Lecture 4, ANIK

Current mirrors
More on amplifiers (frequency domain)

LiU EXPANDING REALITY

What did we do last time?

Voltage swing

How far can we push the transistors?

Target: Force all operate in saturation region

Ways to increase the gain?

0) Physical sizing

1) Electrical handles

2) Cascodes

3) Multiple stages

What will we do today?

Current mirrors

- Simple, Wilson, Wide-Swing, Cascoded
- Decoupling design parameters using current mirrors

Improved amplifier stages

- Folded-cascoded gain stage
- Gain-boosting

The frequency domain

- Dominant-pole, DC gain, unity-gain frequency

Some kind of wrap-up session

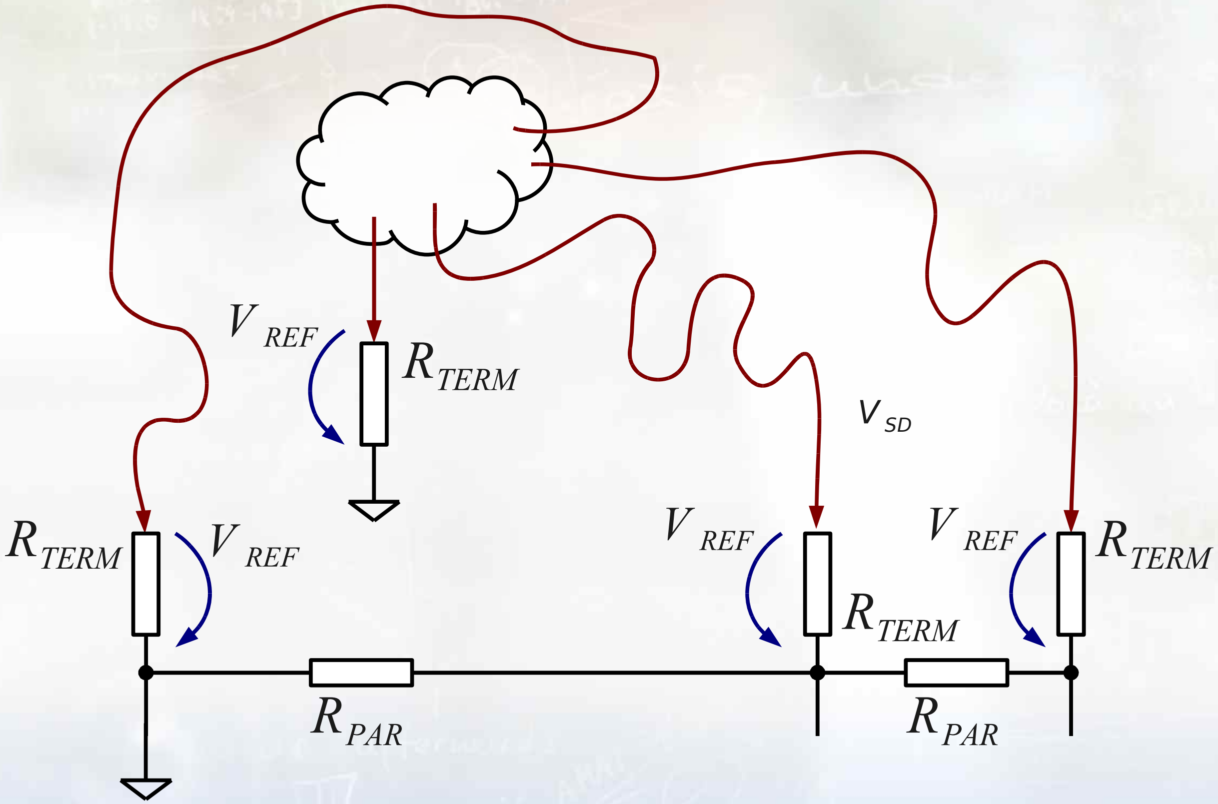
Current mirrors

Use currents to distribute references (low speed) over a chip

Receiver determines voltage across resistor

Resistance in wire does not matter

Local "ground" does not influence the result



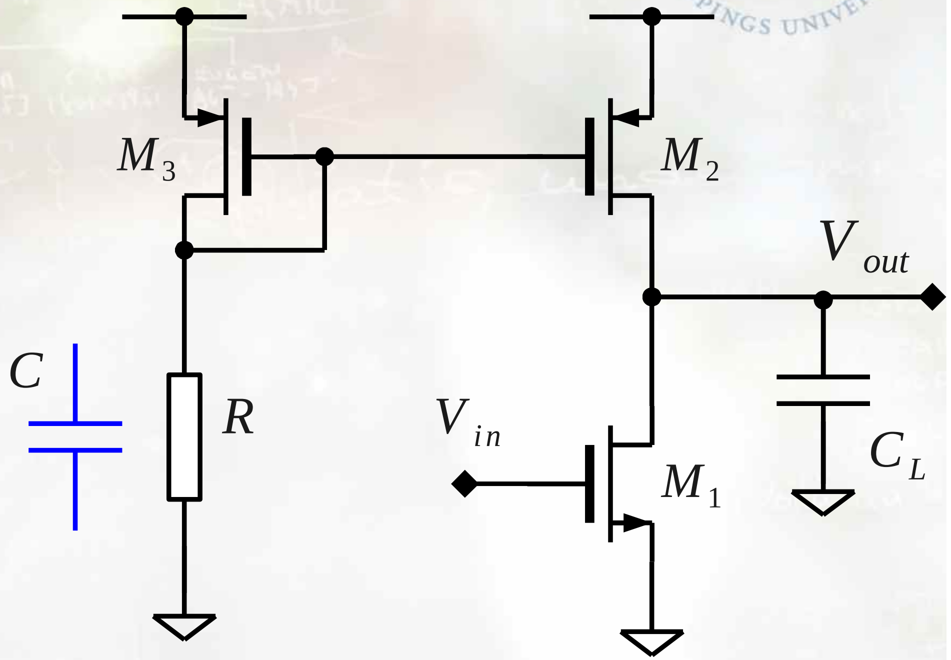
Current mirrors, cont'd

Use currents to bias amplifier stages

Decouples the design parameters!

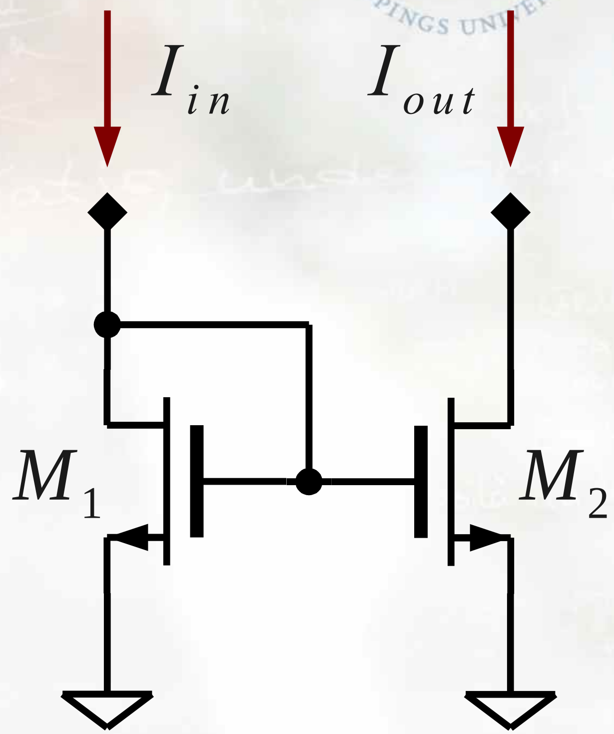
We can "ignore" the size and v_{eff} of the bias transistor (active load)

Set the current through a reference of some kind



LiU EXPANDING REALITY

Current mirrors, cont'd



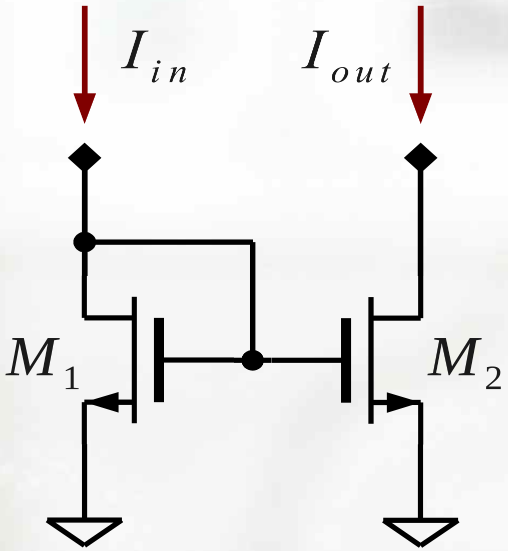
Input (primary) should behave as a current sink, i.e., have

$$Z_{in} = 0$$

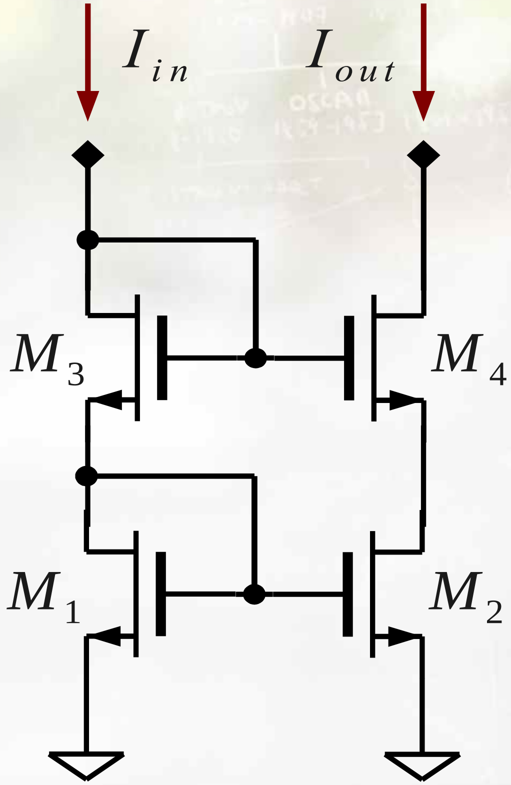
Output (secondary) should behave as a current source, i.e., have

$$Z_{out} = 0$$

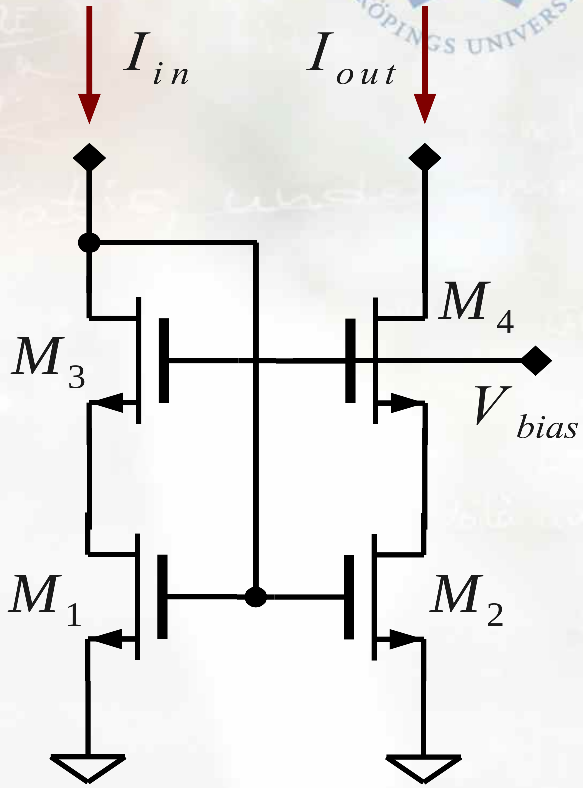
Current mirrors



(a) Simple



(b) Cascode



(c) Wideswing

Current mirrors, operation

The current relationship is given by the transistor sizes.

Notice that the v_{eff} is constant on the lower transistors.

$$I_{out} = \frac{\alpha_{out}}{\alpha_{in}} \cdot I_{in}$$

Compare with second-order model

$$\frac{I_{out}}{I_{in}} = \frac{\alpha_{out}}{\alpha_{in}} \cdot \frac{1 + \lambda v_{out}}{1 + \lambda v_{in}}$$

which will be too big of variations.

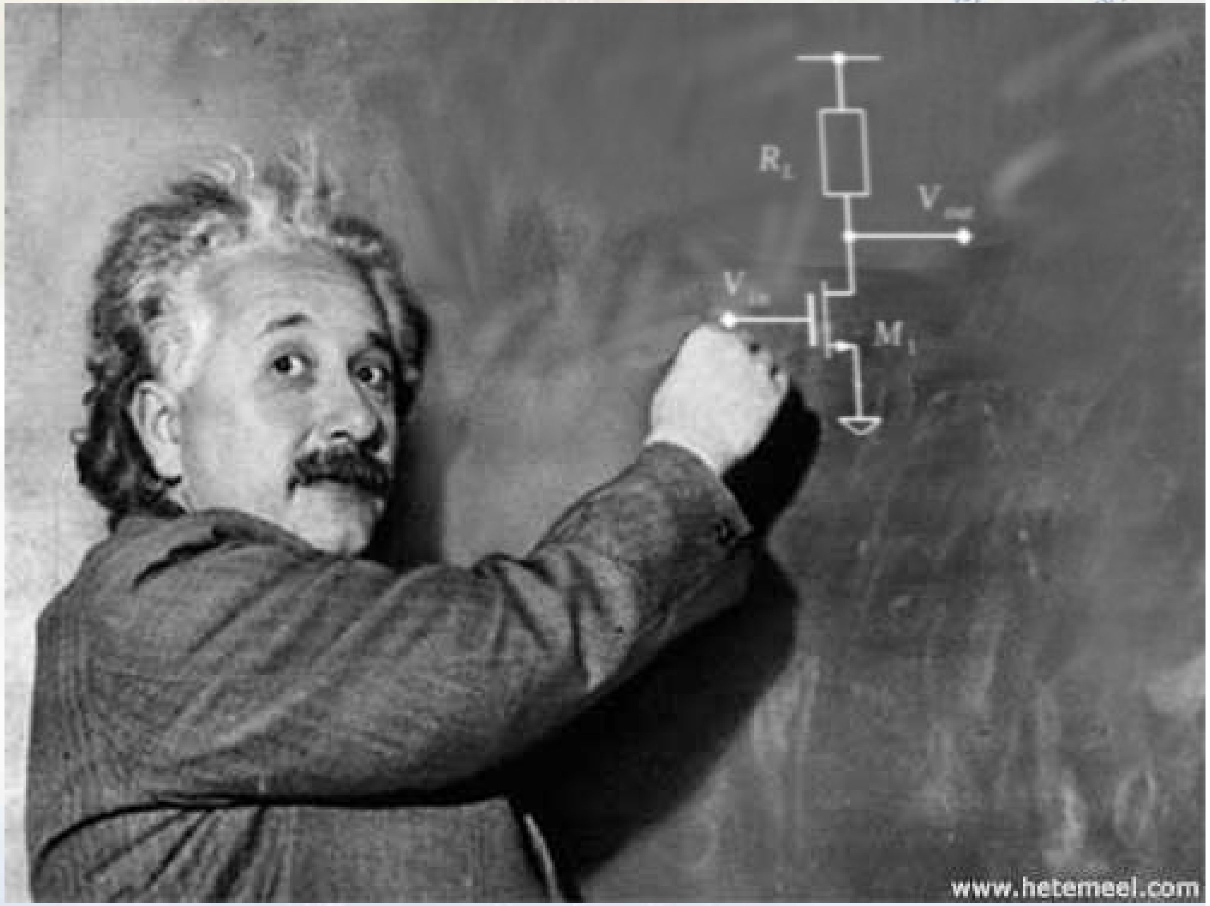
Current mirrors, nonidealties

Voltage swing

- Potential drops back and forth

Calculating the impedances

- Use the quick-trick from cascodes for cascodes

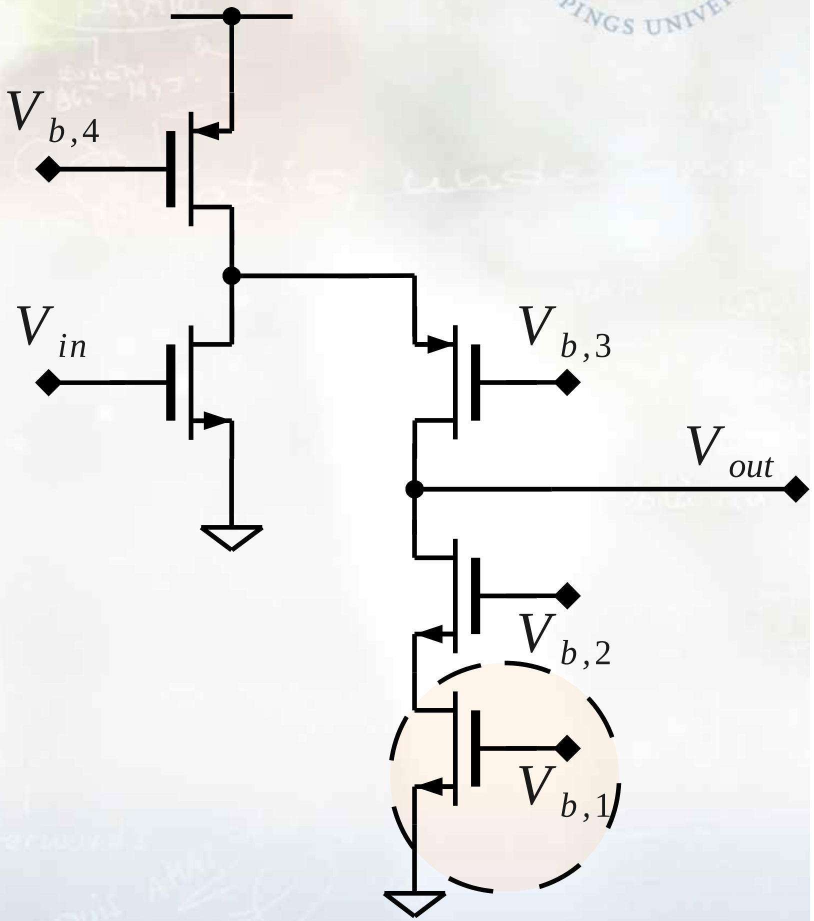


Improved amplifier stages

Folded cascode

- Common-source + common-gate
- Same type of gain as in cascoded gain stage
- Range increases (feedback configuration)

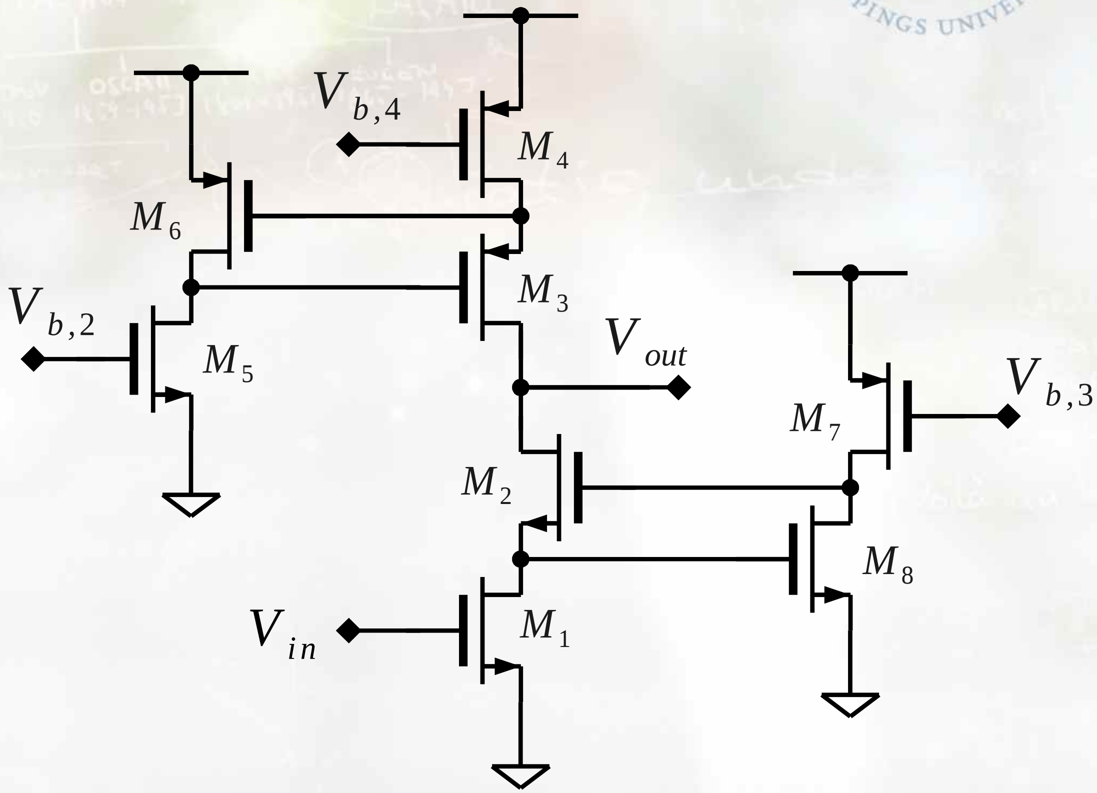
Why do we need the lower NMOS?



Improved amplifier stages

Gain-boosting

Additional amplifier sets the gain of the cascode



"Output impedance is multiplied by cascode"

What about the swing now?

Improved amplifier stages, cont'd

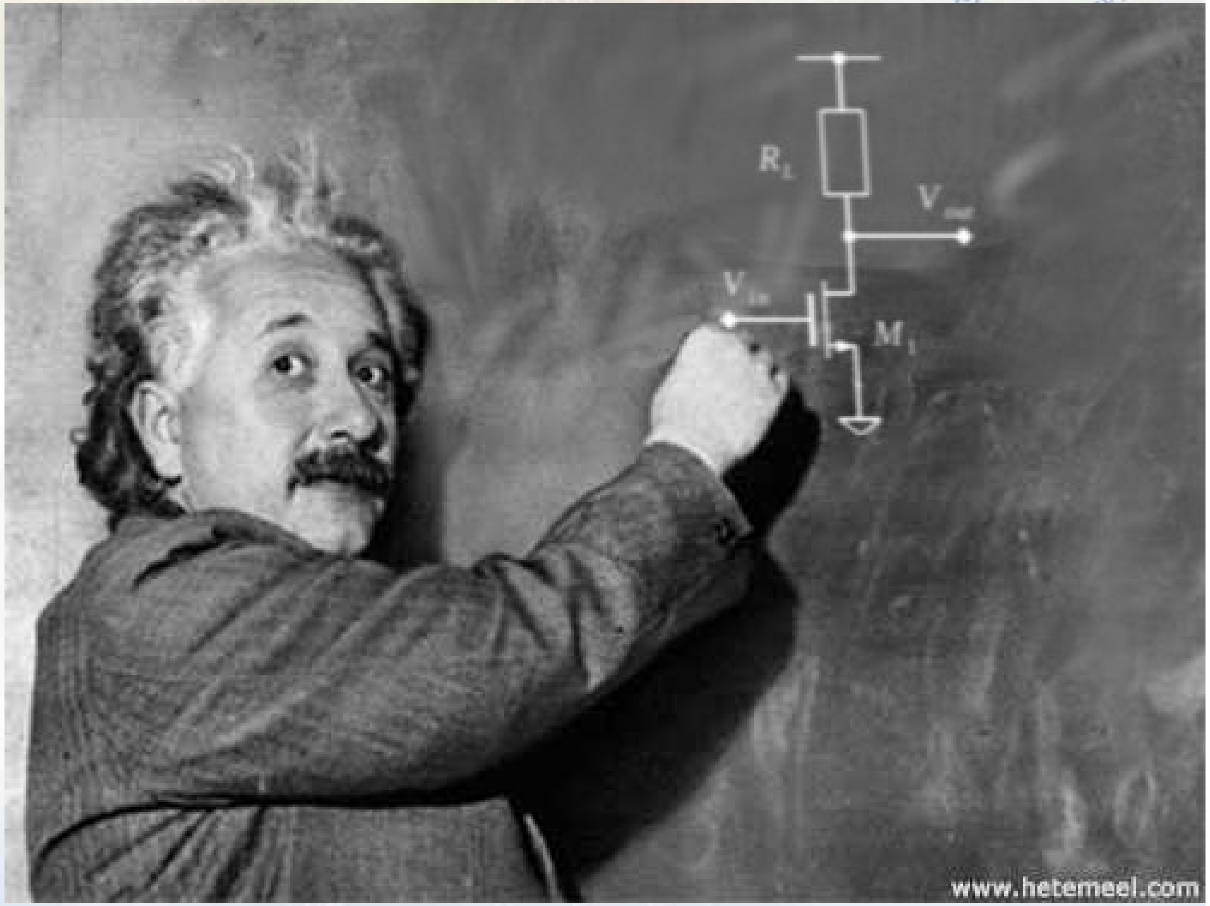
Folded cascode and gain boosting

Operation

Calculating the impedances

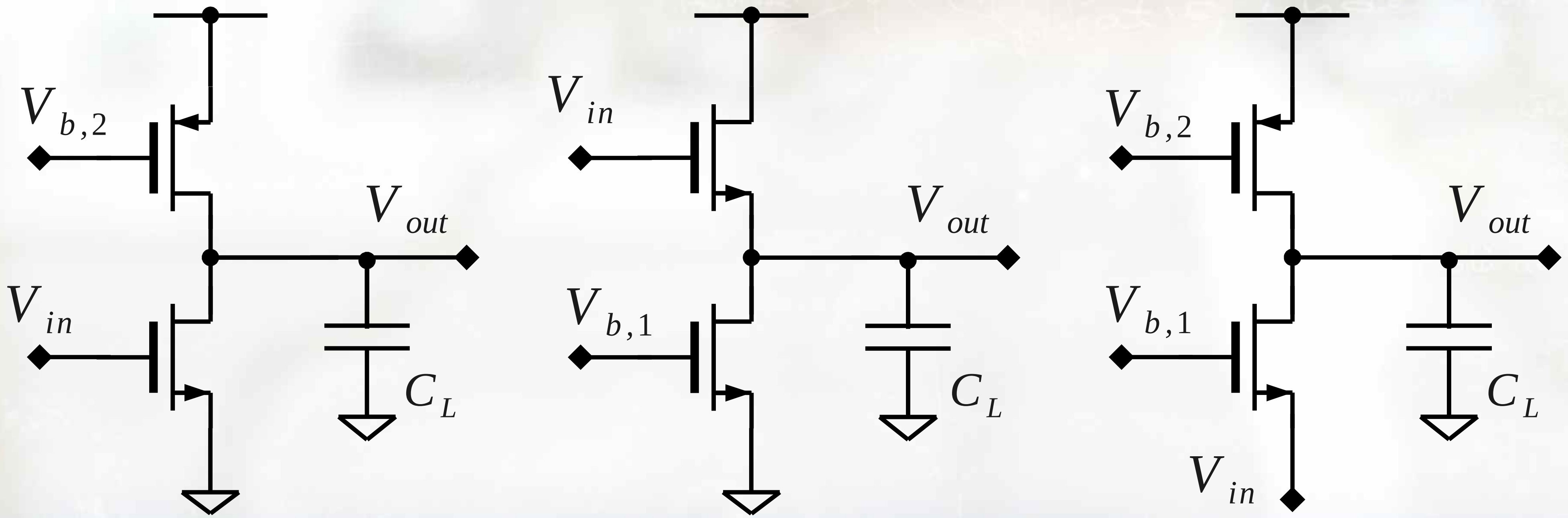
Use the quick-tricks from

cascodes for cascodes



The frequency domain

Include the capacitor in your calculations



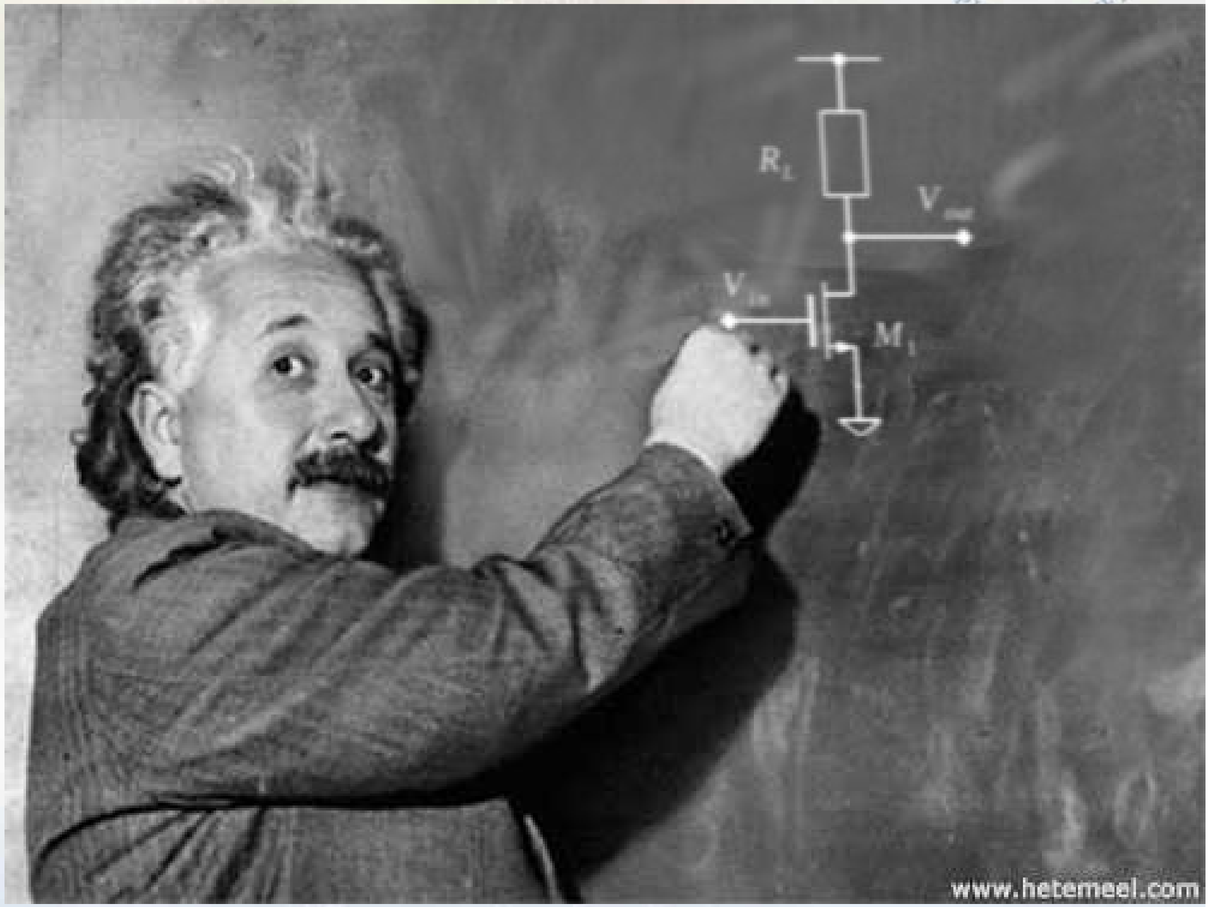
The frequency domain

Small-signal exercise

- Impact of capacitor on common-source stage

Bode plot

- Pole
- DC gain
- Unity-gain frequency



Compilation

The overall transfer function

$$A(s) = \frac{A_0}{1 + \frac{s}{p_1}} = \frac{\frac{g_m}{g_{out}}}{1 + \frac{s}{\frac{g_{out}}{C_L}}}$$

Notice the trade-off between bandwidth and gain!

$$A_0 \cdot p_1 \approx \omega_{ug}$$

Very crucial in your OP amp design

Amplifier stages, compiled 1

	Expression	CS	CD	CG*)
DC gain,	$A_0 \approx \frac{g_m}{g_{out}}$	$\approx \frac{g_m}{g_P + g_N}$	$\approx \frac{g_m}{g_m + g_P + g_N} \approx 1$	$\approx \frac{g_m}{g_P + g_N}$
Output impedance,	$\approx g_{out}$	$\approx g_P + g_N$	$\approx g_m$	$\approx g_P + g_N$
Bandwidth,	$p_1 \approx \frac{g_{out}}{C_L}$	$\approx \frac{g_P + g_N}{C_L}$	$\approx \frac{g_m}{C_L}$	$\approx \frac{g_P + g_N}{C_L}$
Unity gain,	$\approx A_0 \cdot p_1$	$\approx \frac{g_m}{C_L}$	N/A (why?)	$\approx \frac{g_m}{C_L}$

*) Source impedance not mentioned, see the exercise manual.

Amplifier stages, compiled 2

	Expression	CS	CD	CG*)
DC gain,	$A_0 \approx \frac{g_m}{g_{out}}$	$\approx \frac{1}{\lambda \cdot v_{eff}}$	≈ 1	$\approx \frac{1}{\lambda \cdot v_{eff}}$
Output impedance,	$\approx g_{out}$	$\approx \lambda I_D$	$\approx \frac{2 I_D}{v_{eff}}$	$\approx \lambda I_D$
Bandwidth,	$p_1 \approx \frac{g_{out}}{C_L}$	$\approx \frac{\lambda I_D}{C_L}$	$\approx \frac{2 I_D}{C_L \cdot v_{eff}}$	$\approx \frac{\lambda I_D}{C_L \cdot v_{eff}}$
Unity gain,	$\approx A_0 \cdot p_1$	$\approx \frac{I_D}{C_L \cdot v_{eff}}$	N/A (why?)	$\approx \frac{I_D}{C_L \cdot v_{eff}}$

Other tips-and-tricks

Common-drain

- If the voltage levels are not good enough, you can shift up/down
- Isolation of sensitive nodes (buffering)

"Current-stealing"

- Consider the folded cascode amplifier. Notice that the two branches steal current from a common current source. Also remember that gain is inversely proportional to current. By stealing current, we can lower current, and thus increase gain.

The transistor as a switch/resistor

The last operation

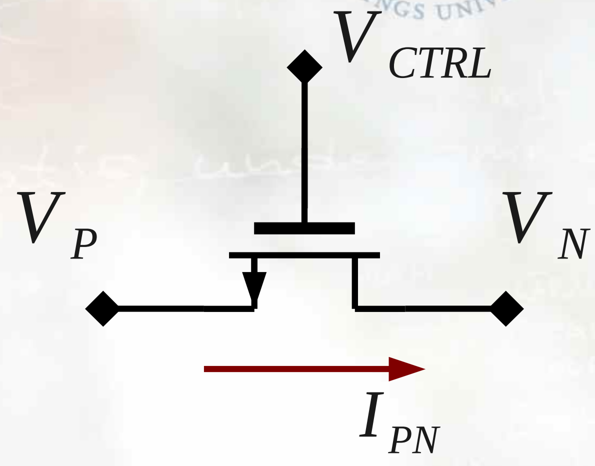
$$I_{PN} = \alpha \cdot \left(2 V_{eff} V_{ds} - V_{ds}^2\right)$$

or

$$I_{PN} = 2\alpha V_{ds} \cdot \left(V_G - V_T - \frac{V_D + V_S}{2}\right)$$

Voltage dependent resistor, with conductance:

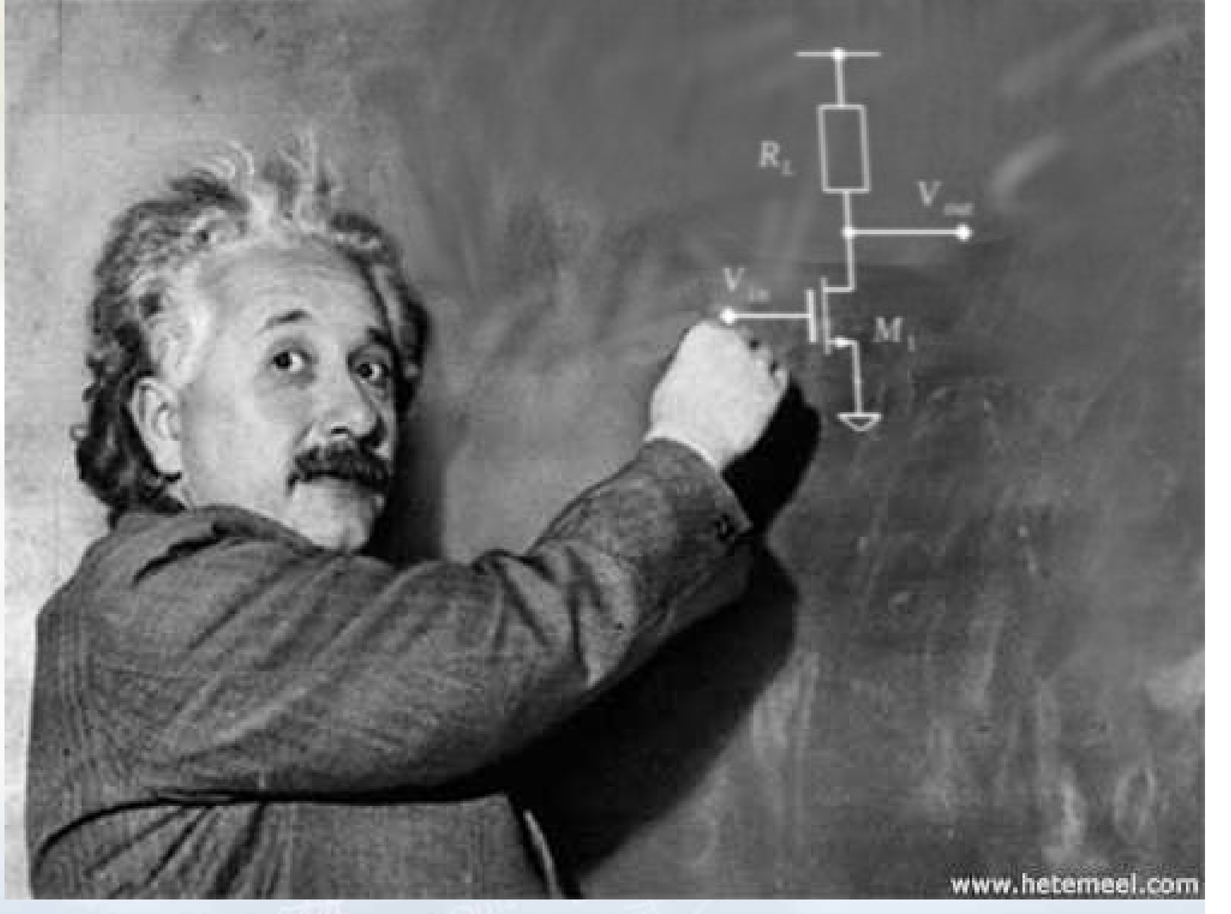
$$G_{PN} = \frac{I_{PN}}{V_{ds}} = 2\alpha \cdot \left(V_G - V_T - \frac{V_D + V_S}{2}\right)$$



The transistor as a switch/resistor

The linearized model

$$G_{PN} = 2\alpha \cdot \left(V_G - V_D - V_T \right)$$



What to think about

How to use it

What did we do today?

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- Simple, Cascoded, and Wide-Swing
- Decoupling design parameters using current mirrors

Improved amplifier stages

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The switch

The frequency domain

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What will we do next time?

Differential signals

- Why differential?
- Common-mode definitions

Differential pair

- Analysis
- Operation

Mismatch

- Impact of mismatch on design/performance/behavior