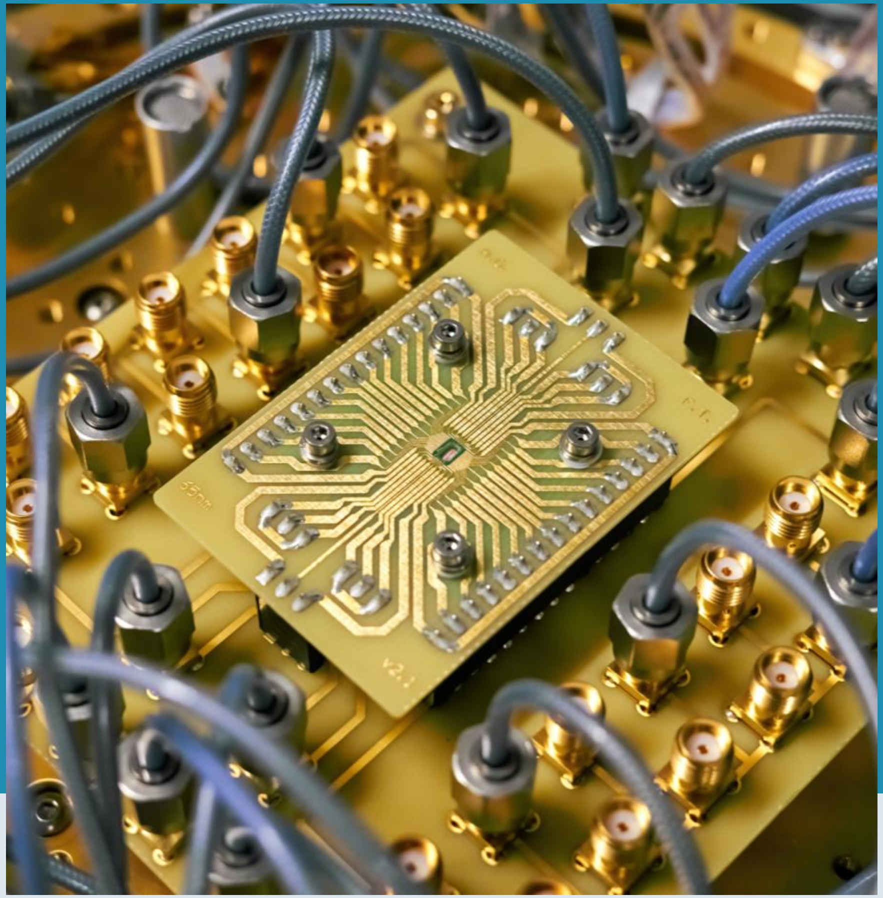
KU LEUVEN

Design of Analog and Mixed-Signal Integrated Circuits B-KUL-H05E3A

Gain-Boosting + Advice
Session 6

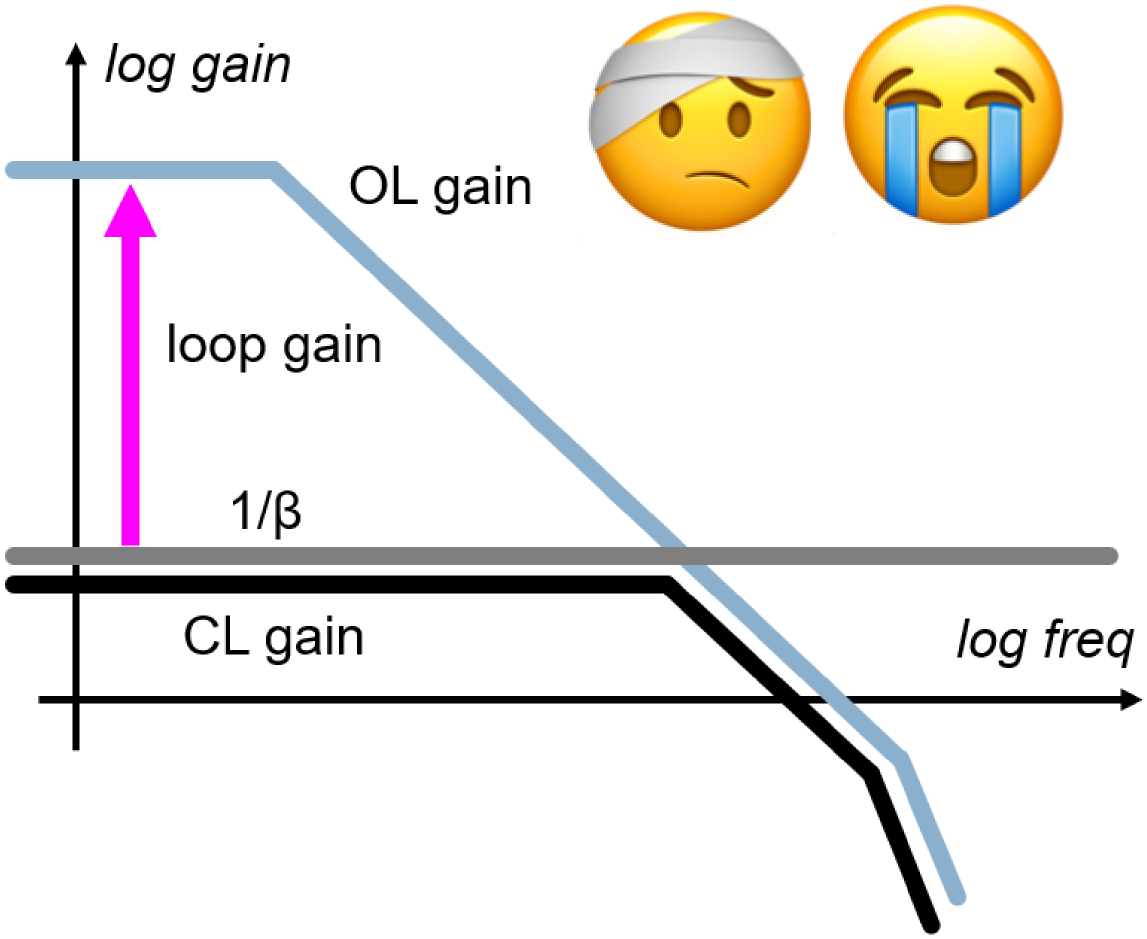


Ir. Alberto Gatti, Jun Feng, Shuangmu Li, Prayag Wakale
Prof. Filip Tavernier and prof. Tim Piessens
Departement Elektrotechniek (ESAT)

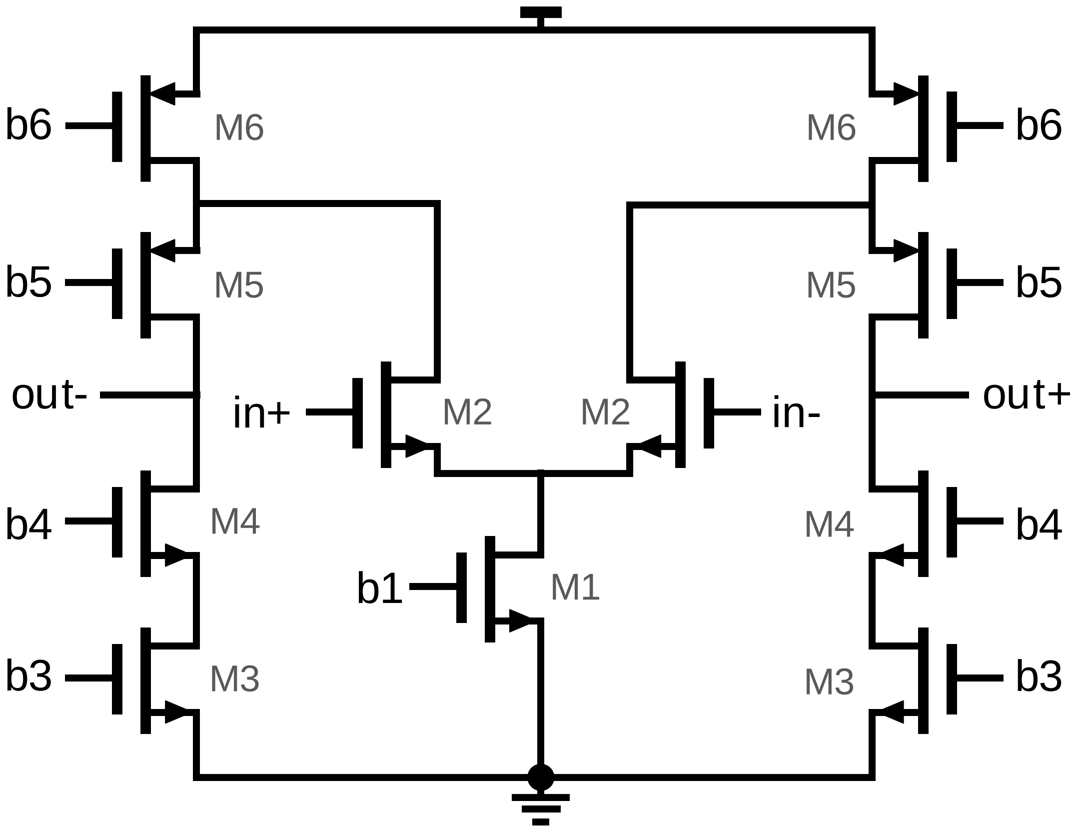
micas KU LEUVEN

Gain Boosting

Struggling to get more gain?



Folded cascode? not much better



- Cascoding through current subtraction, not via mirroring
- But, gain again mainly set by two transistors (M2, M5) and output impedance of M4, M3

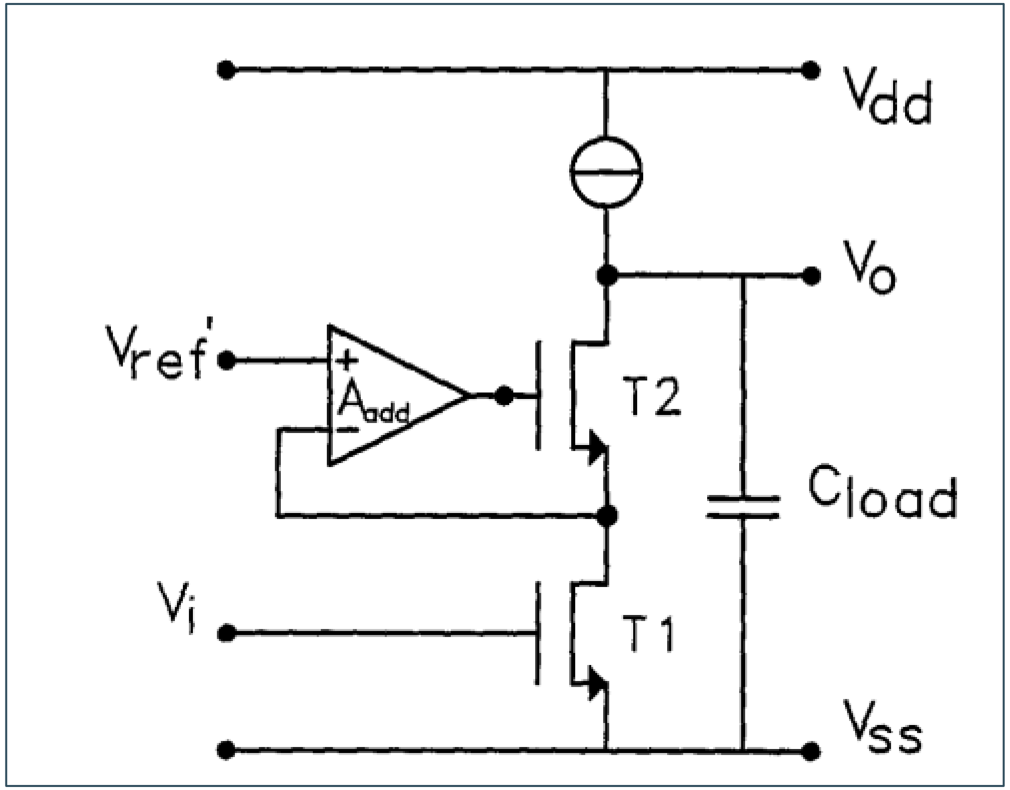
A technique to consider…

The CMOS Gain-Boosting Technique

KLAAS BULT AND GOVERT J.G.M. GEELEN
Philips Research Laboratories, Eindhoven, The Netherlands

Received January 9, 1991; Revised April 5, 1991.

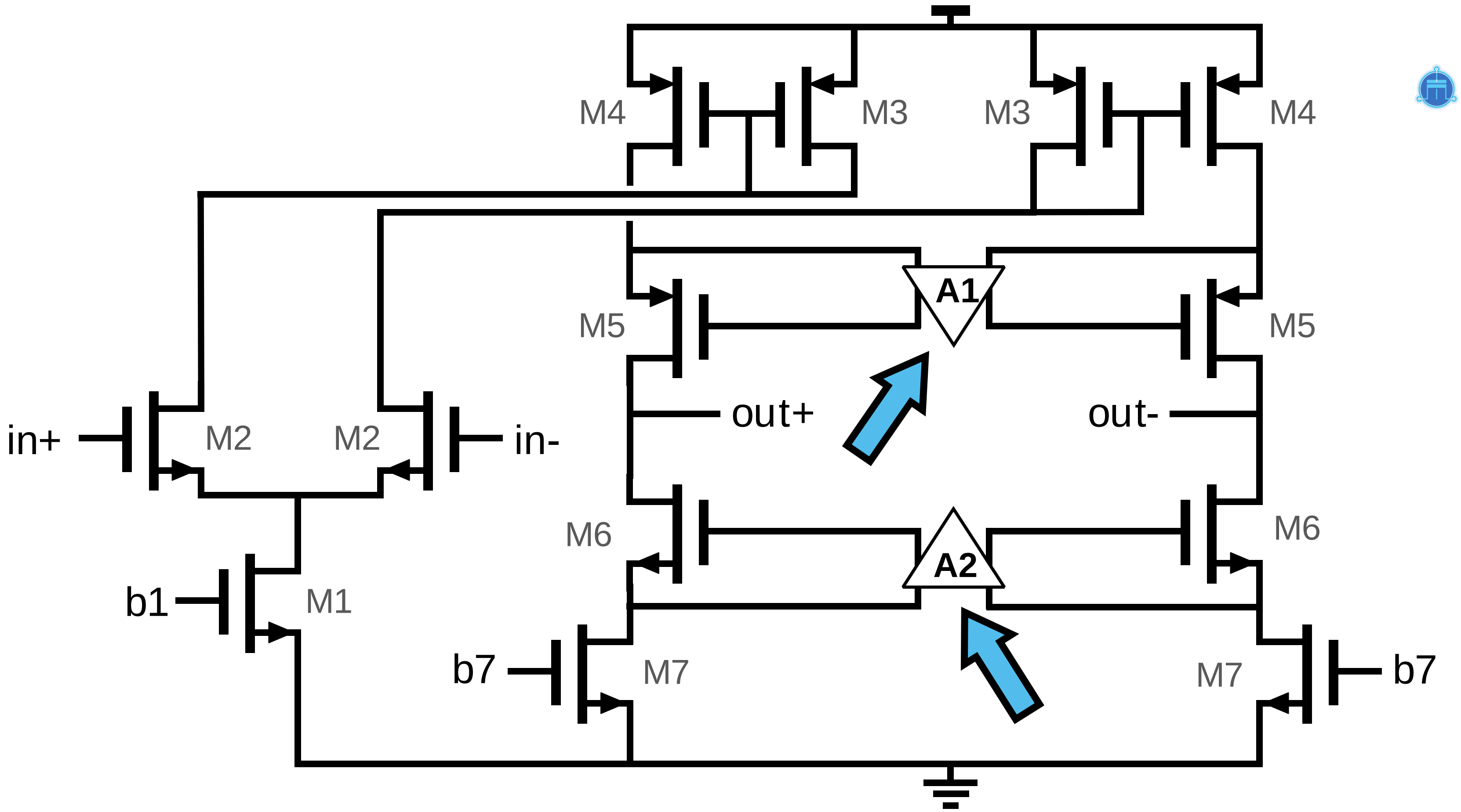
Gain-boosting



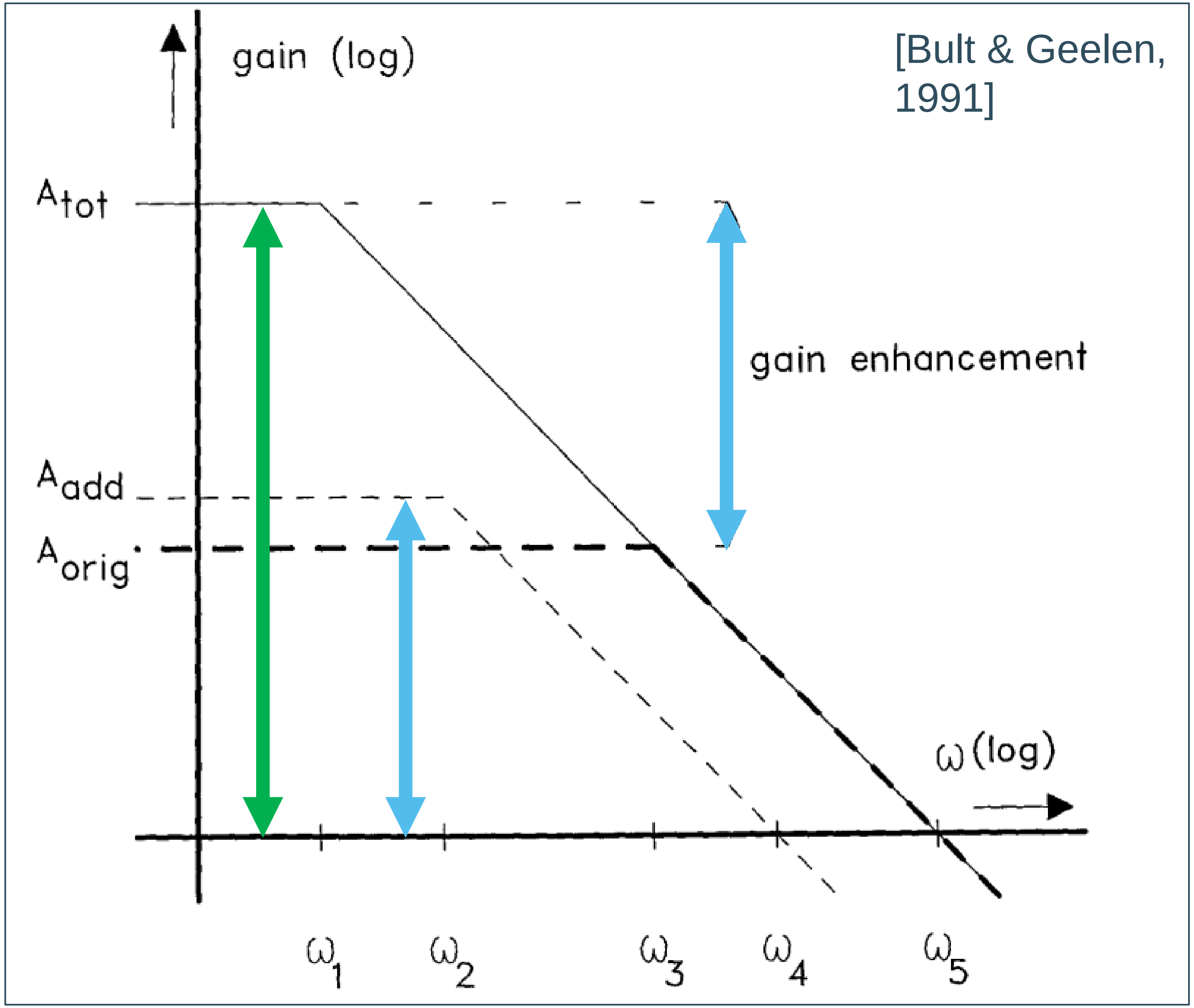
- **Additional gain** A_{add}
- In some books "regulated cascode"

[Bult & Geelen, 1991]

Gain-boosting in DAMSIC



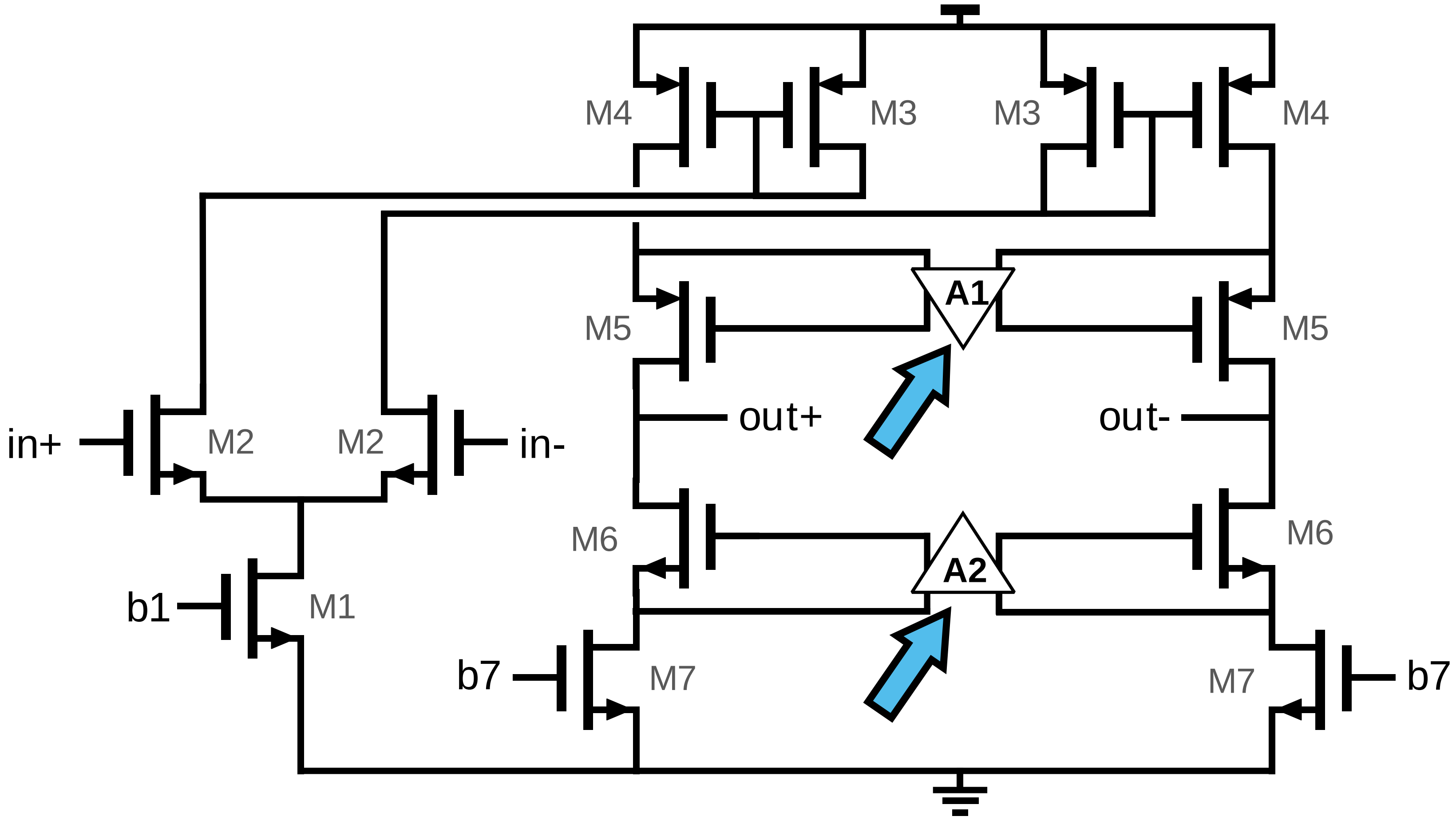
- **On both high and low sides!**



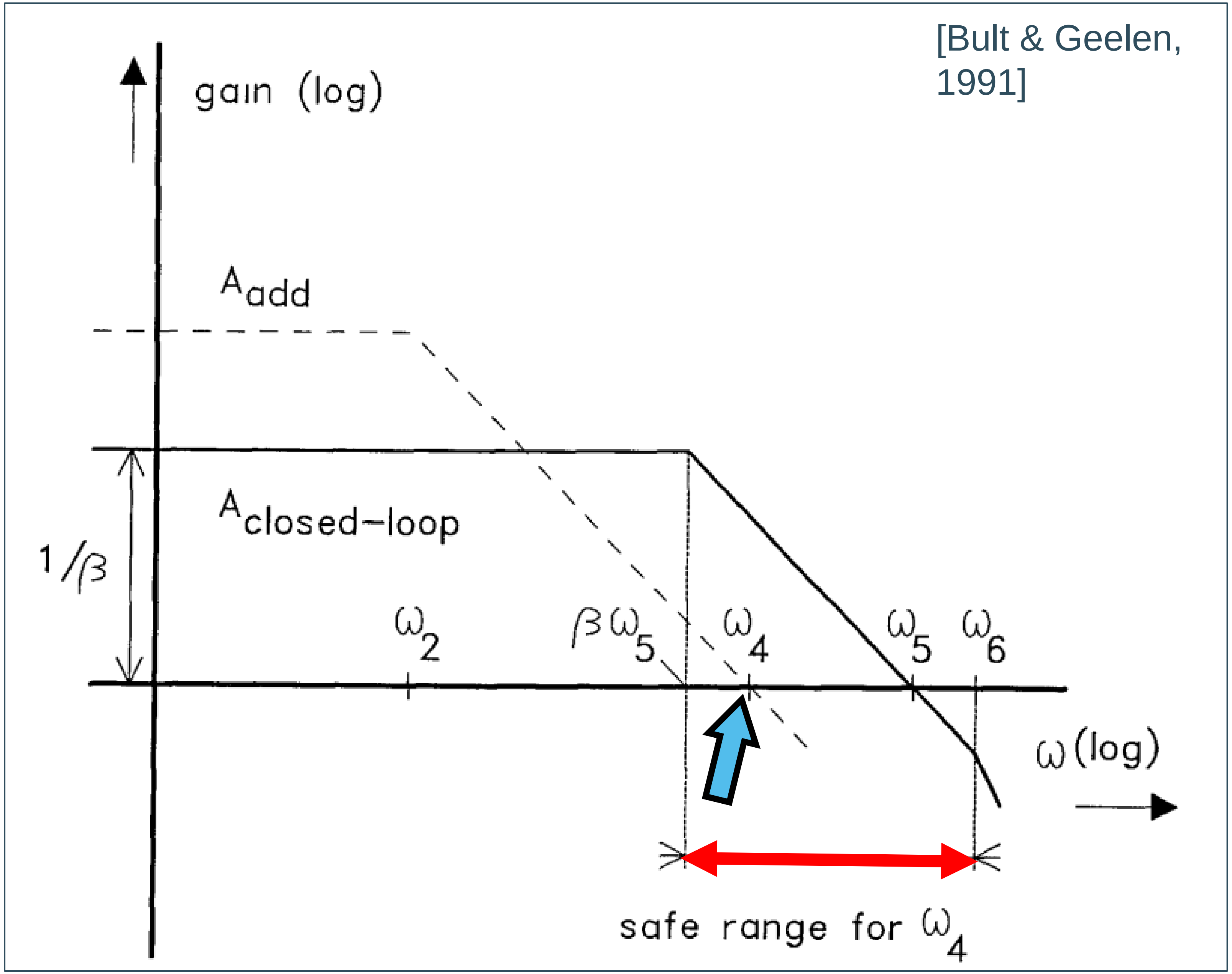
In **your case**:

- $\mathbf{A_{orig}} = (g_m\ r_o)^2$
- $\mathbf{A_{add}}$ depends on the gain boosting OTA
- *"How fast does A_{add} need to be…?"*

Good question!



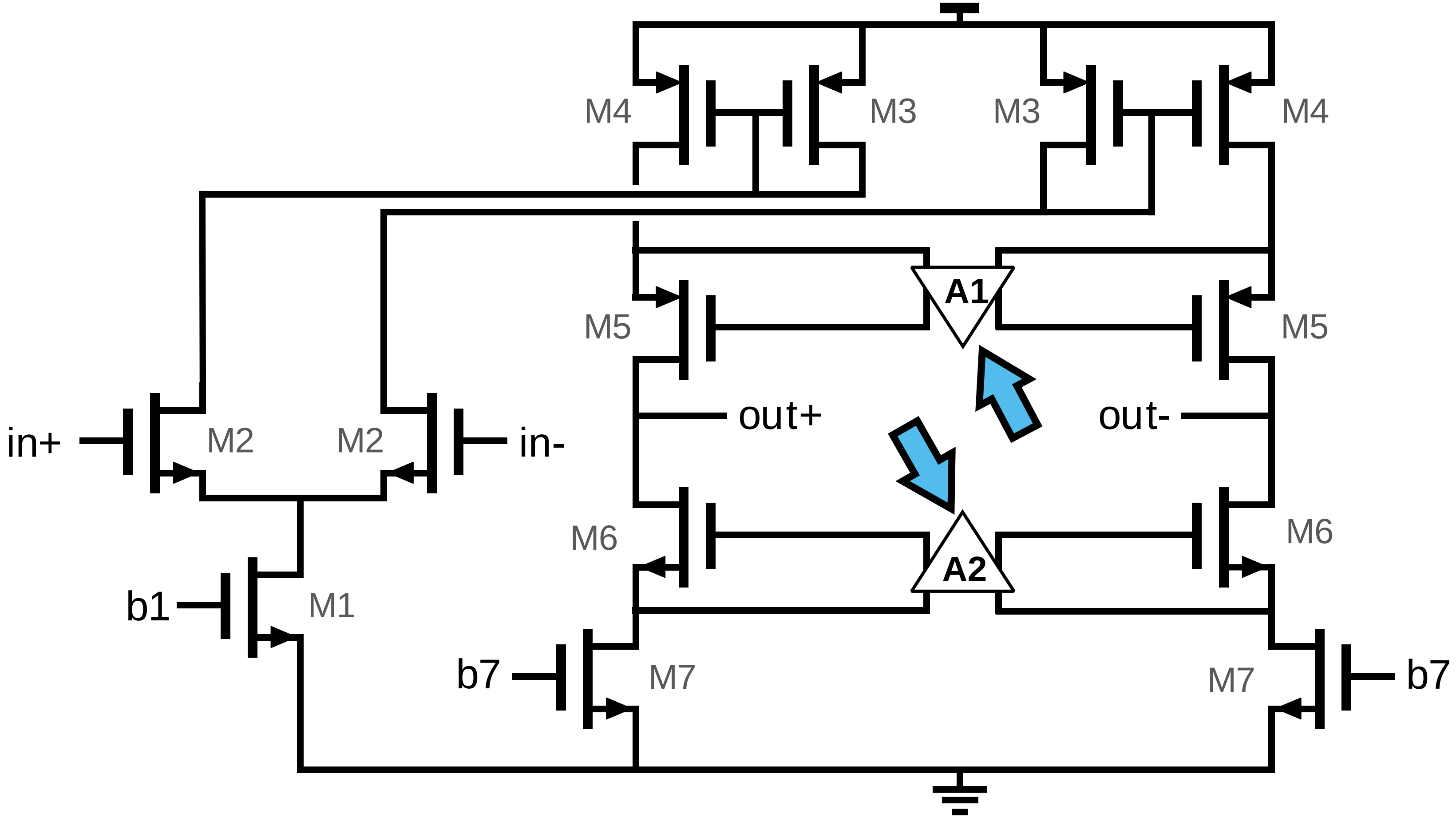
- Too slow:
  - **Settling issues**
- Too fast:
  - **Stability issues!**
- Main difference?
  - Small load…



Bult to the rescue, again

- Within safe range, near the GBW of the original design
- Start with the **same speed**…!

In practice? Recall that the load is small!



- Just insert an additional **capacitor** that dominates the loop. Your OTA is small ☺
- **STB analysis** is your friend!

Why is this such a popular technique?

- Infinite gain @ max. speed
- Good use of supply!

[Bult & Geelen, 1991]

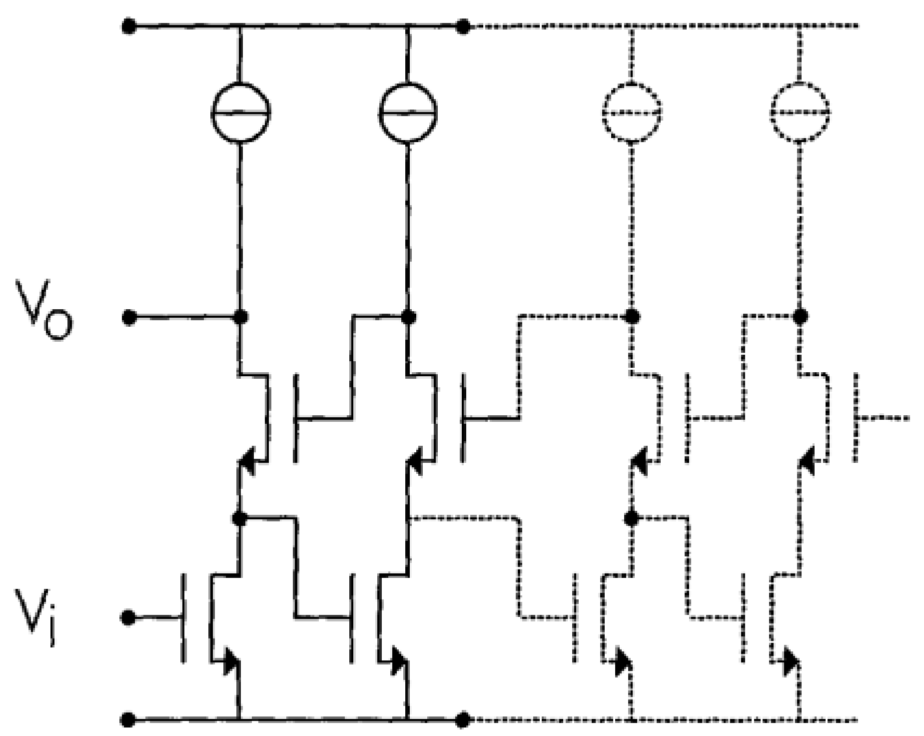
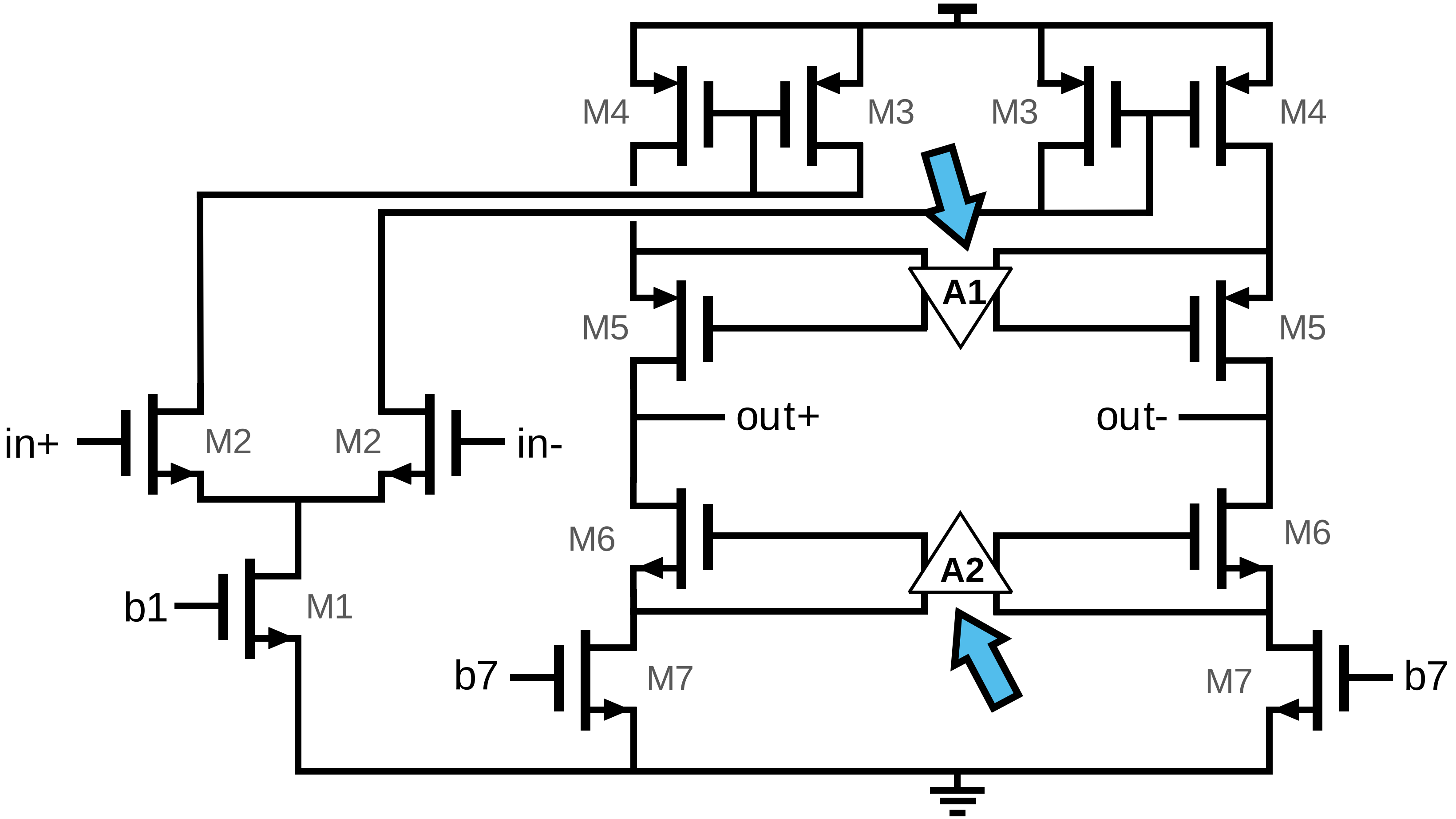


Fig. 3. Repetitive implementation of gain enhancement.

Suggested design method

- Use the **idealOTA** to verify/understand gain-boosting
  - Main difference is lack of CMFB..!
  - Especially learn to check stability!

- **Draw up specs** for the boosting OTA
  - Main difference = size, output CM… + add another CMFB loop!
- **Design** boosting OTA – what can you do with a folded-cascode?
  - Check DC operating point and stability! Probably need to retune C_{ADD}
- **Rescale** for noise if needed



If time is tight:

A1 can be the same as A2…
➔ **Use DC sources to shift operating points**

Feel free to do even better!

References

- Paper by Bult and Geelen ➔ see Toledo
  - Should be enough
- Razavi's CMOS design book has a short subsection on it
  - But no deep explanation of the settling / stability issues
- Some videos on Youtube, but above should be sufficient!

Next Weeks & Final Assessment

Remaining design sessions 6, 7, 8

- For you to work on gain boosting with folded cascode
  - No more extra material
- Intermediate report 2: symmetric OTA by next Monday noon
  - Feedback next week Tuesday morning
- Session 8: extra 30 mins to compensate for P&D

After that: prepare for final assessment

- Final Report: May 2nd at noon
  - Merge 3 reports, key npart is gain-boosted OTA design
  - **Everyone** submits one on their own (for admin reasons)

- Oral Presentations: May 9th
  - Slides: **upload in advance by 7th of May**
  - 5 min presentation + 10 min Q&A (longer for trio)
  - Detailed info + schedule will follow on Toledo

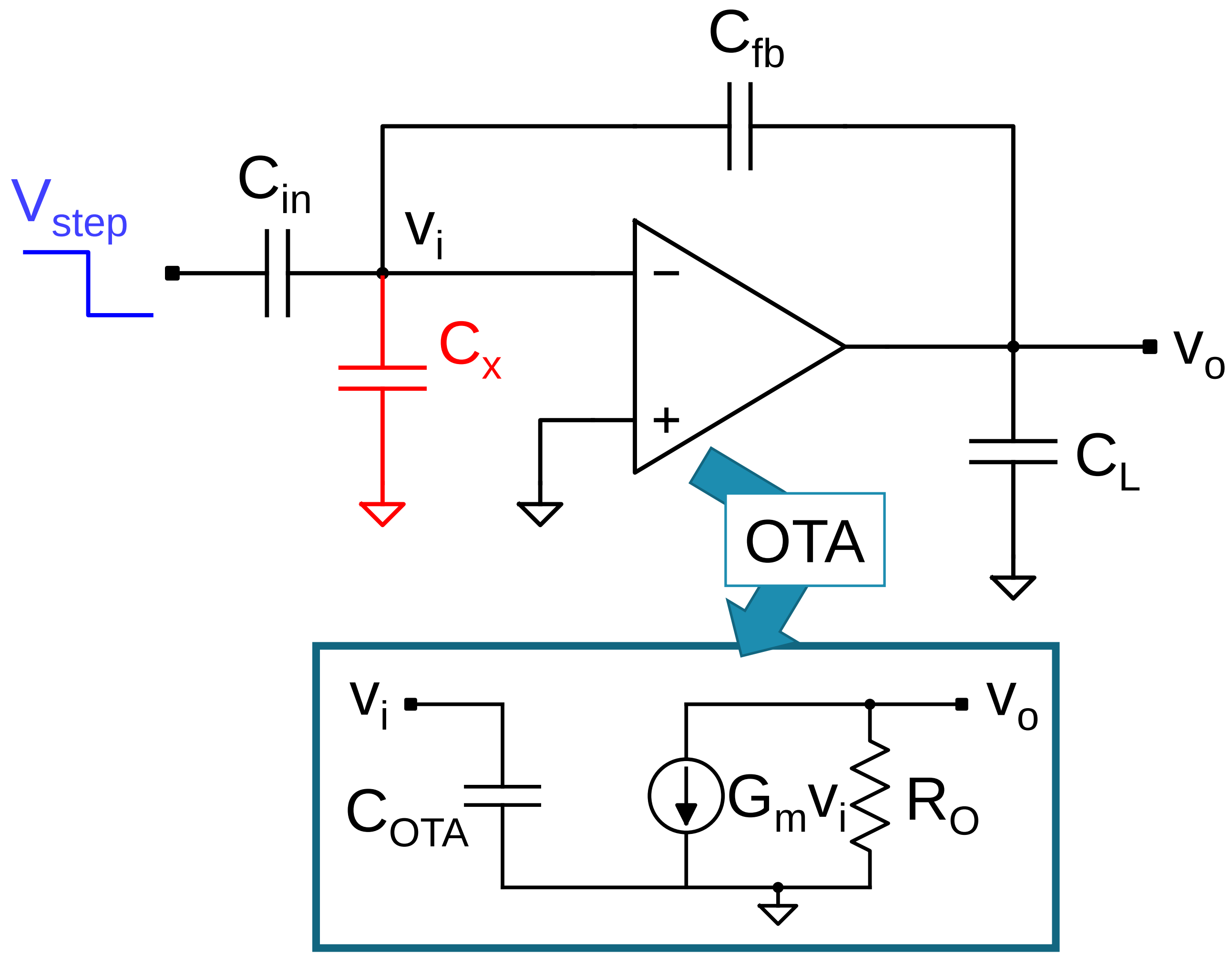
Thanks, questions?

Bonus Material

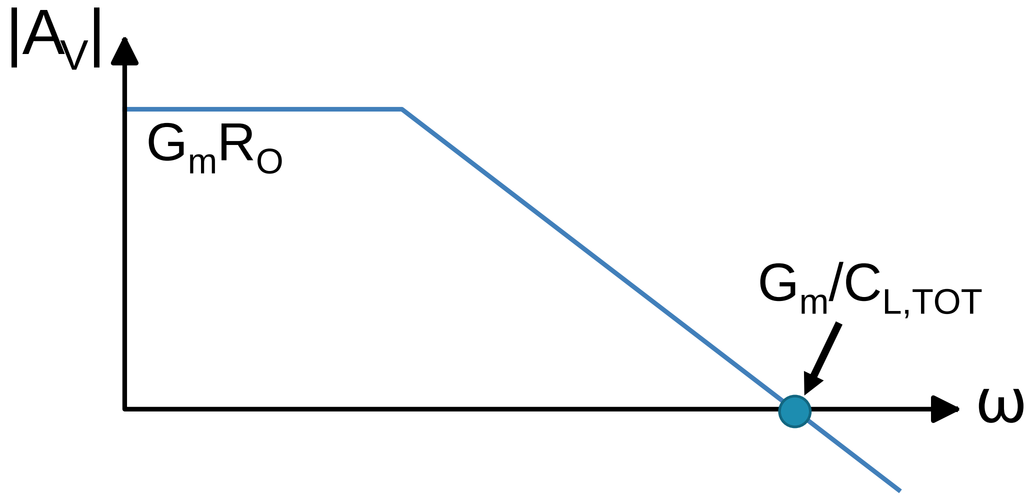
“Why don’t the posted targets work from the get-go?”

One aspect: parasitics at OTA input

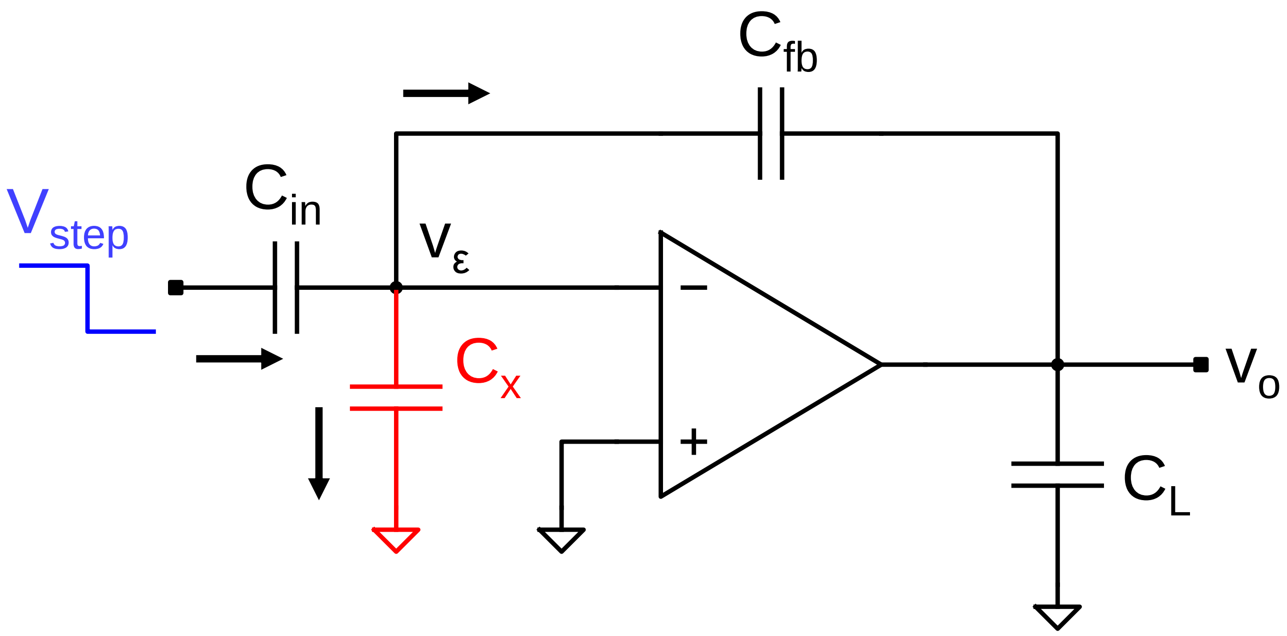
Analysis of transient response in phase ϕ_2



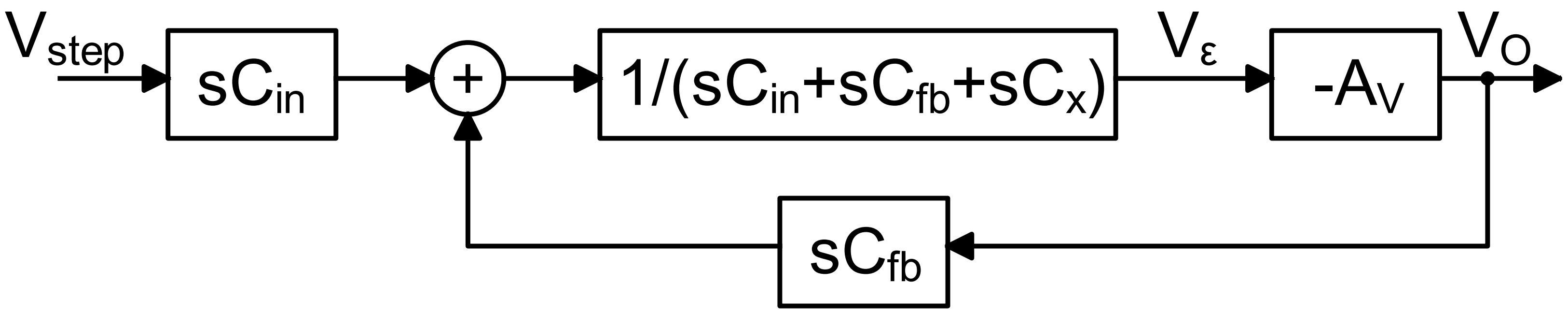
- V_{step} = voltage on C_{in} at the end of the sampling phase
- $\frac{V_O(s)}{V_I(s)} = -A_V = -\frac{G_m R_O}{1+sR_O C_{L,TOT}}$



Effective circuit

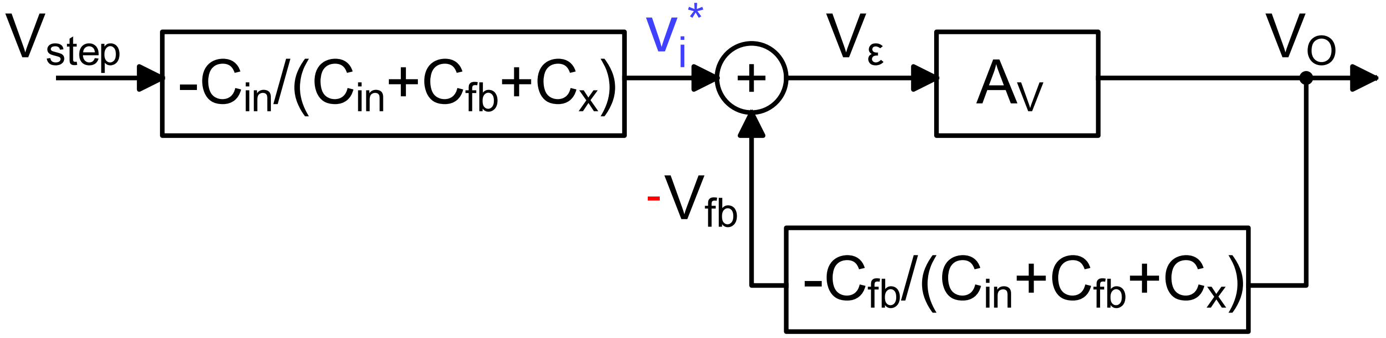


- Finite gain OTA → $V_\varepsilon \neq 0$
- $sC_{in}(V_{step} - V_\varepsilon) = sC_x V_\varepsilon + sC_{fb}(V_\varepsilon - V_O)$
- $V_\varepsilon = \frac{sC_{in}V_{step}+sC_{fb}V_O}{s(C_{in}+C_x+C_{fb})}$
- The feedback signal is a current!



Shunt/shunt feedback!

A few tricks on the block diagram…



v_i^* is just a rescaled version of the input

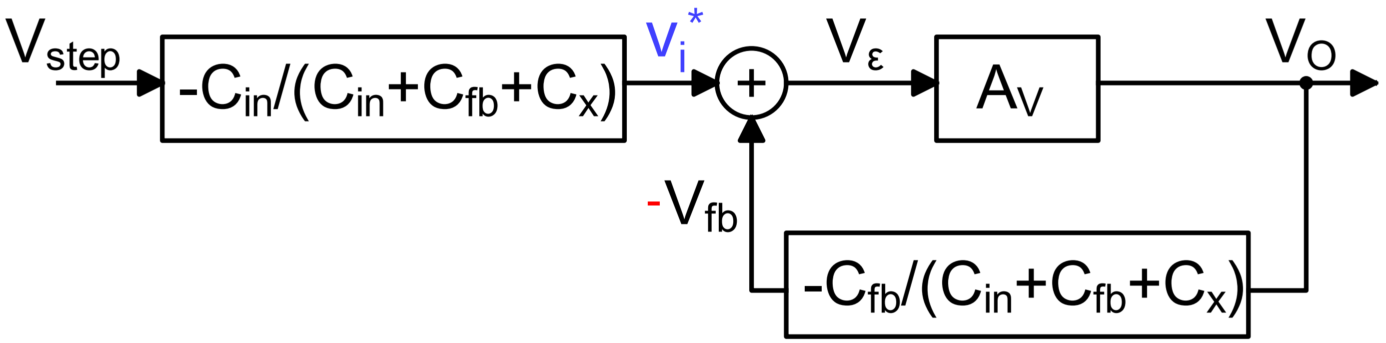
$$\boxed{\beta = \frac{V_{fb}}{V_O} = \frac{C_{fb}}{C_{in}+C_{fb}+C_x}}$$

- $$-\frac{C_{in}}{C_{in}+C_{fb}+C_x} = -\frac{C_{in}}{C_{fb}}\beta$$

Ideal gain **Gain error** **Settling error**

- $$\frac{V_O}{V_{step}} = -\frac{C_{in}}{C_{fb}}\beta\frac{A_V}{1+\beta A_V} = \boxed{-\frac{C_{in}}{C_{fb}}} \cdot \boxed{\frac{G_m R_O \beta}{1+G_m R_O \beta}} \cdot \boxed{\frac{1}{1+s\frac{C_{L,TOT}}{\beta G_m}}}$$

To the time domain



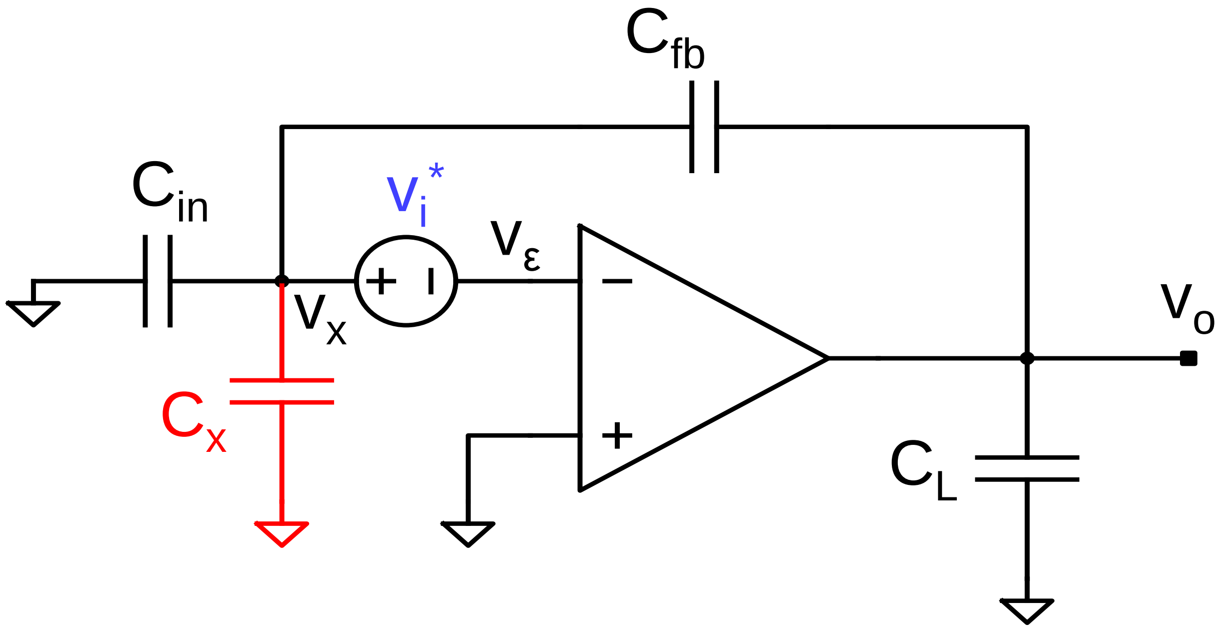
v_i^* is just a rescaled version of the input

$$\boxed{\beta = \frac{V_{fb}}{V_O} = \frac{C_{fb}}{C_{in} + C_{fb} + C_x}}$$

- $$v_O(t) = -\frac{C_{in}}{C_{fb}} V_{step} \cdot \frac{G_m R_O \beta}{1+G_m R_O \beta} \cdot \left(1 - e^{-t/\tau}\right)$$

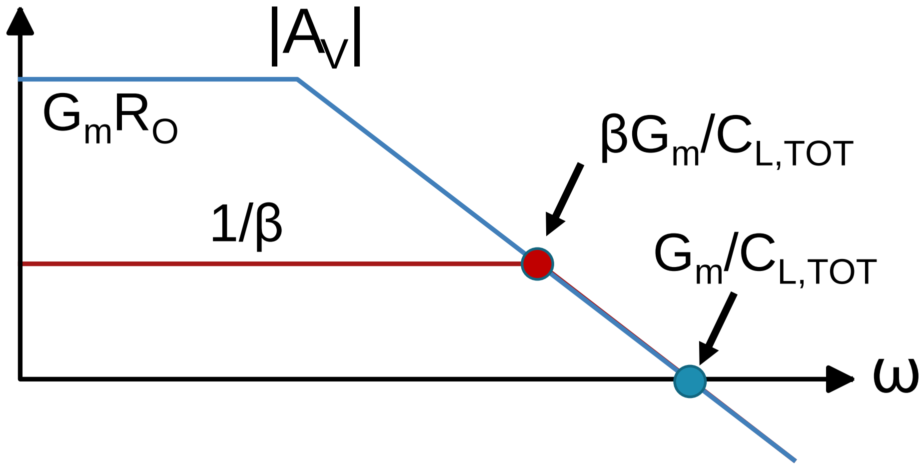
$$\boxed{\tau = \frac{1}{\omega_u} = \frac{1}{\frac{\beta G_m}{C_{L,TOT}}}}$$

Feedback and load



$$\boxed{\beta = \frac{C_{fb}}{C_{in} + C_{fb} + C_x}}$$

- $$\frac{V_O}{V_I^*} = \frac{A_V}{1+\beta A_V} \cong \frac{1}{\beta}\frac{1}{1+\frac{sC_{L,TOT}}{\beta G_m}}$$



- $$C_{L,TOT} = C_L + \frac{C_{fb}(C_{in}+C_x)}{C_{fb}+C_{in}+C_x} = C_L + C_{fb}(1-\beta)$$