Lab 7: Single-Stage MOSFET Amplifiers

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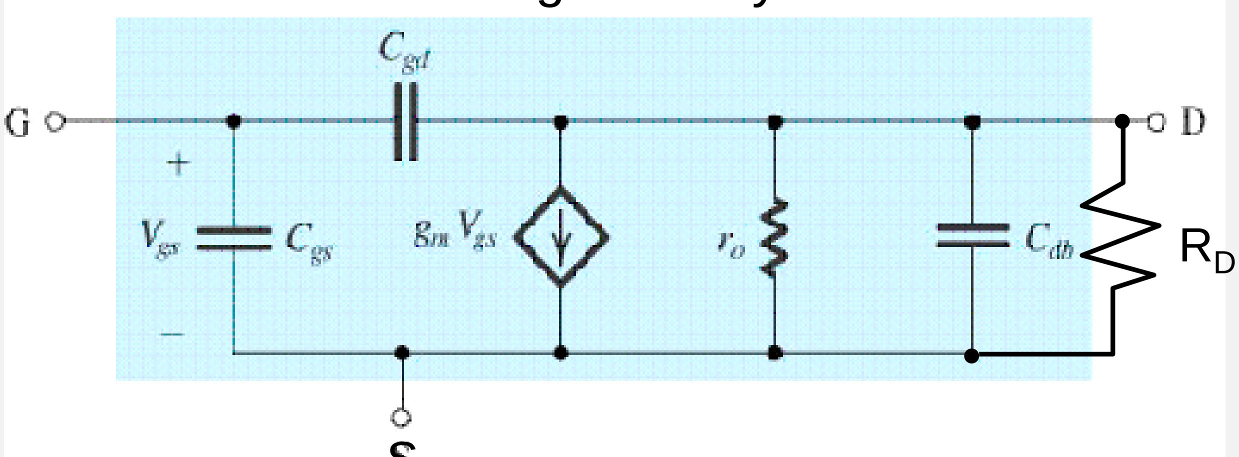
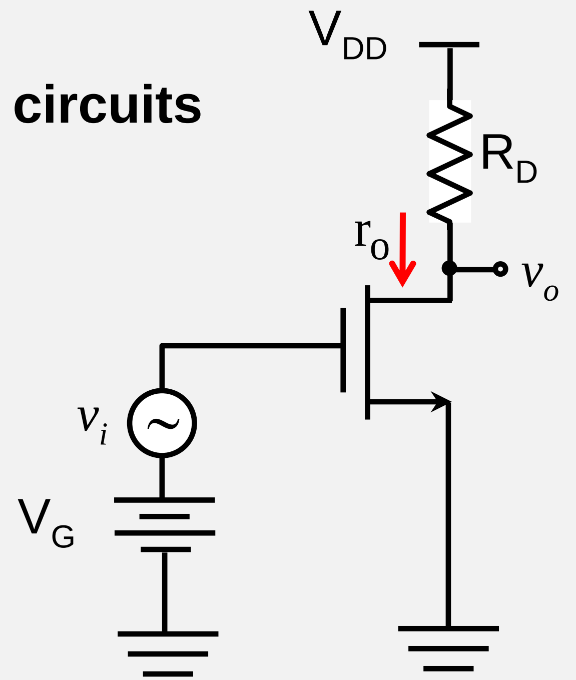
Common-Source (CS) Amplifier

- Common-source amplifier
  - The most widely used of all MOSFET amplifier circuits
  - Suitable for gain stage
  - High input impedance
  - High output impedance

Small-signal analysis





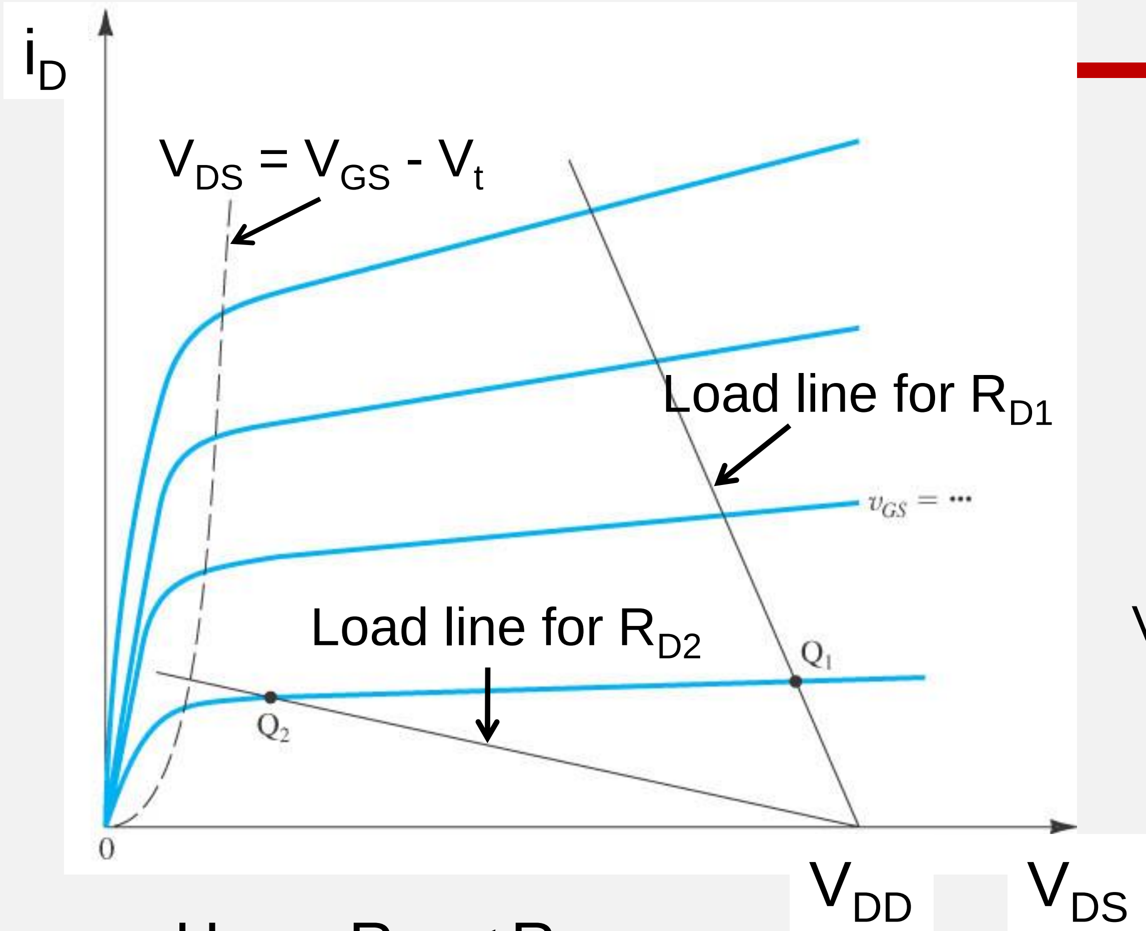
$$v_o = -g_m v_i (r_o \parallel R_D)$$

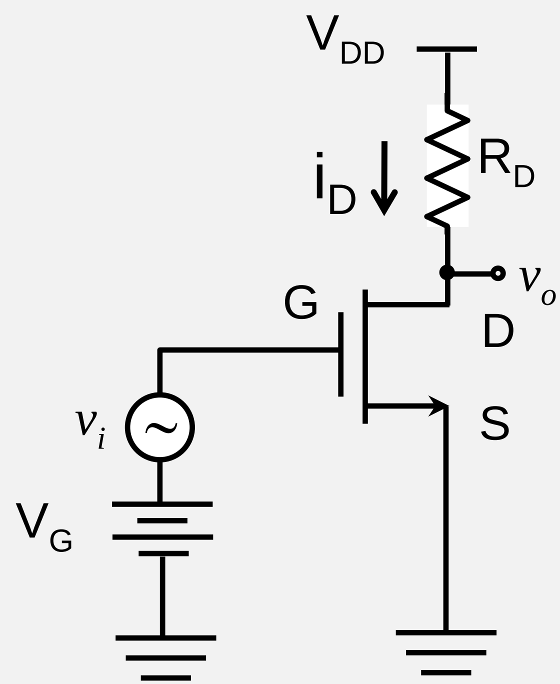
$$\Rightarrow \frac{v_o}{v_i} = -g_m (r_o \parallel R_D)$$

Note: Make sure that $V_{ds} > V_{gs} - V_t$ for the transistor to operate in the saturation region

$$g_m = \mu_n C_{ox} \frac{W}{L}(V_{gs} - V_t) = \frac{2I_D}{V_{gs} - V_t}$$

Output Signal Swing and Load Line





Here, $R_{D1} < R_{D2}$

Case 1: not enough "headroom"

Case 2: not enough "legroom"

$$\text{First}, \ v_o = V_{DS}$$

$$\text{load line}: i_D = \frac{V_{DD} - v_o}{R_D}$$

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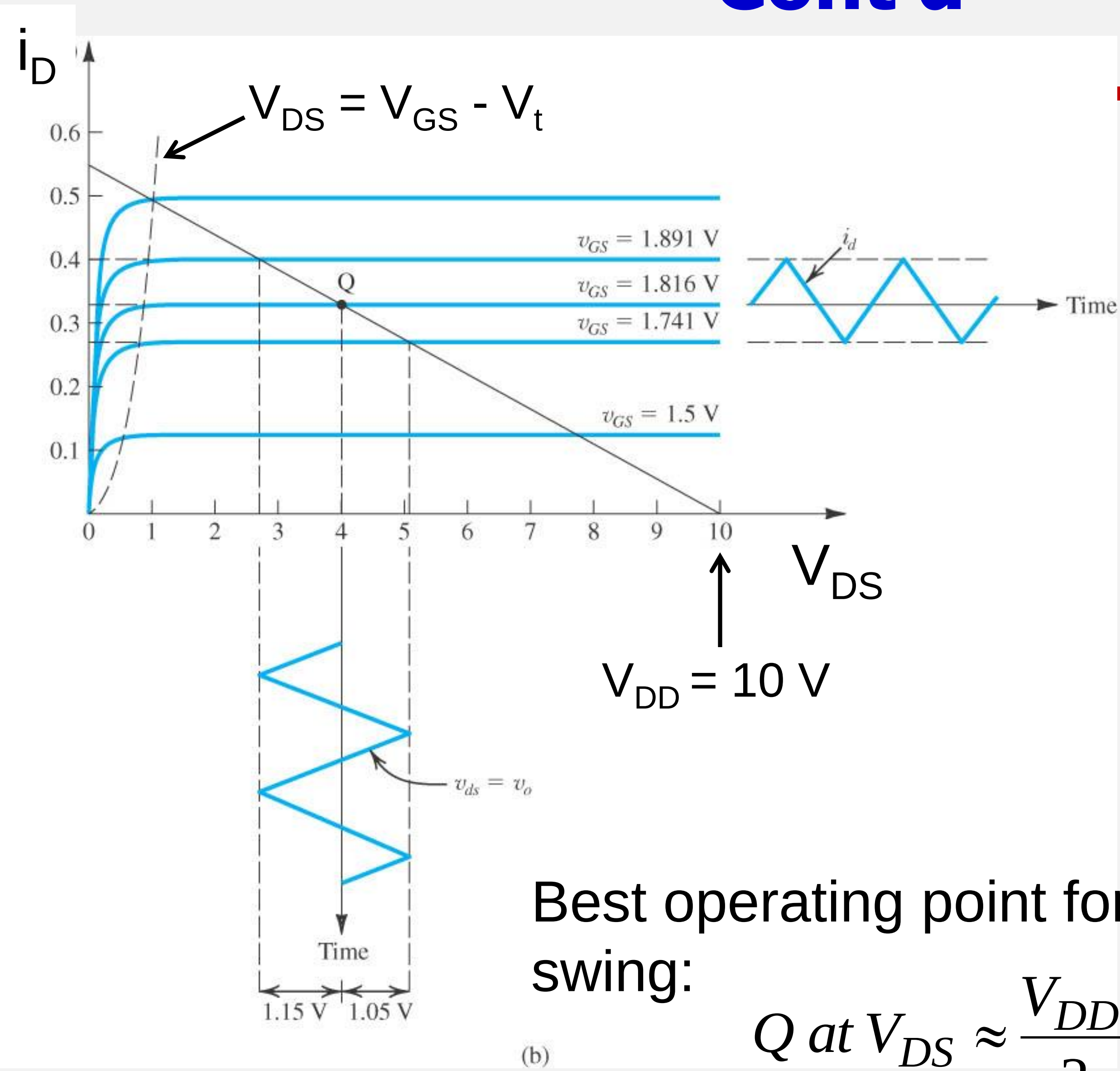
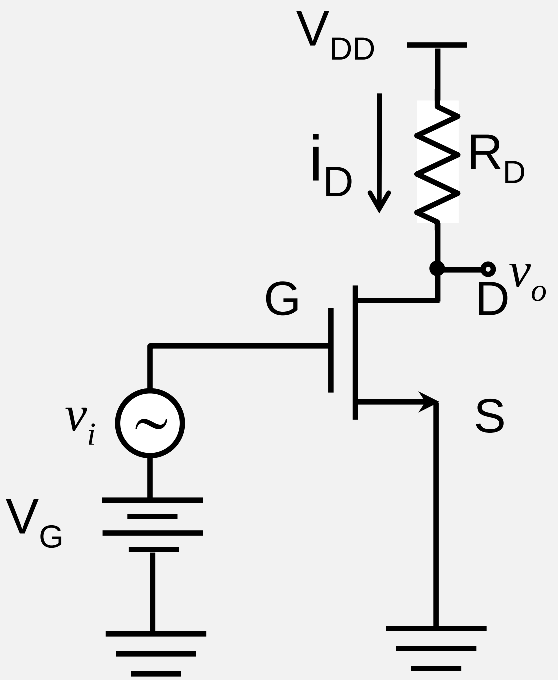




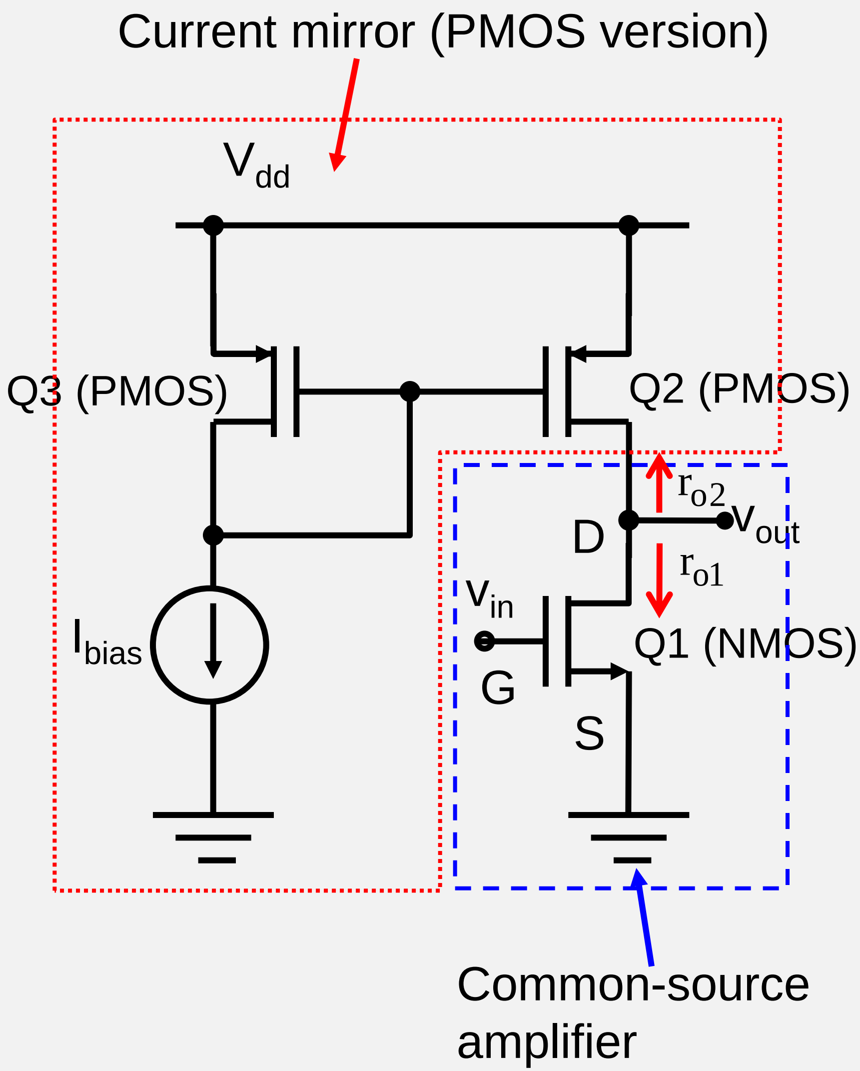
Best operating point for maximum swing:

$$Q \text{ at } V_{DS} \approx \frac{V_{DD}}{2} = 5V$$

CS Amplifier with an Active Load

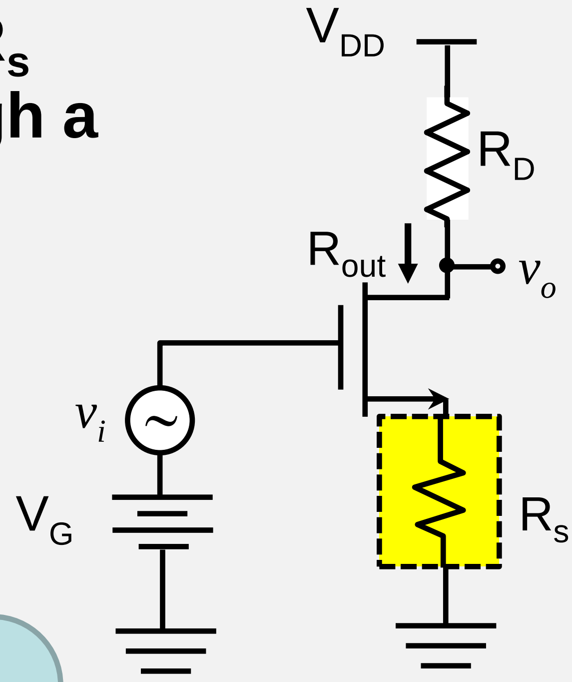
- **A p-type current mirror provides the bias current and active load to a n-type common-source amplifier Q1**
- **Using small-signal analysis, the voltage gain:**

$$A_v = \frac{v_{out}}{v_{in}} = -g_{m1}\left(r_{o1} // r_{o2}\right)$$



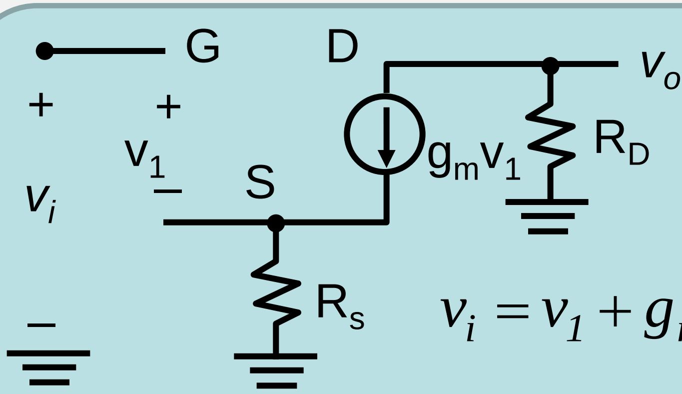
CS Amplifier with Source Degeneration

The source degeneration resistance R_s can stabilize the bias current I_D through a feedback mechanism (why?)



Gain reduces by a factor of $(1 + g_m R_s)$

$$\frac{v_o}{v_i} \approx -\frac{g_m R_D}{1 + g_m R_s} \qquad (\lambda = 0)$$

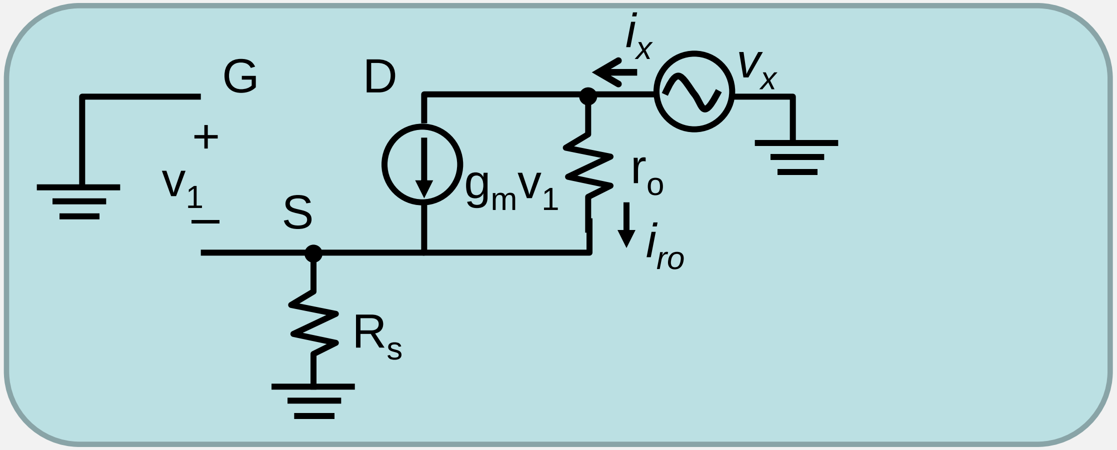


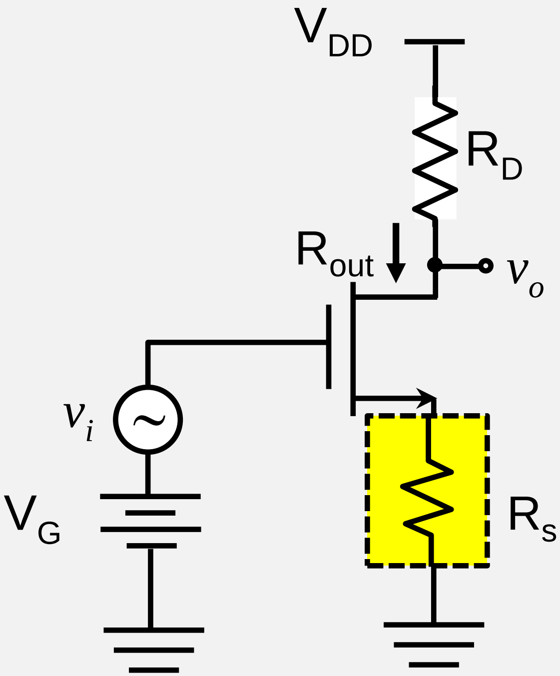
$$v_i = v_1 + g_m v_1 R_s \Rightarrow v_1 = \frac{v_i}{1 + g_m R_s}$$

R_{out} of CS Amplifier with Source Degeneration

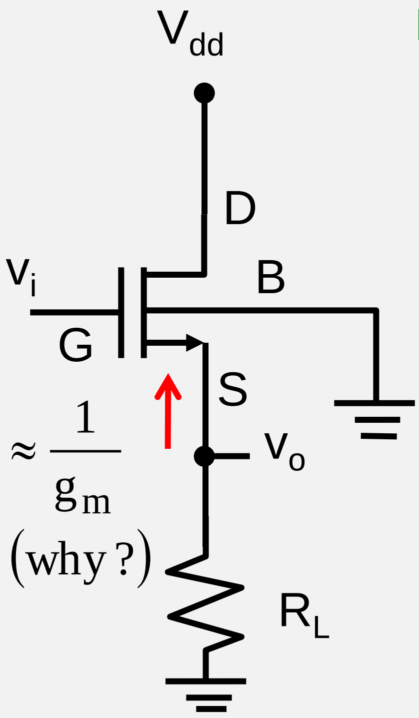
If $\lambda \neq 0$, $$R_{out} = \frac{v_x}{i_x} = (1 + g_m r_o) \cdot R_s + r_o$$

same as that of the common-gate amplifier



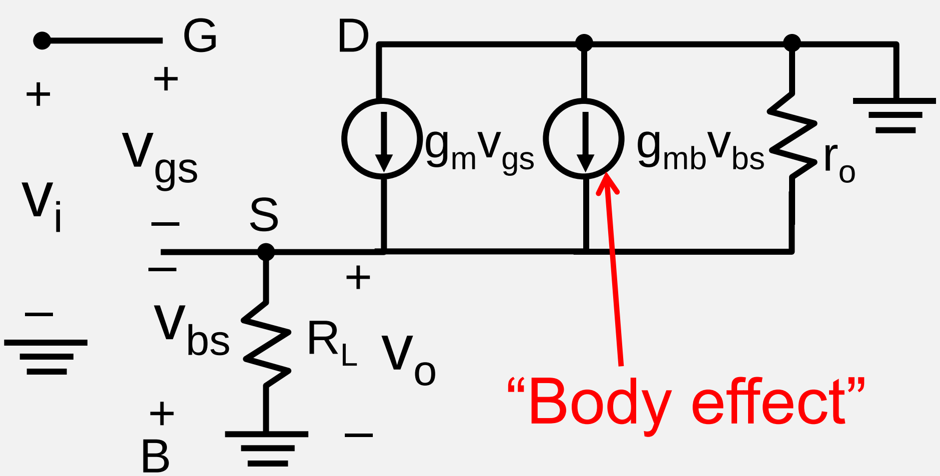


Common-Drain (CD) Amplifier (Source Follower)



- **Characteristics:**
  - **Voltage buffer amplifier with a gain close to 1**
  - **High input impedance: most of the voltage drop of v_i occurs on the gate**
  - **Low output impedance: most of the voltage drop occurs on R_L**
  - **Used often as the output stage in a multi-stage amplifier**

Small-Signal Analysis of CD Amplifier



- **Small signal gain (without body effect)**

$$v_o = g_m v_{gs} (r_o // R_L) \quad (1)$$

$$v_i = v_{gs} + v_o \quad (2)$$

Solve (1) and (2):

$$\frac{v_o}{v_i} = \frac{R_L \| r_o}{(R_L \| r_o) + \frac{1}{g_m}} \approx 1$$

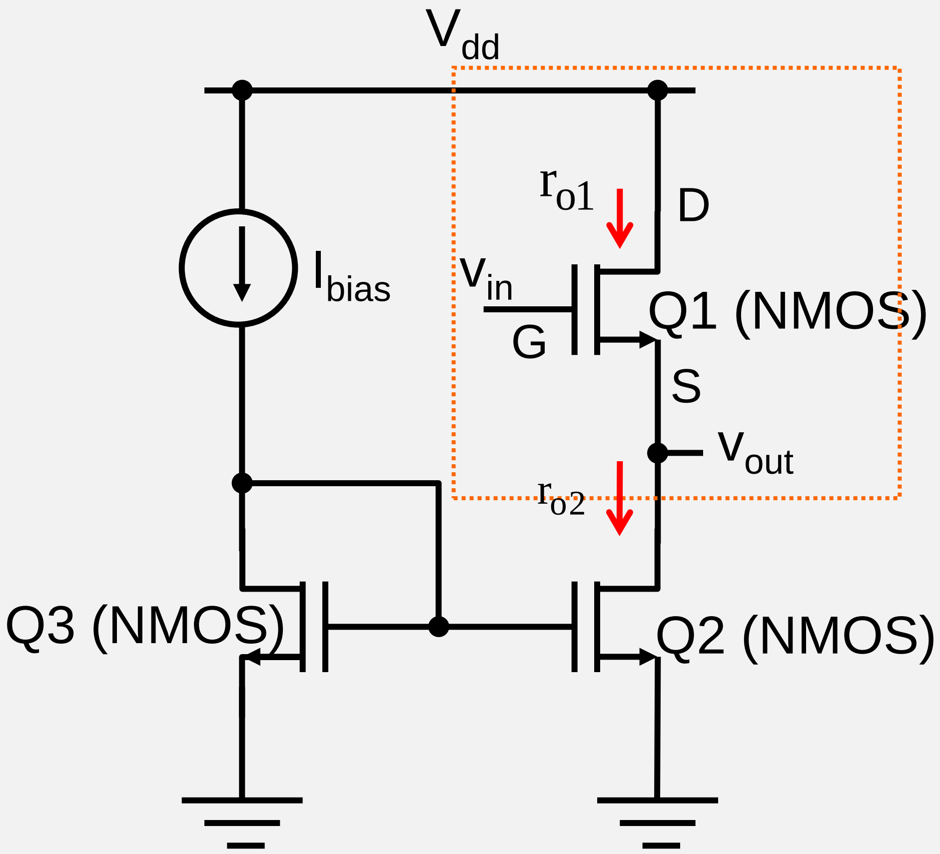
$$\left(for\ R_L \| r_o >> 1/g_m \right)$$

"Body effect": The threshold voltage increases when the source and the body terminals are not connected.

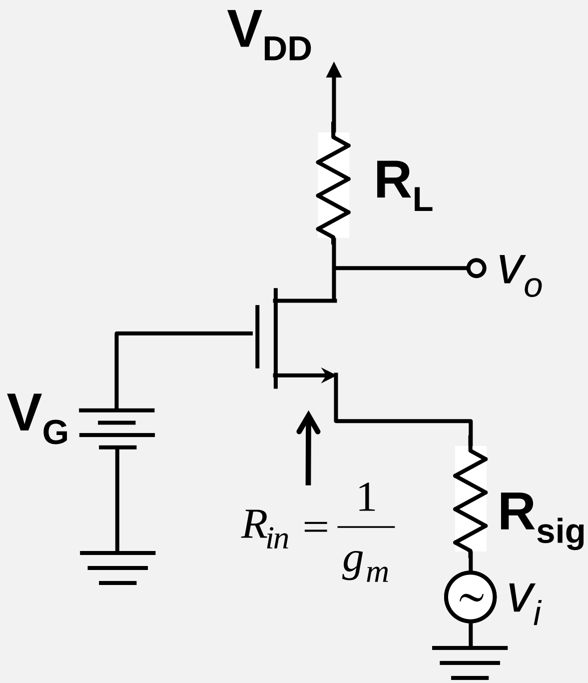
Source Follower with an Active Load

- **Q1 is the source follower (a <u>voltage buffer</u>) with an active load implemented by a n-type current mirror**

$$\frac{v_o}{v_i} = \frac{r_{o1} \,||\, r_{o2}}{\left(r_{o1} \,||\, r_{o2}\right) + \frac{1}{g_{m1}}}$$



Common-Gate (CG) Amplifier



- **Why uses a common-gate amplifier?**
  - It's a unity-gain current amplifier (current buffer) that reproduces the current in the drain terminal at a high output resistance
  - Can be used to make the cascode circuit

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

- **Compare a CG amplifier to a CS amplifier**
  - low input resistance
  - CG's overall voltage gain is smaller by a factor of about $1+g_mR_{sig}$
  - CG's gain is non-inverting
  - more influence by the body effect since the source cannot be connected to the body

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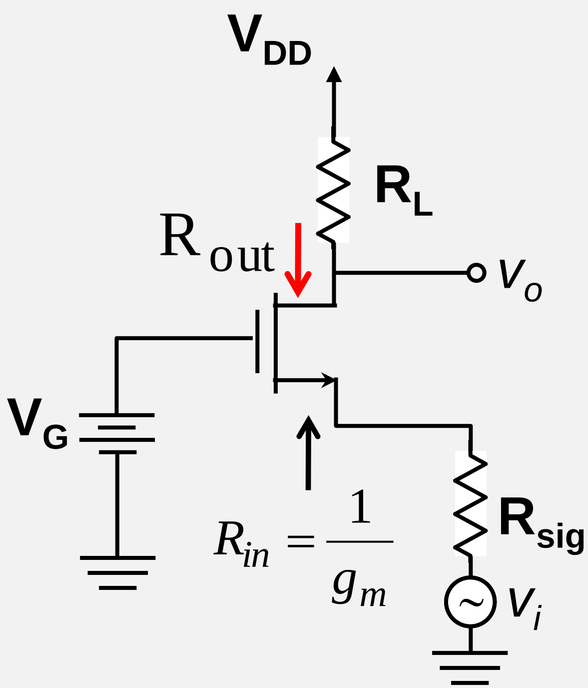


- **Without channel-length modulation (λ = 0)**

$$v_o = -g_m \cdot v_{gs} \cdot \left(R_L \parallel R_{out}\right)$$

$$= -\left(\frac{-R_{in}}{R_{in} + R_{sig}} \cdot v_i\right) \cdot g_m \cdot \left(R_L \parallel \underbrace{R_{out}}_{\infty}\right)$$

$$\Rightarrow \frac{v_o}{v_i} = \frac{g_m \cdot R_L}{1 + g_m R_{sig}}$$

- **With channel-length modulation (λ ≠ 0)**

$$\frac{v_o}{v_i} = \frac{g_m \cdot \left(R_L // R_{out}\right)}{1 + g_m R_{sig}}$$

$$R_{out} = \left(1 + g_m r_o\right) \cdot R_{sig} + r_o \approx g_m\, r_o\, R_{sig}$$

(if R_{sig} is large)

在CG中R_{out}被提升了，可利用製作cascode電路

same as the common-source amplifier with source degeneration (p. 7)

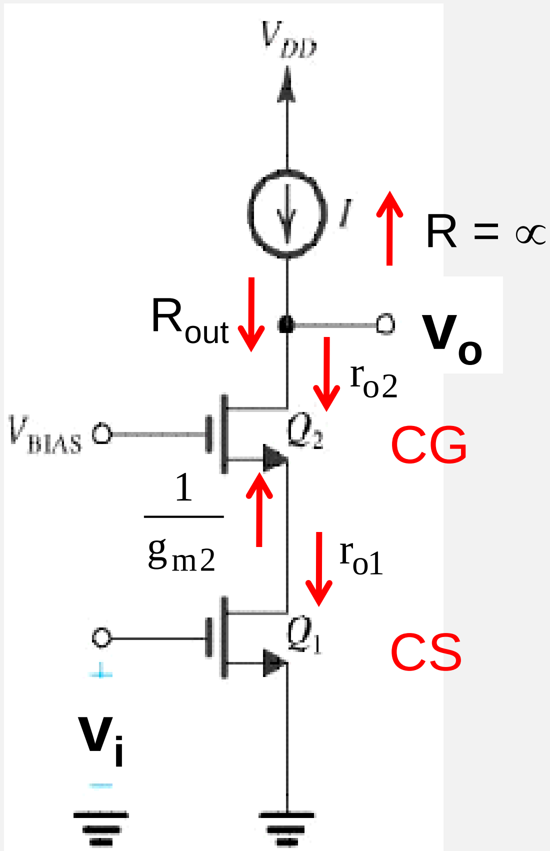
Cascode Amplifier (CS + CG)

- **The cascode transistor Q2 provide a low input resistance at the drain of Q1 and a high resistance at the output**

考慮上頁的圖:當$R_L = \infty$，$R_{sig} = r_{o1}$:

$$R_{out} = g_{m2} \cdot r_{o2} \cdot r_{o1}$$

$$\frac{v_o}{v_i} = -g_{m1} \cdot R_{out}$$



Mini Project: 3-Stage Amplifier

注意: $V_{ds} > V_{gs} - V_t$，以確保在saturation region工作

$$g_m = \frac{2I_D}{V_{gs} - V_t}$$