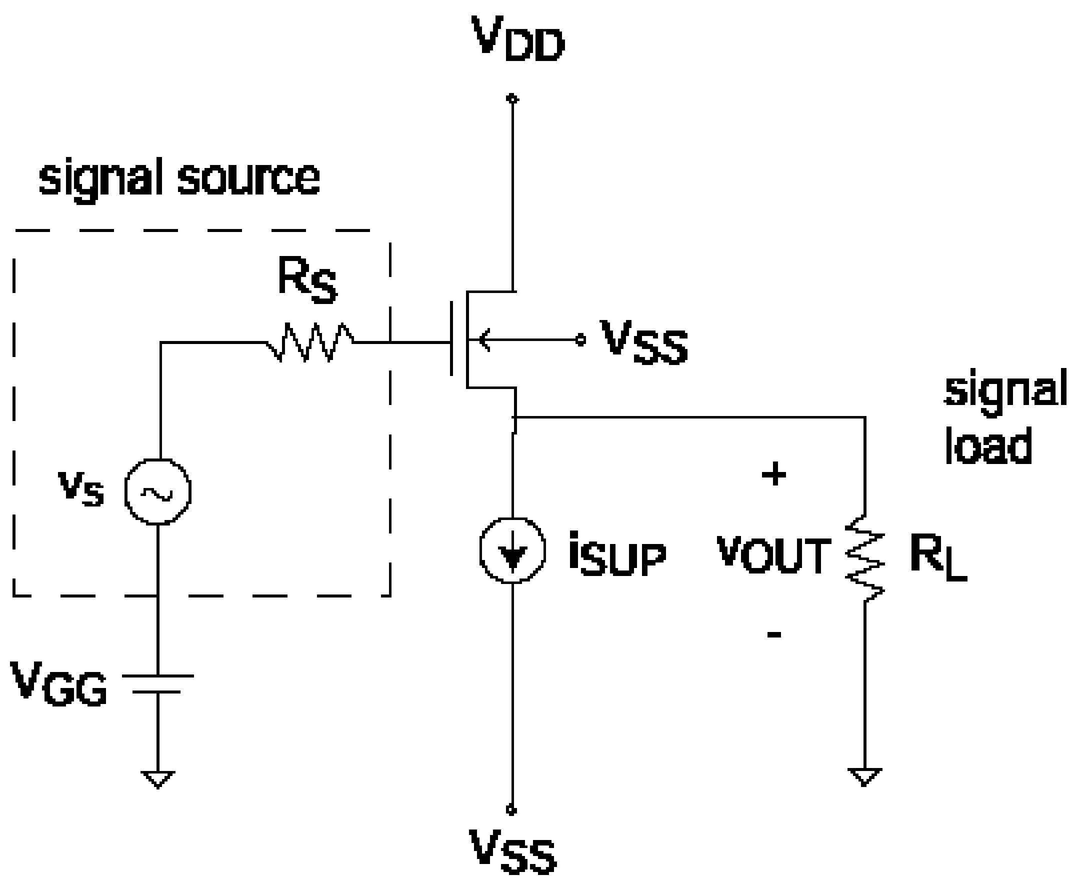
$$R_{Tdb} = R_{out} // R_L$$

Bandwidth

What is the bandwidth?

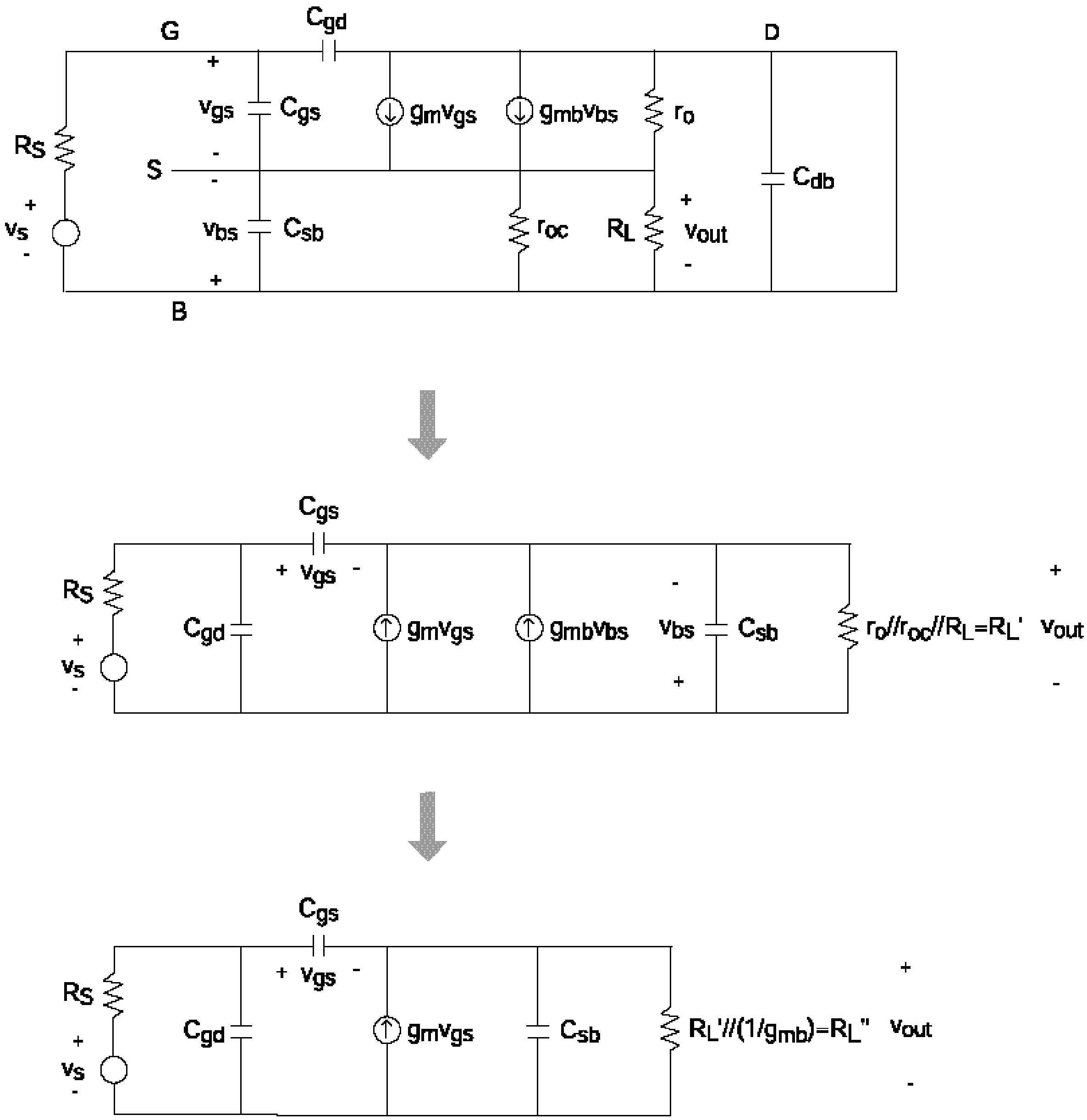
$$\omega_H \approx \frac{1}{\tau_{gs} + \tau_{gd} + \tau_{db}} = \frac{1}{C_{gs}\frac{R_S + R_L'}{1 + g_m R_L'} + C_{gd} R_S + C_{db}\frac{R_L'}{1 + g_m R_L'}}$$

If the back-gate is not connected to source:



Bandwidth
(backgate not connected to source)

Small-signal equivalent circuit:



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

Bandwidth
(backgate not connected to source)

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

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

Simplify:

- CD amplifier is often used for driving low R_L from high R_S $\Rightarrow R_S >> R_L''$, and

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

- CD amplifier stage operates as a voltage buffer with $A_{v,LF} \approx 1 \Rightarrow g_m R_L'' >> 1$, and

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

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

What happened to the Miller Effect in the CD amplifier?

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

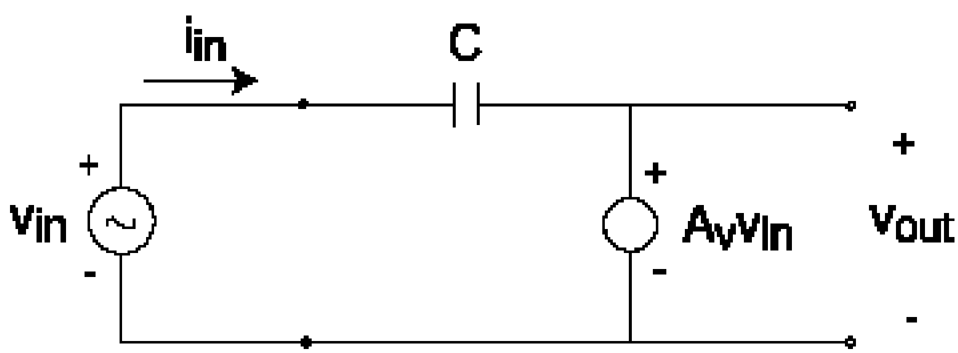
Miller analysis of C_{gs}:

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

agree with above result.

Note, since $A_v \rightarrow 1$, $C_{gs}" \rightarrow 0$.

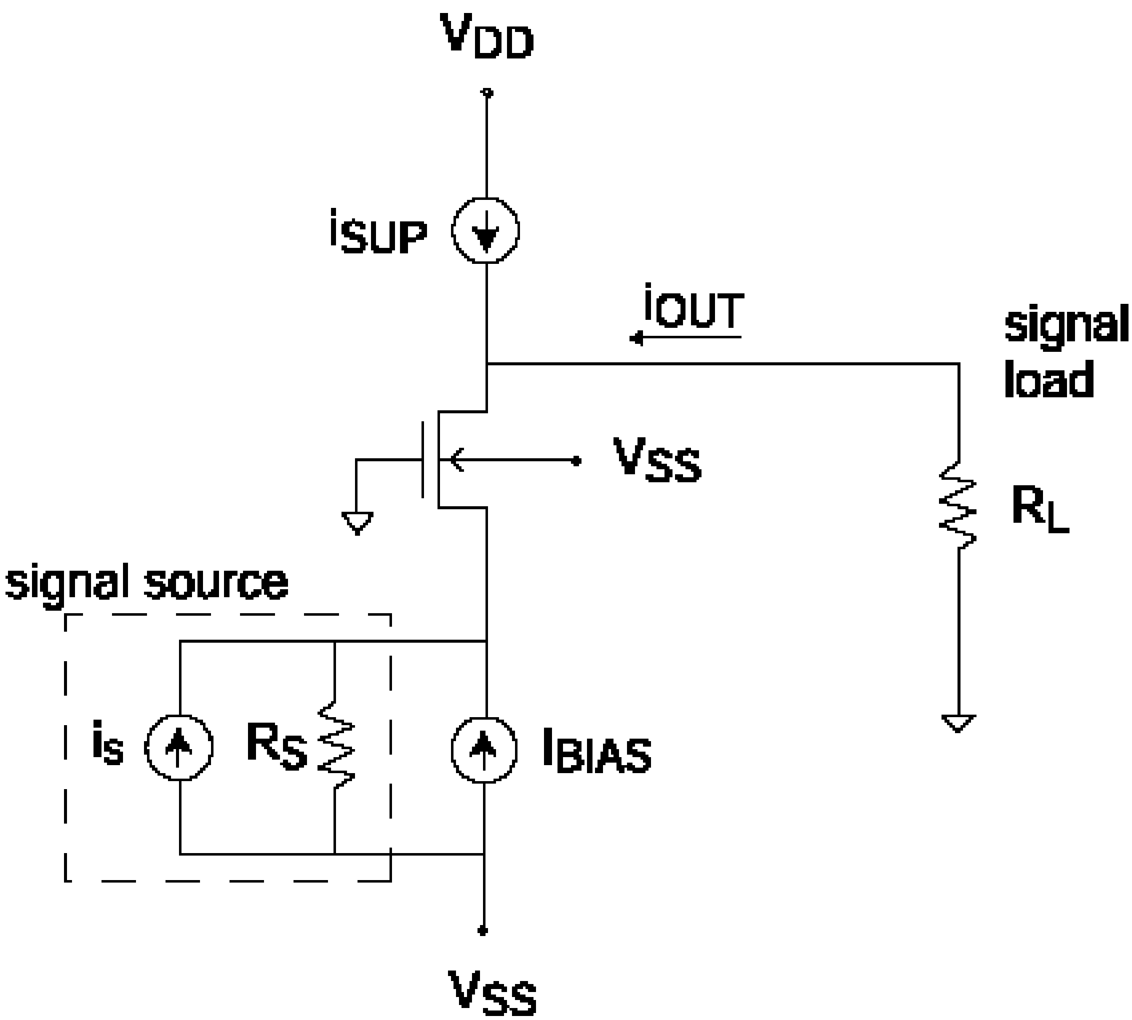
See in circuit below:



$$\mathbf{C_M} = \mathbf{C}(1-\mathbf{A_v})$$

If $A_v \approx 1 \Rightarrow C_M \approx 0$: ***bootstrapping***

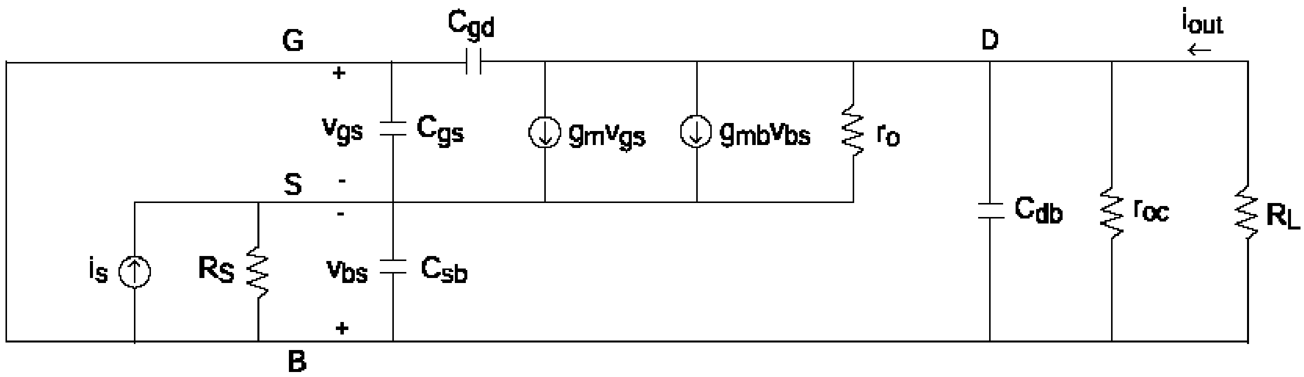
2. Frequency Response of the Common-Gate Amplifier

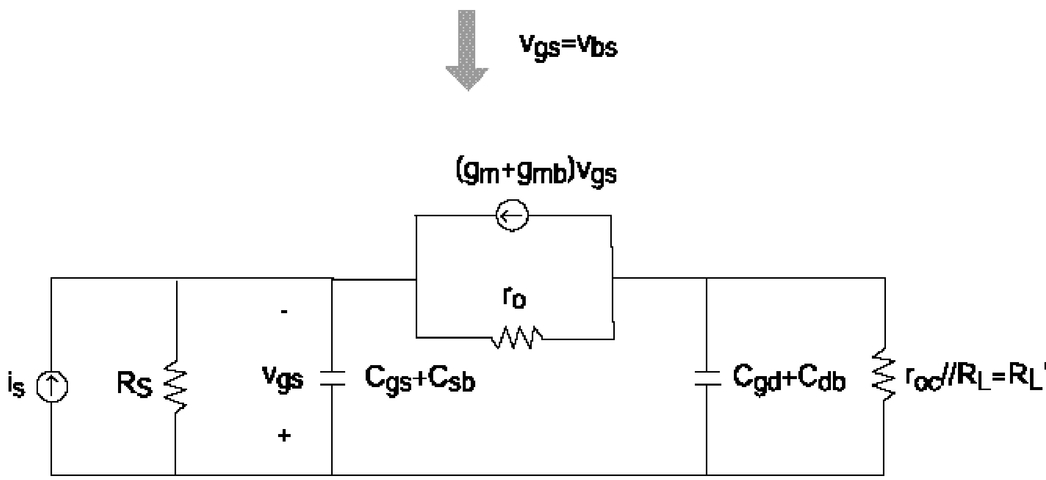


Key features:

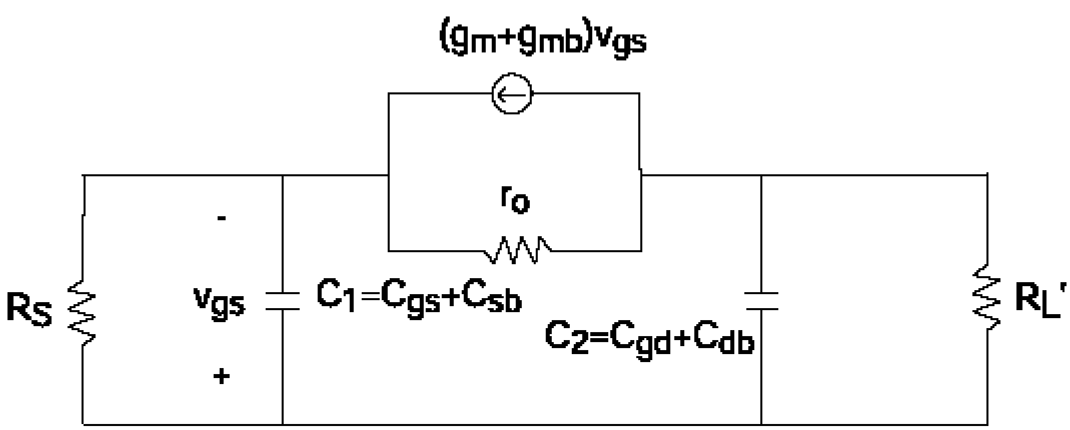
- Current gain ≈ 1
- Low input resistance
- High output resistance
- ⇒ Good current buffer

High-frequency small-signal model

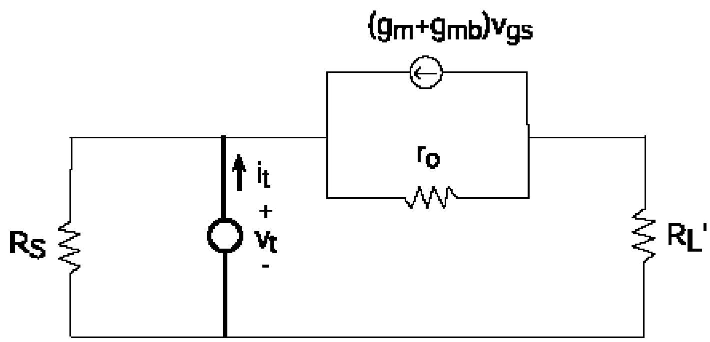


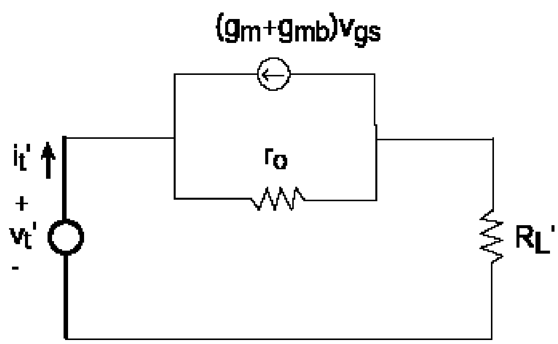


Frequency analysis: first open i_s:



Time constant associated with C_1:





Do not need to solve:

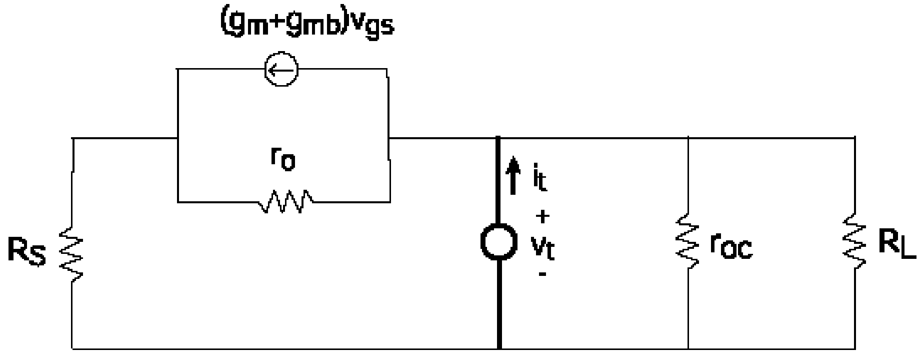
- Test probe is in parallel with R_S,
- Test probe looks into input of amplifier ⇒ sees R_{in}!

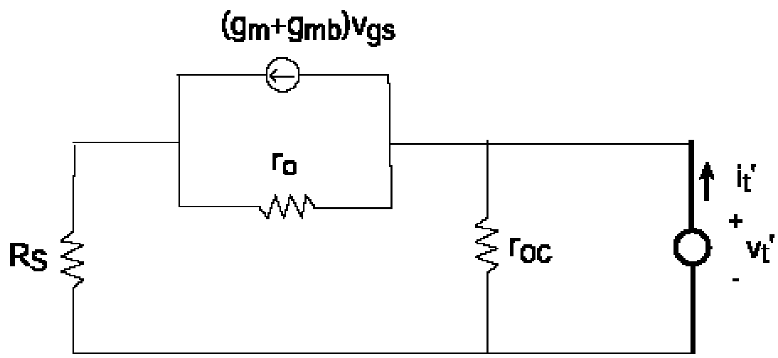
$$\mathbf{R_{T1} = R_S // R_{in}}$$

And:

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

Time constant associated with C_2:





Again, do not need to solve:

- Test probe is in parallel with R_L,
- Test probe looks into output of amplifier $\Rightarrow$ sees R_{out}!

$$\mathbf{R_{T2} = R_L \,//\, R_{out}}$$

And:

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

Bandwidth of CG Amplifier

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

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

Simplify:

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

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

- At output:

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

or

$$R_{T2} \approx R_L // r_{oc} // \{ r_o [1 + g_m R_S] \} \approx R_L$$

Then:

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

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

What did we learn today?

Summary of Key Concepts

- Common-drain amplifier:
  - Voltage gain ≈ 1, ***Miller Effect*** nearly completely eliminates the effect of C_{gs} (***bootstrapping***)
  - If R_S is not too high, CD amplifier has high bandwidth
- Common-gate amplifier
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- R_S, R_L affect bandwidth of amplifiers.