Lecture 3, ANIK

Current mirrors, Improved gain stages

What did we do last time?

"Simple" amplifier stages

- A single transistor can be troublesome enough ...

Small-signal schematics practice

- Practice, practice, practice

How do we increase gain?

- What are our handles?

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What will we do today?

Swing

- How many transistors can we stack?

Improving the gain

- What are our handles? (again)
- We need high gain - how do we do it?

Voltage swing

Walk around the circuit

- Check for all the required voltage levels to maintain transistors in their saturation region

Use the following relations

$$V_{GS} = V_{EFF} + V_T \, , \quad V_{DS} > V_{EFF} \Rightarrow V_{DS} = V_{EFF} \, , \quad V_{EFF} = \sqrt{\frac{I_D}{\alpha}}$$

The lower v_{eff} ...

- the higher swing
- the higher gain

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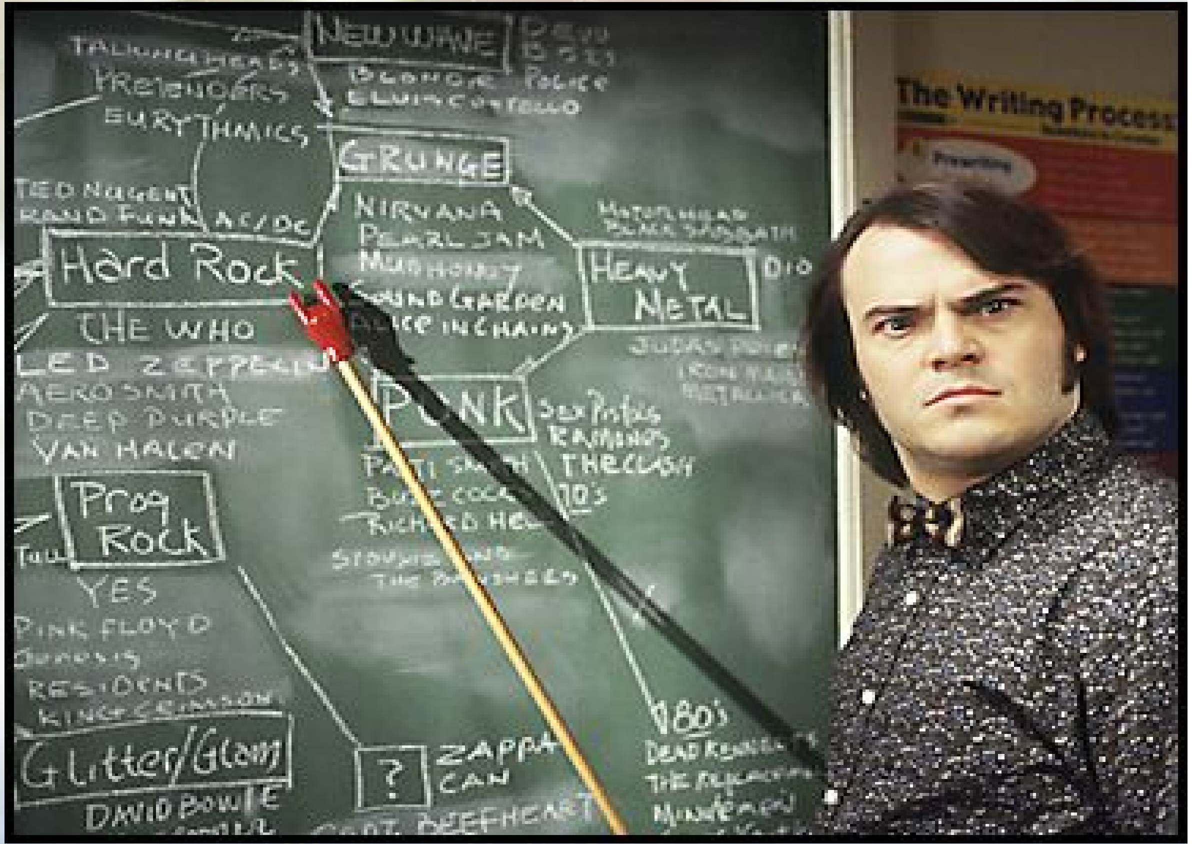
Examples on the board

Consider the three amplifiers

- CG, CD, CS
- Check the potentials
- When are the transistors saturated?
- What does this imply?



How do I increase my gain?

Assuming a simple common-source stage:

$$A = \frac{g_m}{g_{out}} = \frac{1}{\lambda \cdot v_{eff}} = \frac{2\sqrt{\alpha}}{\lambda \sqrt{I_D}}$$

The answer depends on the biasing conditions

- Decrease v_{eff}
- Decrease $\lambda \sim 1/L$, i.e., increase the channel length.
- Decrease (!) the current I_D
- Increase the transistor sizes, $\alpha \sim S \sim W$

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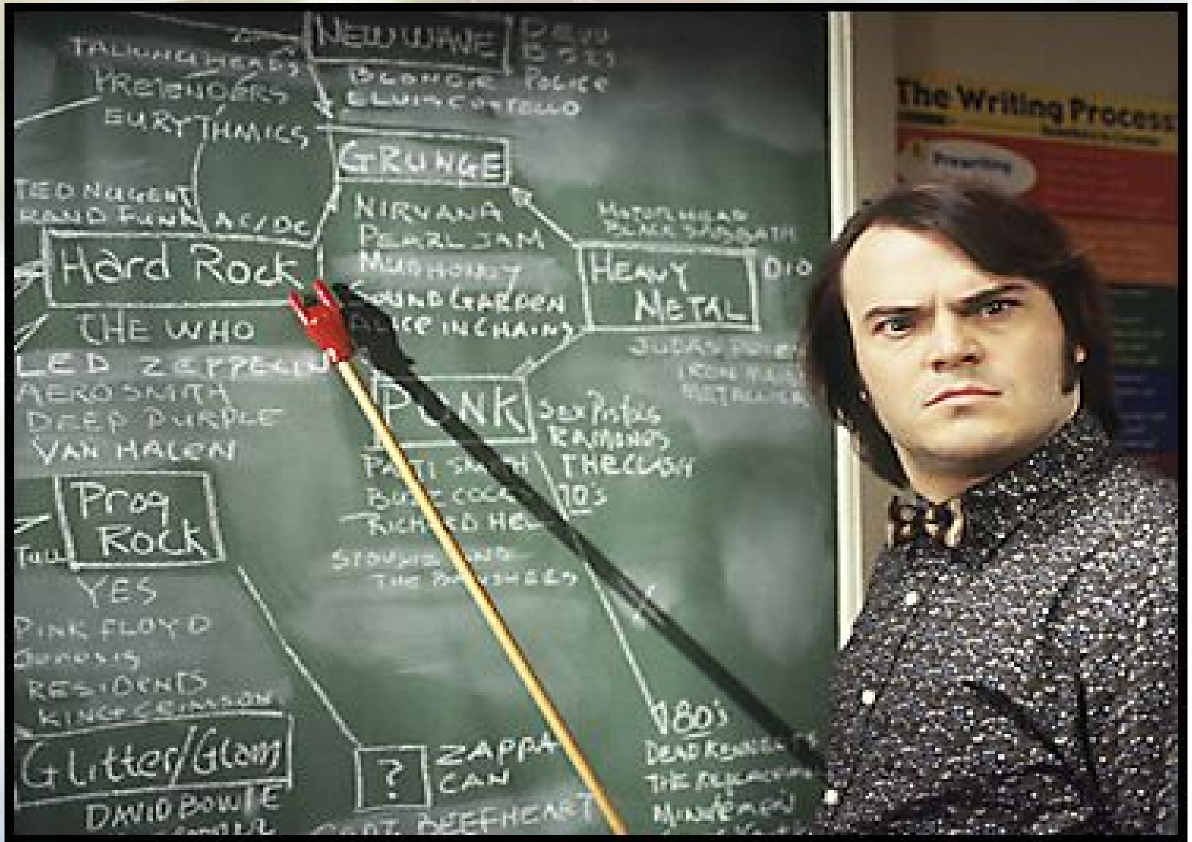
Another observation

DC gain vs the effective

voltage and currents



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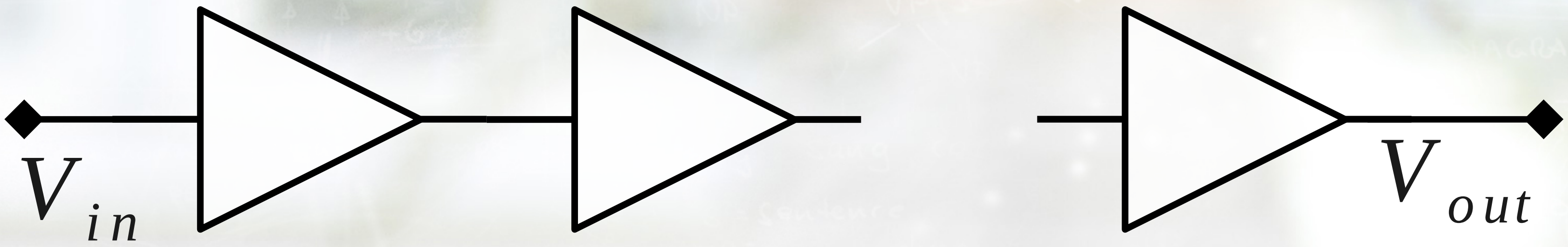
Improving the gain, the obvious option

We can put several stages in series



Gain is formed by simply taking the product of all gains

Offers high swing

Might cost us more power consumption (each stage needs a current).

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Improving the gain, the electrical option

Revisit the expression on gain!

$$A = \frac{g_m}{g_{out}}$$

Increase the transconductance

Decrease the output conductance (i.e., increase output impedance)

We've done that kind of, c.f., lowering the v_{eff}, etc.

Cascodes, the hardware option

Introduce more hardware to increase impedance

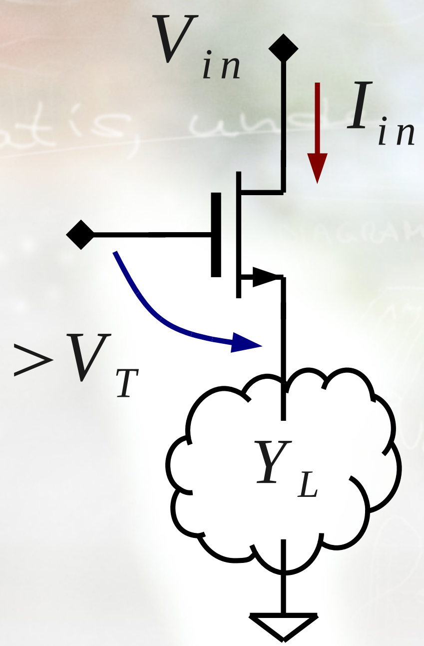
Cascodes increase the gain

- How? - a small-signal exercise

We must balance the load

- both in PMOS and NMOS "direction"
- (Traditional way to maximize power efficiency)

So ... it's all about impedance levels



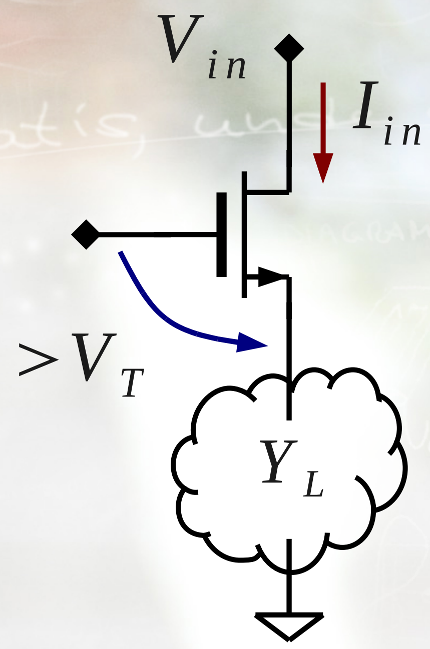
$$Y_{out} = \frac{I_{in}}{V_{in}} \approx \frac{Y_L}{A} \approx \frac{Y_L \cdot g}{g_m}$$

Cascodes

(Quickly) eats up the voltage headroom

For every diode-connected transistor, we loose

one V_T of swing



We can save current since only one stage

Complexing biasing schemes

$$Y_{out} = \frac{I_{in}}{V_{in}} \approx \frac{Y_L}{A} \approx \frac{Y_L \cdot g}{g_m}$$

"The output impedance is multiplied"

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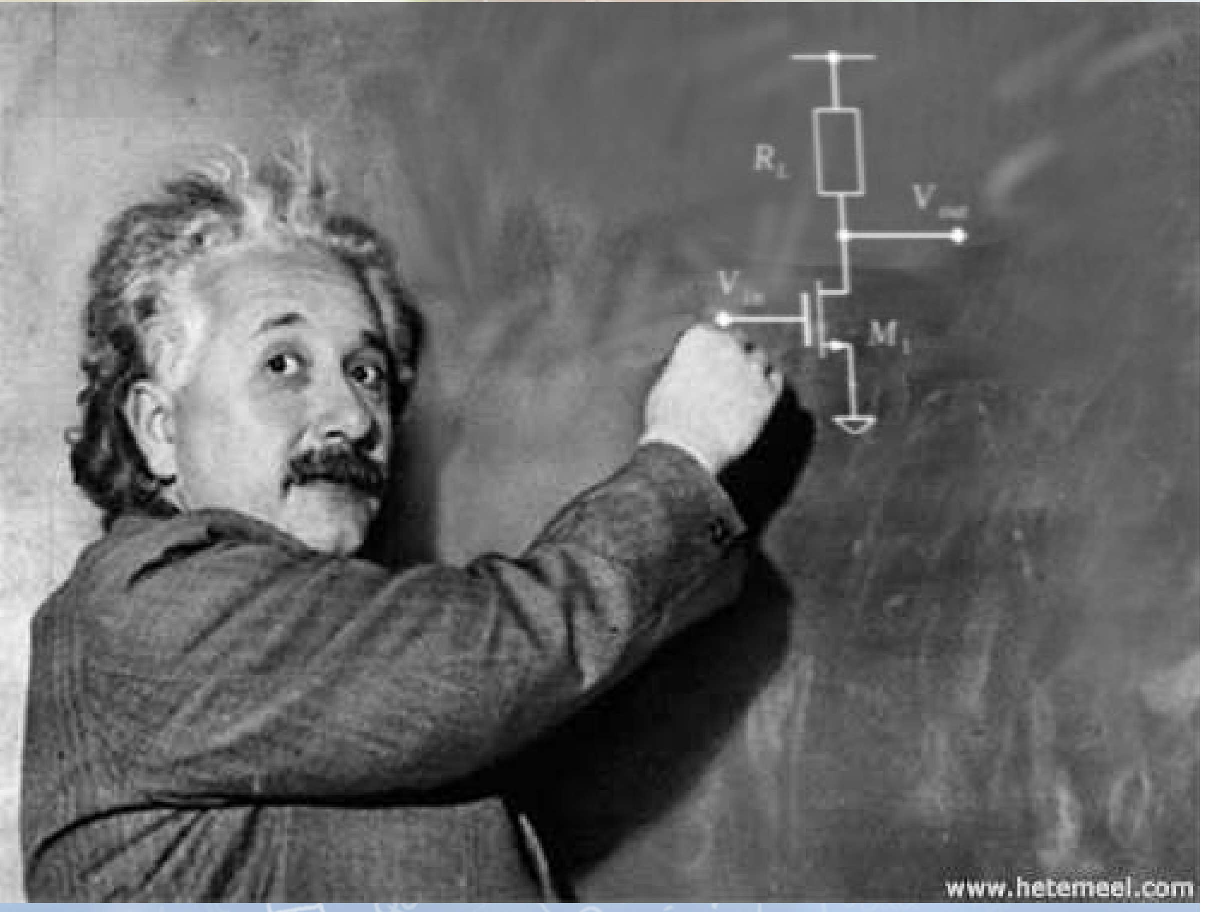
Cascodes, common-source example

Voltage swing

Calculating the gain



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Cascodes, common-source example

This formula still holds $A = g_m / g_{out}$ and the output conductance is

$$A = \frac{g_{m1}}{\frac{g_{n1} \cdot g_{n2}}{g_{m2}} + \frac{g_{p3} \cdot g_{p4}}{g_{m3}}} \approx \frac{g_{m1} \cdot g_{m2}}{2 \cdot g_{n1} \cdot g_{n2}}$$

Now, we have some more handles to increase (set) the gain.

Effective voltage of input can be decoupled.

Classical analog trade-offs to distribute the gain).

But ... what happens to the gain if
the impedance levels are not balanced?

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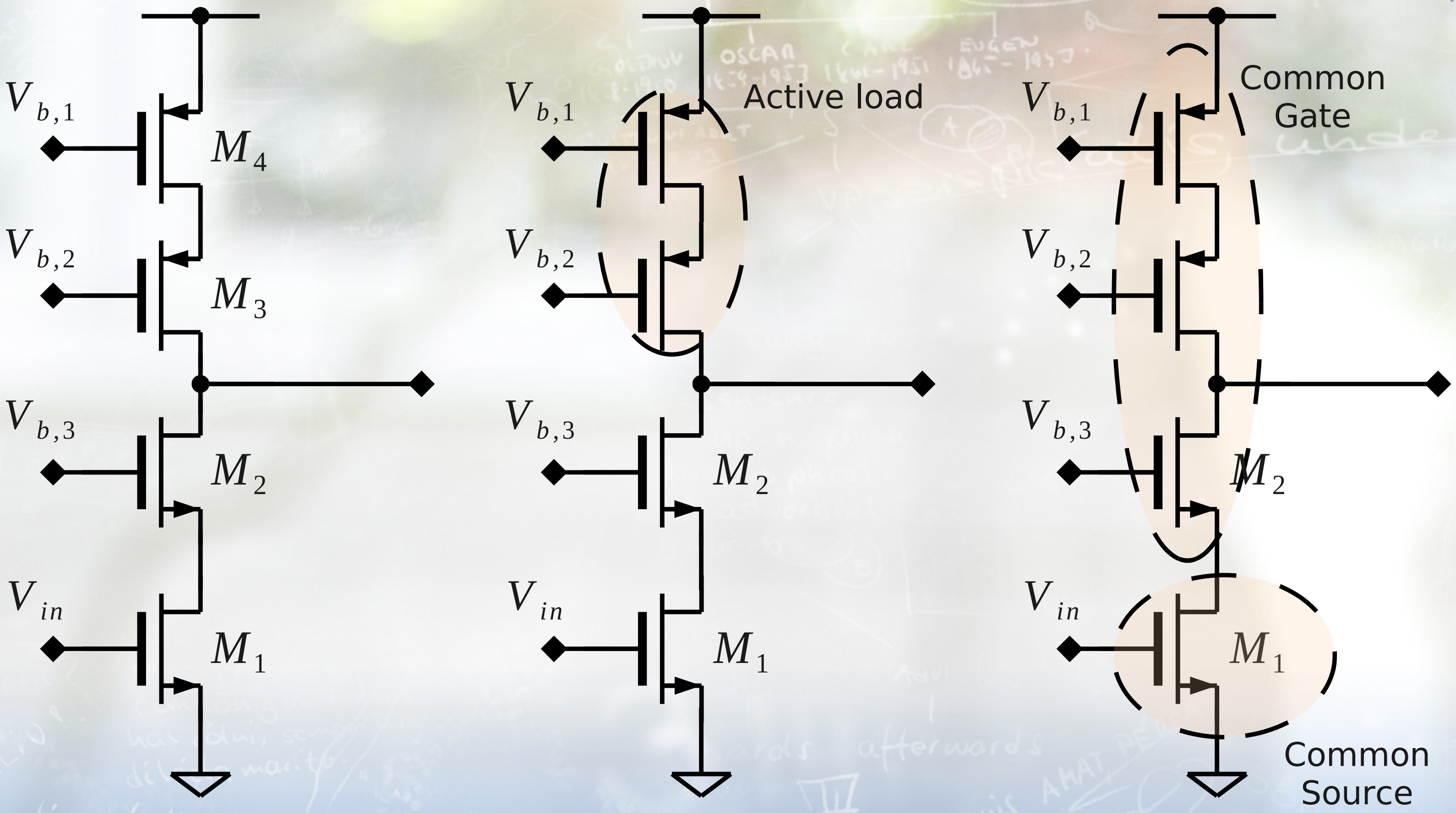
Cascodes are also multiple stages ...



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Some conlusions on one slide

Cascodes eat up the swing

Cascodes save current compared to multi-stage

Cascodes and multi-stage have comparatively same area

Cascodes have more complex biasing schemes compared to multi-stage

Cascodes might not be feasible in future (analog) designs

What did we do today?

Voltage swing

Cascodes to increase gain

What will we do next time?

Current mirrors

- Simple, Wilson, Wide-Swing, Cascoded

Improved amplifier stages

- Folded-cascoded gain stage

Decoupling design parameters

- Using for example current mirrors