EE105
Microelectronic Devices and Circuits
Current Sources

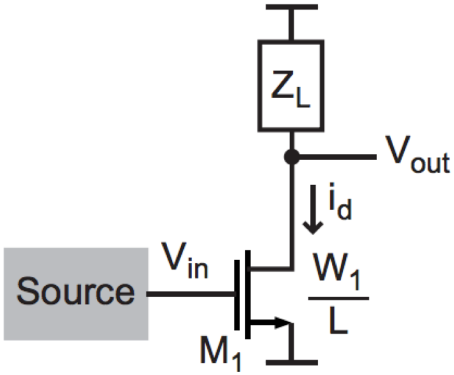
Prof. Ming C. Wu

wu@eecs.berkeley.edu

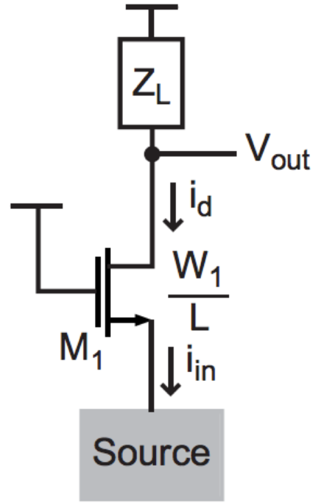
511 Sutardja Dai Hall (SDH)

Load Impedance

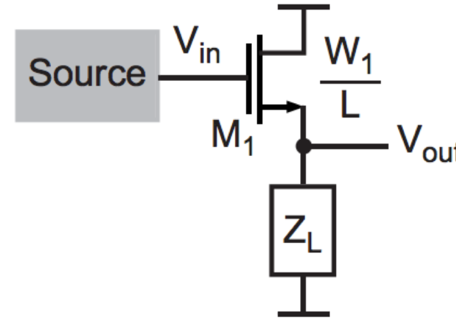
Common Source



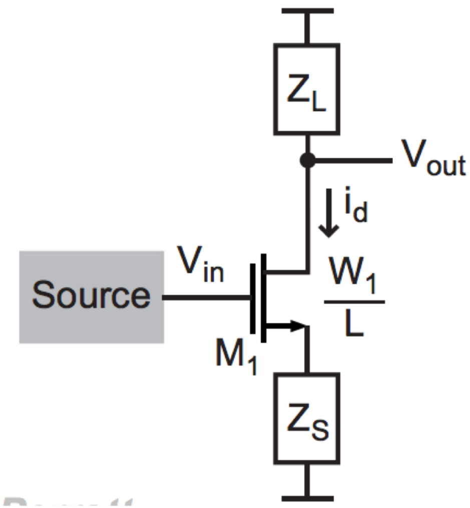
Common Gate



Source Follower

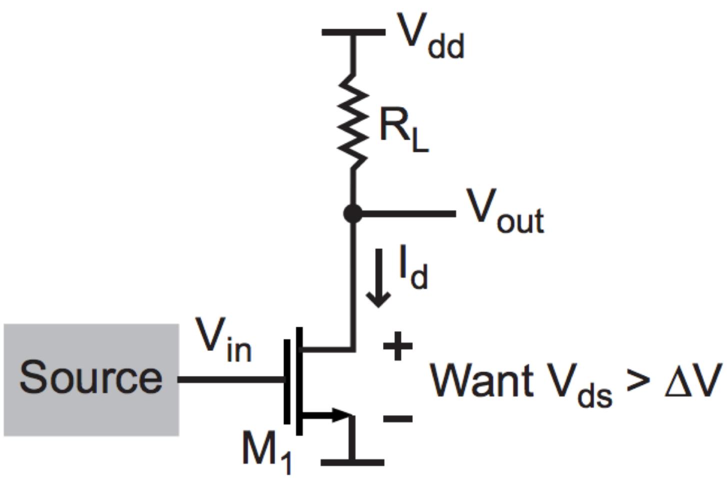


Common Source with Source Degeneration



- **To achieve high gain (or low attenuation in the case of a source follower), it is very desirable to achieve high load impedance, Z_L**
  - **Unfortunately, using a simple resistor of high value has issues**
    - What are these issues?

Issue: Headroom Limitations



- The bias current of the device is a direct function of R_L

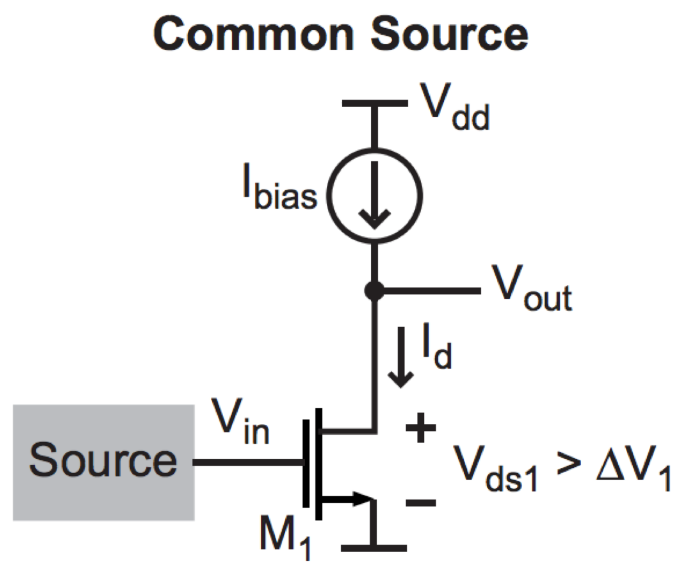
$$I_d = \frac{V_{dd} - V_{ds}}{R_L}$$

  - V_{dd} is < 3.6V for most modern CMOS processes
  - V_{ds} must be greater than ΔV to maintain device saturation

Large R_L implies small I_d
(implies small g_m, poor frequency response, etc.)

Courtesy M. Perrott

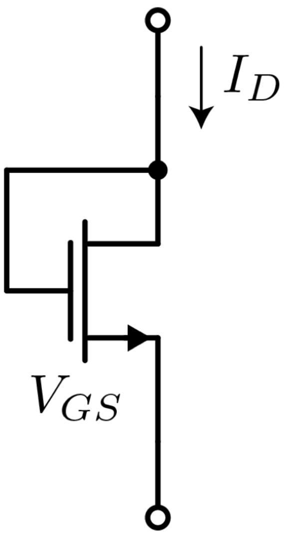
Achieving High Gain



- Replacement of resistor load with a current source yields the highest possible DC gain out of the amplifier
  - Current source determines I_d of device
- We can make current sources out of transistors
  - Generally smaller area than polysilicon resistors

What is the small signal gain of the above circuit?

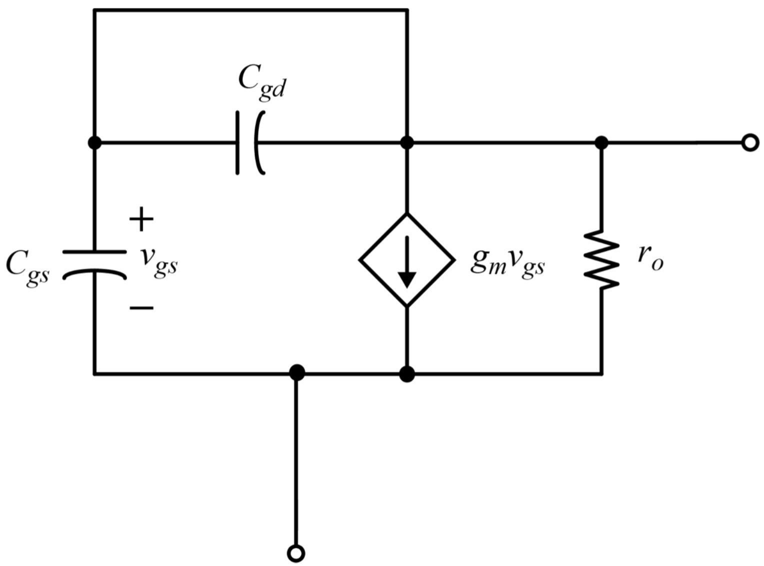
Diode Connected Device



$$V_{GS} = V_{DS}$$

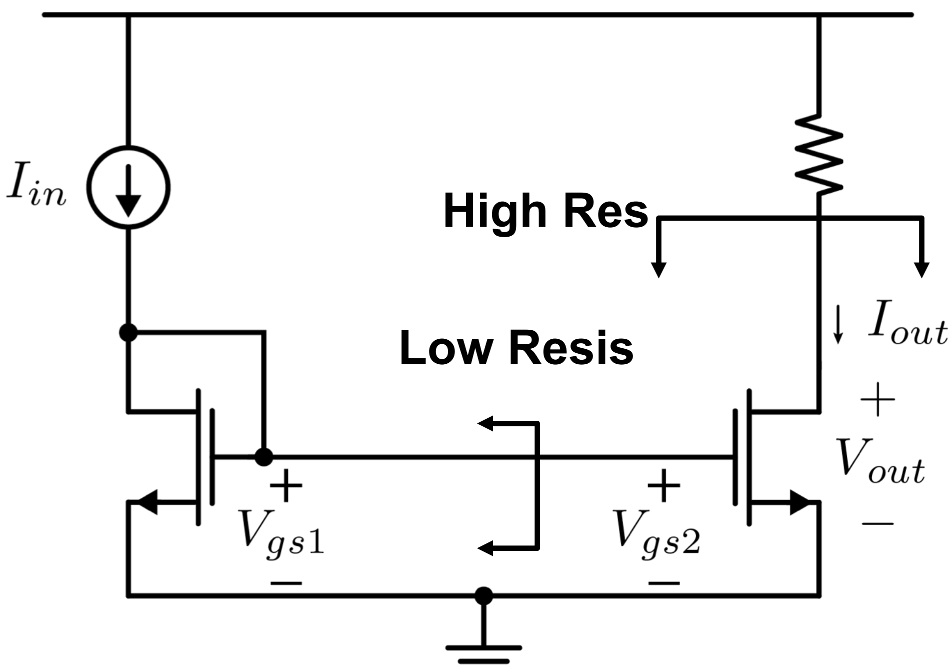
- **How do we build current sources?**
- **Let’s start with a “diode connected” device**
- **A MOS device with gate and drain shorted operates like a diode (but not exponential)**

Diode Connected -- SS Model



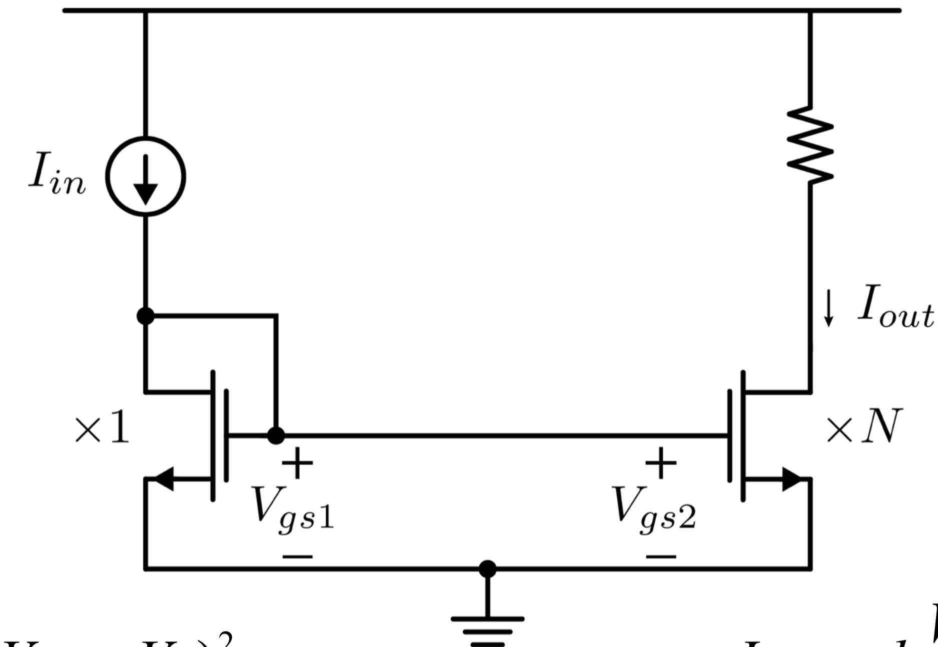
- We can derive the small-signal model by shorting out the hybrid-pi model
- Note that a Gm generator with it's controlling terminals connected to the Gm is more simply a …?

The Integrated "Current Mirror"



- M_1 and M_2 have the same V_{GS}
- If we neglect CLM (λ=0), then the drain currents are equal
- Since λ is small, the currents will nearly mirror one another *even if V_{out} is not equal to V_{GS1}*
- We say that the current I_{REF} is mirrored into i_{OUT}
- Notice that the mirror works for small and large signals!

Multiplication Ratio

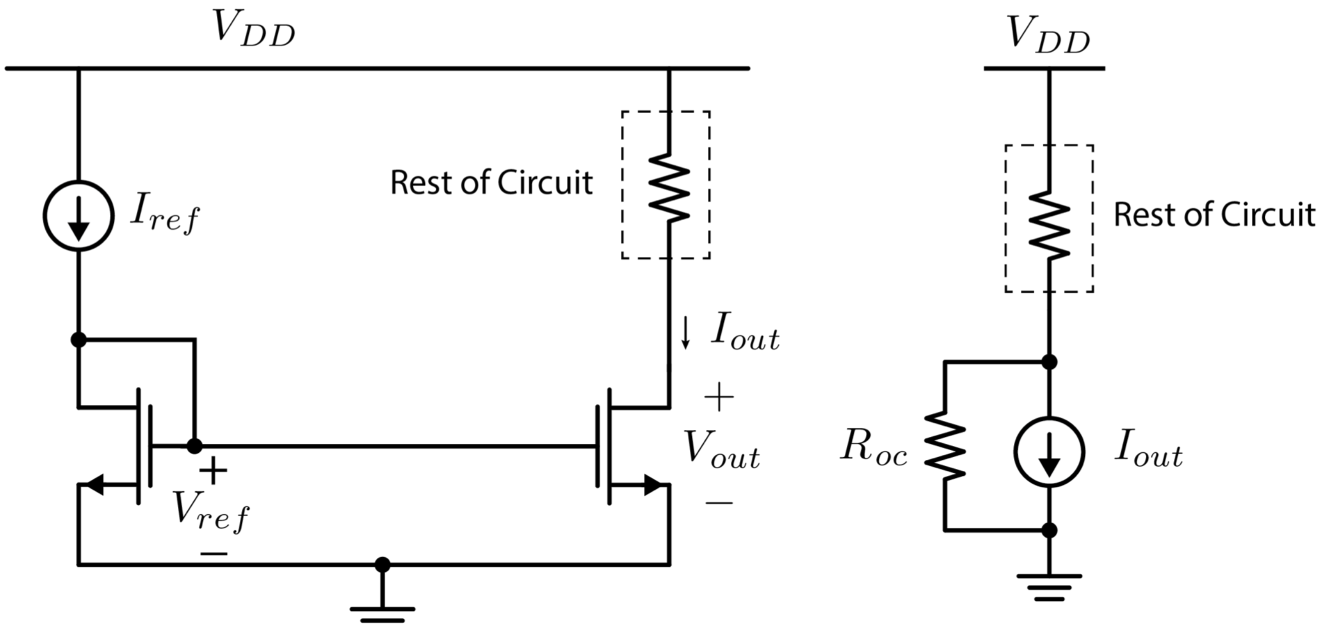


$$I_{IN} = k\frac{W_1}{L_1}(V_{GS1} - V_T)^2 \qquad I_{OUT} = k\frac{W_2}{L_2}(V_{GS2} - V_T)^2$$

$$V_{GS1} = V_{GS2}$$

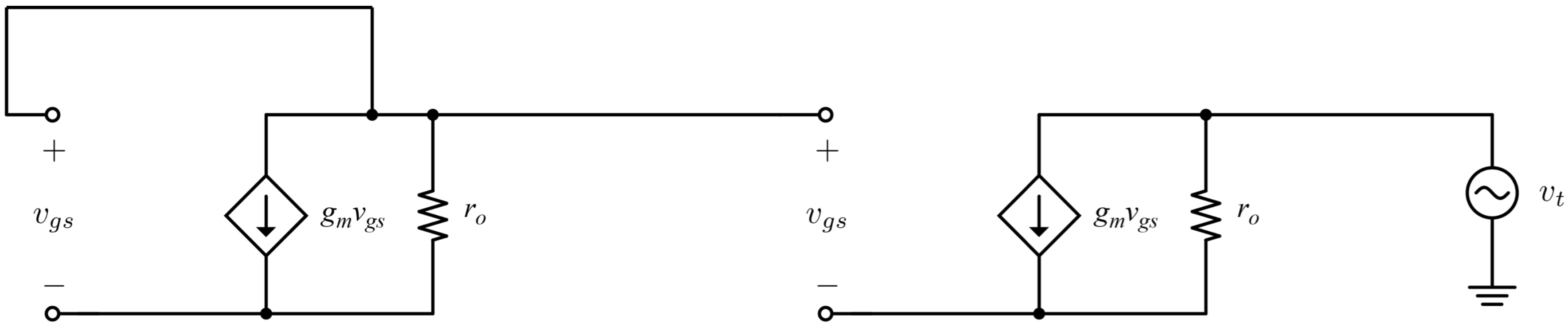
$$I_{OUT} = k\frac{W_2}{L_2}(V_{GS2} - V_T)^2 = I_{IN}\frac{W_2/L_2}{W_1/L_1} = NI_{IN}$$

Current Mirror as Current Source



- **The output current of M_2 is only weakly dependent on v_{OUT} due to high output resistance of FET**
- **M2 acts like a current source to the rest of the circuit**
- **For good current source behavior, what is the minimum v_{OUT}?**

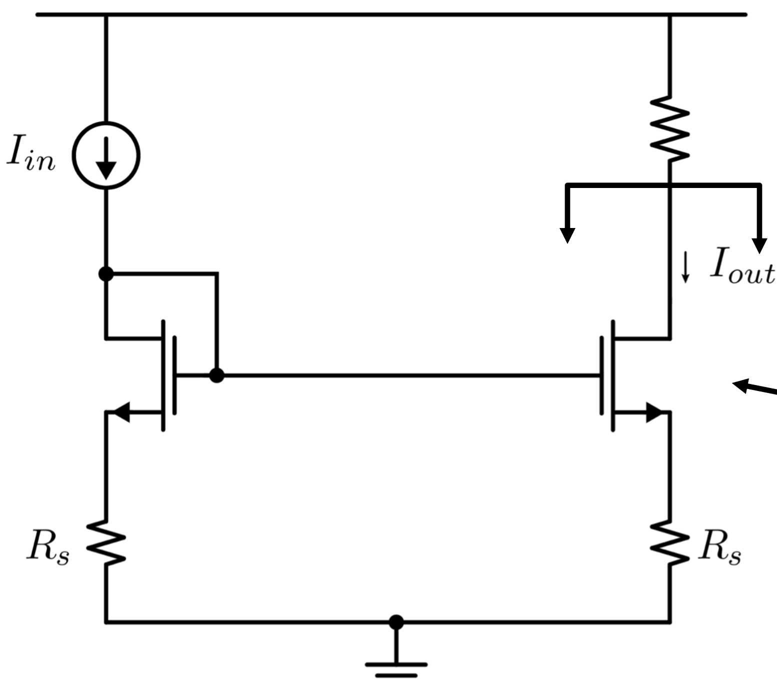
Small-Signal Resistance of *I*-Source



Improved Current Sources

Goal: increase *R*$_{o(ut)}$

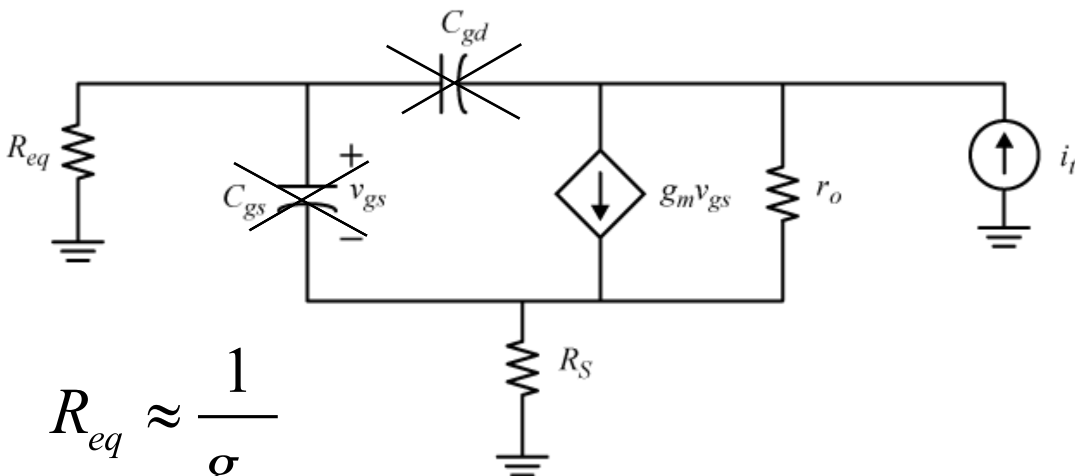
Approach: look at *amplifier* output resistance results … to see topologies that boost resistance



$R_{out} >> r_o$

Looks like the output impedance of a common-source amplifier with source degeneration

Effect of Source Degeneration



$$R_{eq} \approx \frac{1}{g_m}$$

$$v_t = (i_t - g_m v_{gs}) r_o + v_{R_S}$$

$$v_{gs} \approx -v_{R_S}$$

$$v_{R_S} = i_t R_S$$

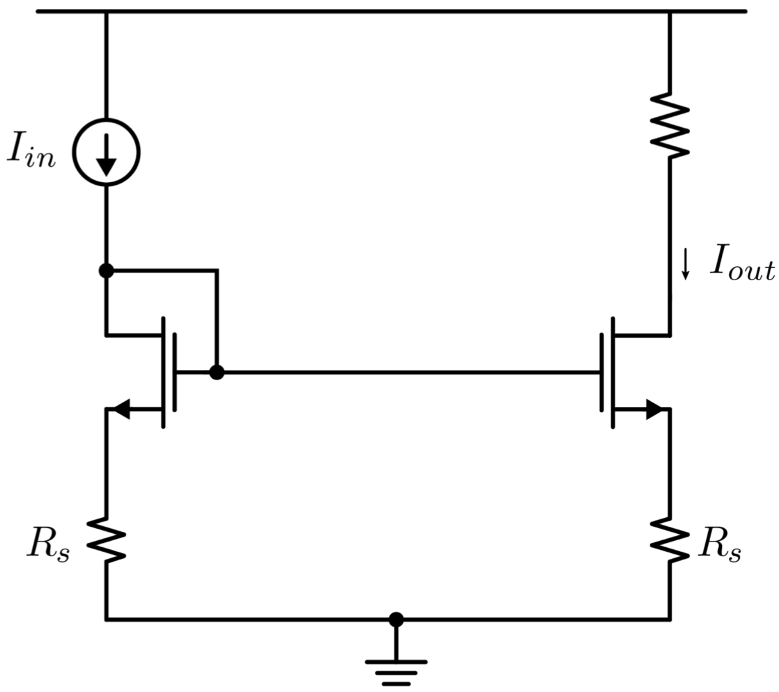
$$v_t = (i_t + g_m R_S i_t) r_o + i_t R_S$$

$$R_o = \frac{v_t}{i_t} \approx \left(1 + g_m R_S\right) r_o$$

- **Equivalent resistance loading gate is dominated by the diode resistance … assume this is a small impedance**
- **Output impedance is boosted by factor** $(1 + g_m R_S)$

Improved Current Sources

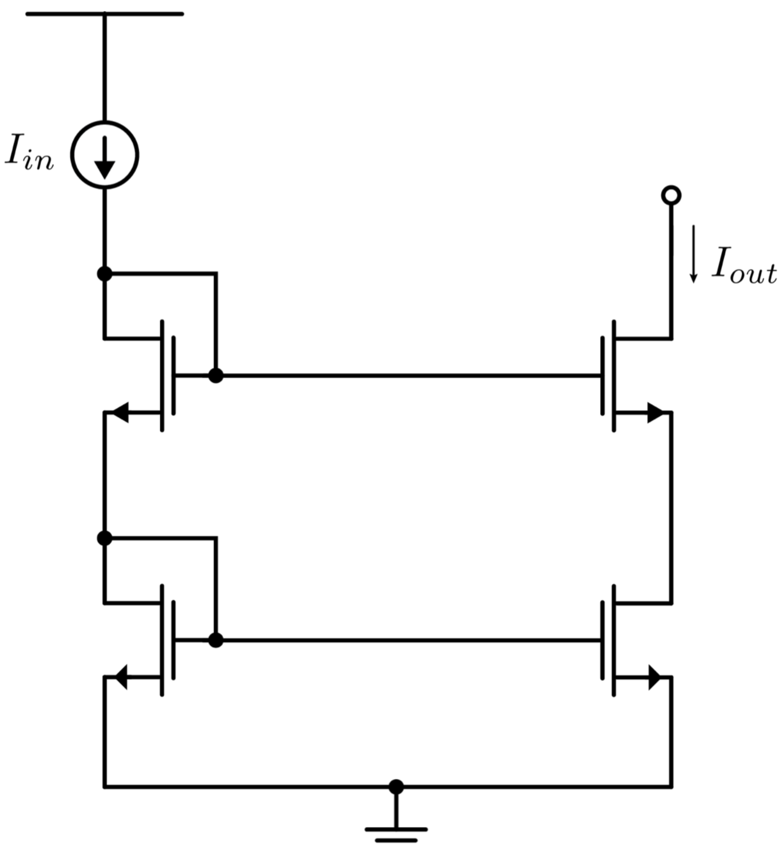
How would you scale the output current?



$$I_{IN} = k\frac{W_1}{L_1}(V_G - V_S - V_T)^2$$

$$V_S = I_{IN} R_S$$

Cascode (or Stacked) Current Source



Insight: V_{GS2} **= constant AND**
V_{DS2} **= constant**

Small-Signal Resistance R_o**:**

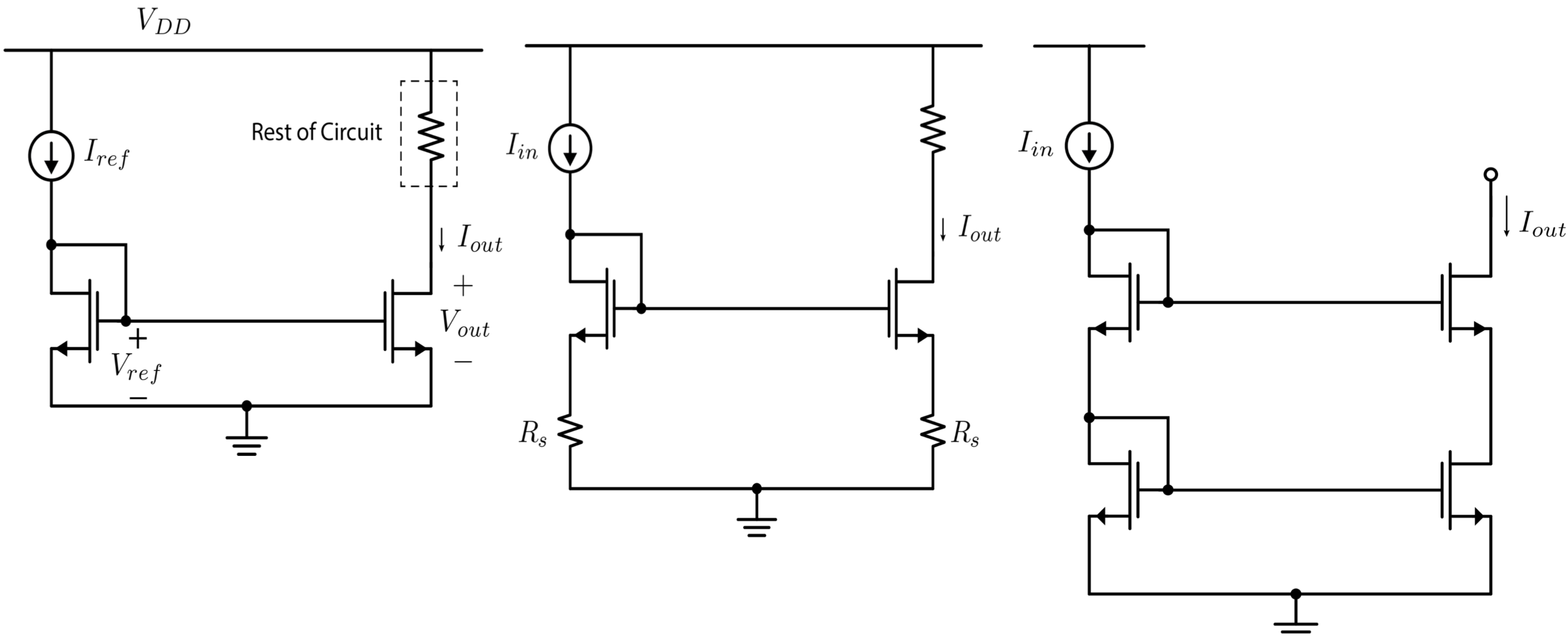
$$R_o \approx \left(1 + g_m R_S\right) r_o$$

$$R_o \approx \left(1 + g_m r_o\right) r_o$$

$$R_o \approx g_m r_0^2 >> r_o$$

Drawback of Cascode *I*-Source

What is the minimum output voltage to keep <u>all</u> transistors in saturation?



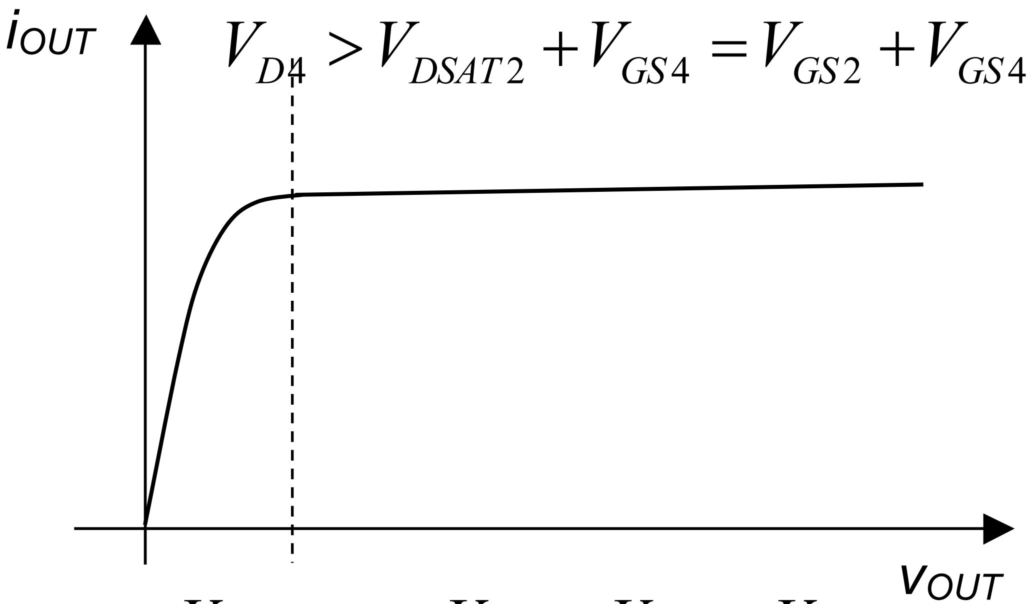
Drawback of Cascode *I*-Source

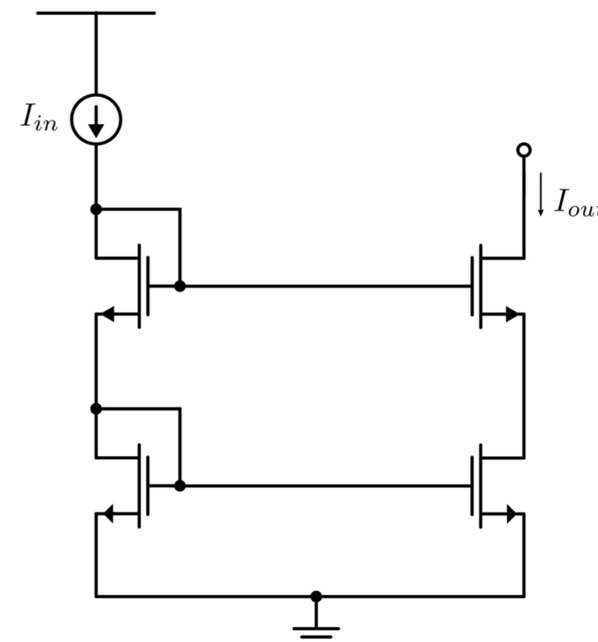
Minimum output voltage to keep both transistors in saturation:

$$V_{OUT,MIN} = V_{DS4,MIN} + V_{DS2,MIN}$$

$$V_{DS2,MIN} > V_{GS2} - V_{T0} = V_{DSAT2}$$

$$V_{D4} > V_{DSAT2} + V_{GS4} = V_{GS2} + V_{GS4} - V_{T0}$$



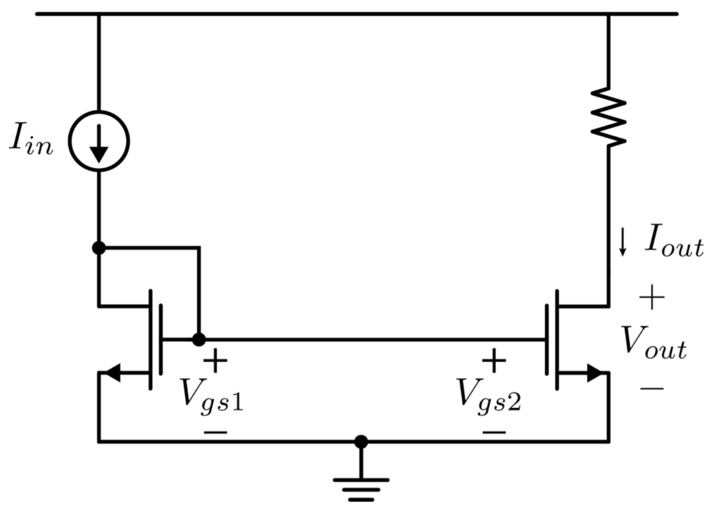


$$V_{OUT,MIN} = V_{GS2} + V_{GS4} - V_{T0}$$

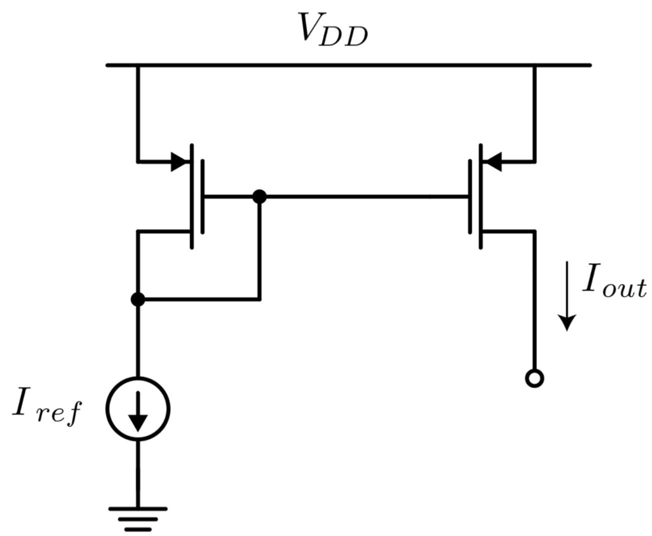
In EE140 you will learn circuit tricks to overcome this problem!

Current Sinks and Sources

Sink: output current goes to ground

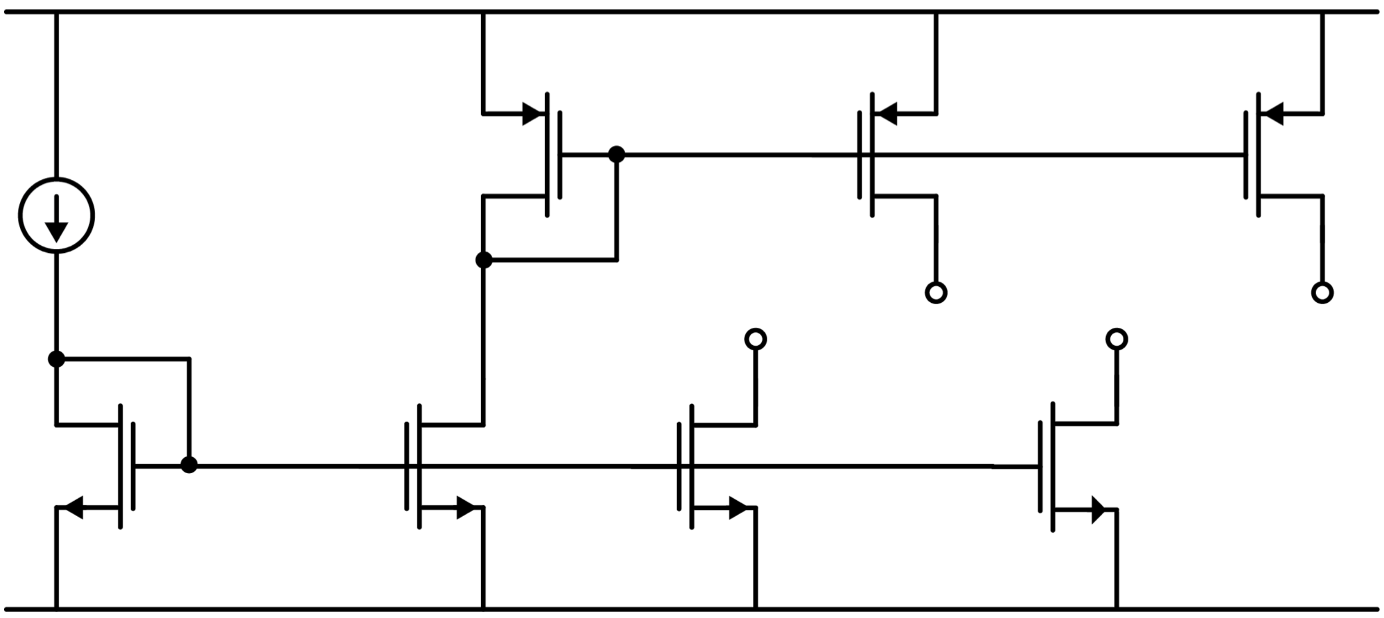


Source: output current comes from voltage supply

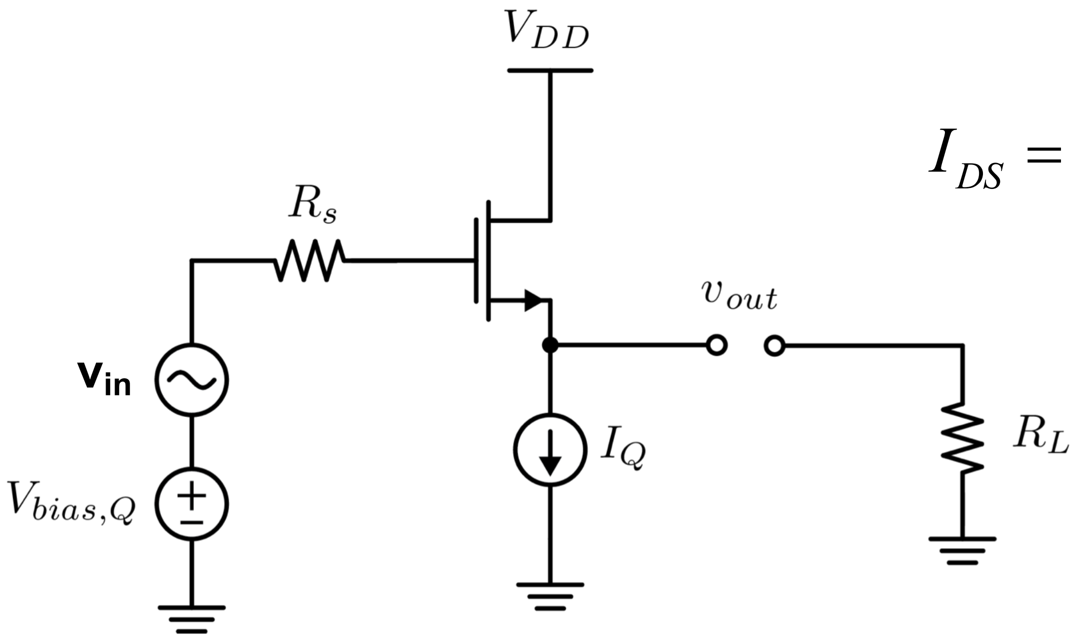


Current Mirrors

Idea: we only need one reference current to set up all the current sources and sinks needed for a multistage amplifier.



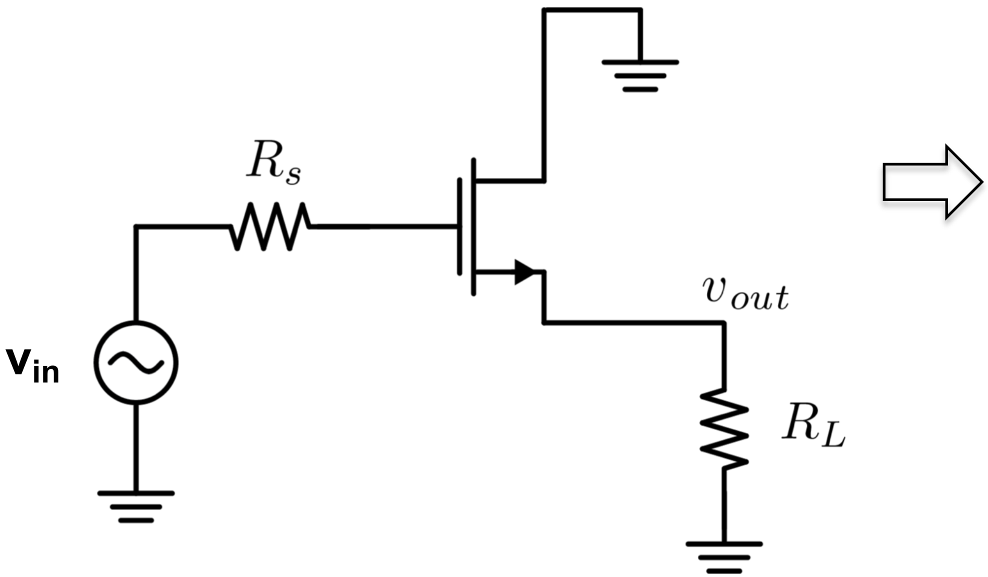
Example: Common-Drain Amplifier



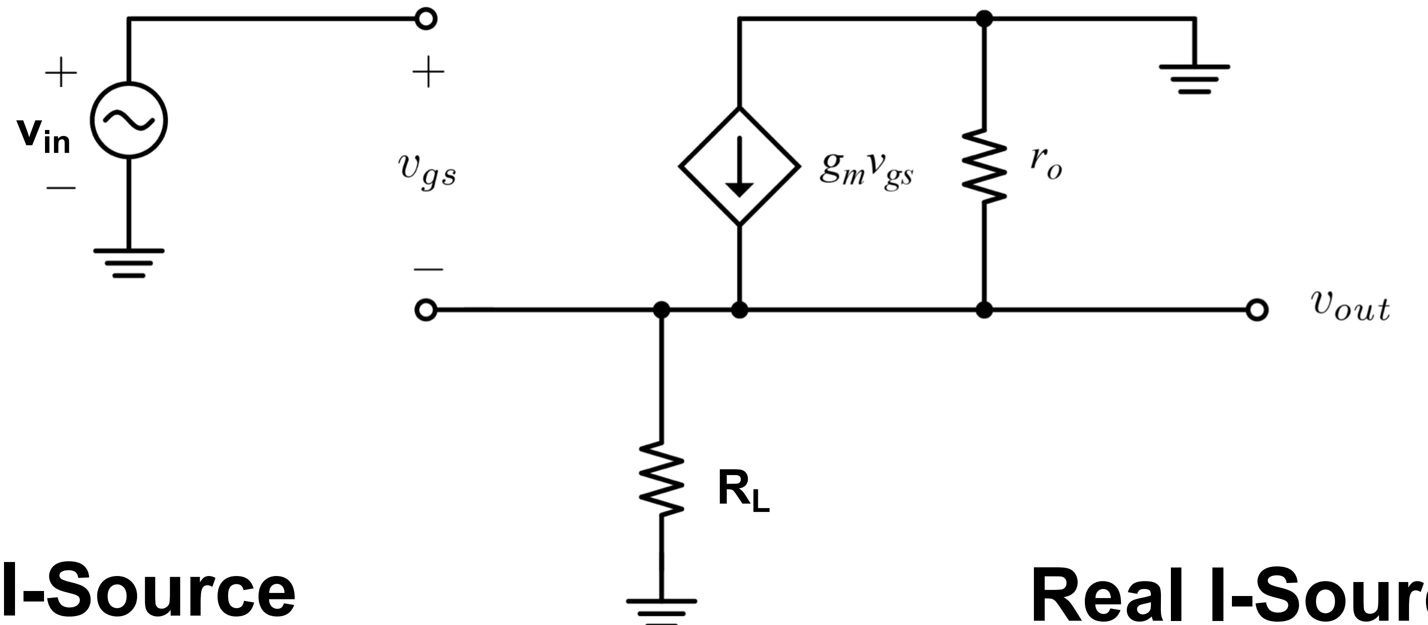
$$I_{DS} = \mu C_{ox} \frac{W}{L} \frac{1}{2} (V_{GS} - V_T)^2$$

Common Drain AC Schematic

How does a REAL current source fit in to the small-signal model?



CD Voltage Gain With Real I-Source



Ideal I-Source

Real I-Source

$$\frac{v_{out}}{R_L \parallel r_o} = g_m v_{gs}$$

$$\frac{v_{out}}{R_L \parallel r_o} = g_m \left(v_{in} - v_{out} \right)$$