



Exercise: DC Feedback of the Charge Amplifier

Prof. Dr. P. Fischer

Lehrstuhl für Schaltungstechnik und Simulation
Uni Heidelberg



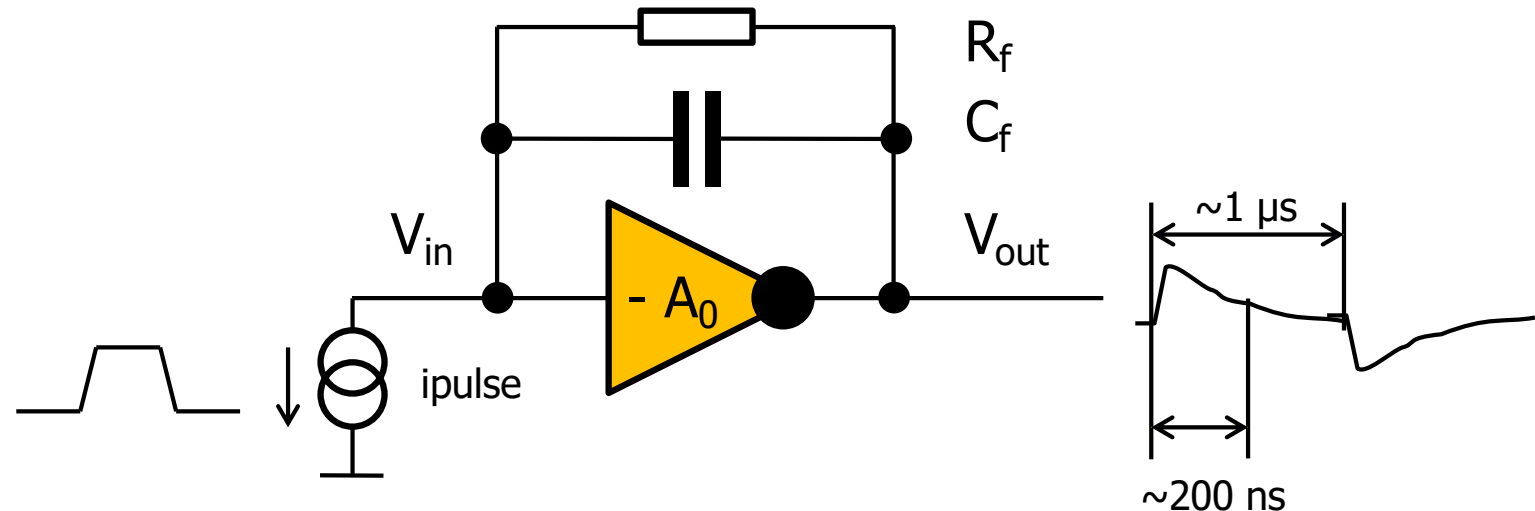
Overview

- We have seen in part 1 that the charge sensitive amplifier (**CSA**) needs a 'DC feedback' which
 - 'discharges C_f '
 - 'removes the signal charge from the input node'
- We want to replace the resistor first by a MOS and then by a more complicated transconductor
 - We will see that the MOS is difficult to bias and unable to cope with both signal polarities
 - We will see that the transconductor allows us to charge the 'resistance' electronically
 - It also gives us a way to get a linear discharge, which can be useful



Reminder

- Start again with an ideal amplifier with gain $-A_0 \sim 100$, no detector capacitance and $C_f = 50$ fF.



- Add two sources i_{pulse} (one shown) which deliver charges of $+Q_{\text{in}}$ and $-Q_{\text{in}}$ (e.g. ± 1 fC) so that we get positive and negative output pulses, offset by 1 μ s
- Chose R_f such that we discharge in roughly 200ns
- How does the time constant change when you vary the input charge from 1 fC to 10 fC ?



MOS as Feedback Resistor

- Now use an NMOS N_18_MM of W/L = 500nm/200nm instead of the feedback resistor
 - You may want to duplicate the circuit in your schematic so that you keep the resistive feedback as a reference
- Us $Q_{in} = 1\text{fC}$. Find the gate voltage such that you get roughly the same 200ns time constant.
- Does this work for both polarities? Exactly?
- Increase the charge to 20fC. What happens? Explain! This is tricky! Hint: What is V_{GS} of the feedback MOS?
- Go back to 1fC. Change the gate voltage by 50mV (this can easily happen from run to run). How much does the time constant change?
- The gate voltage sensitivity can be reduced by making the MOS very long (100 μm or so). Why?

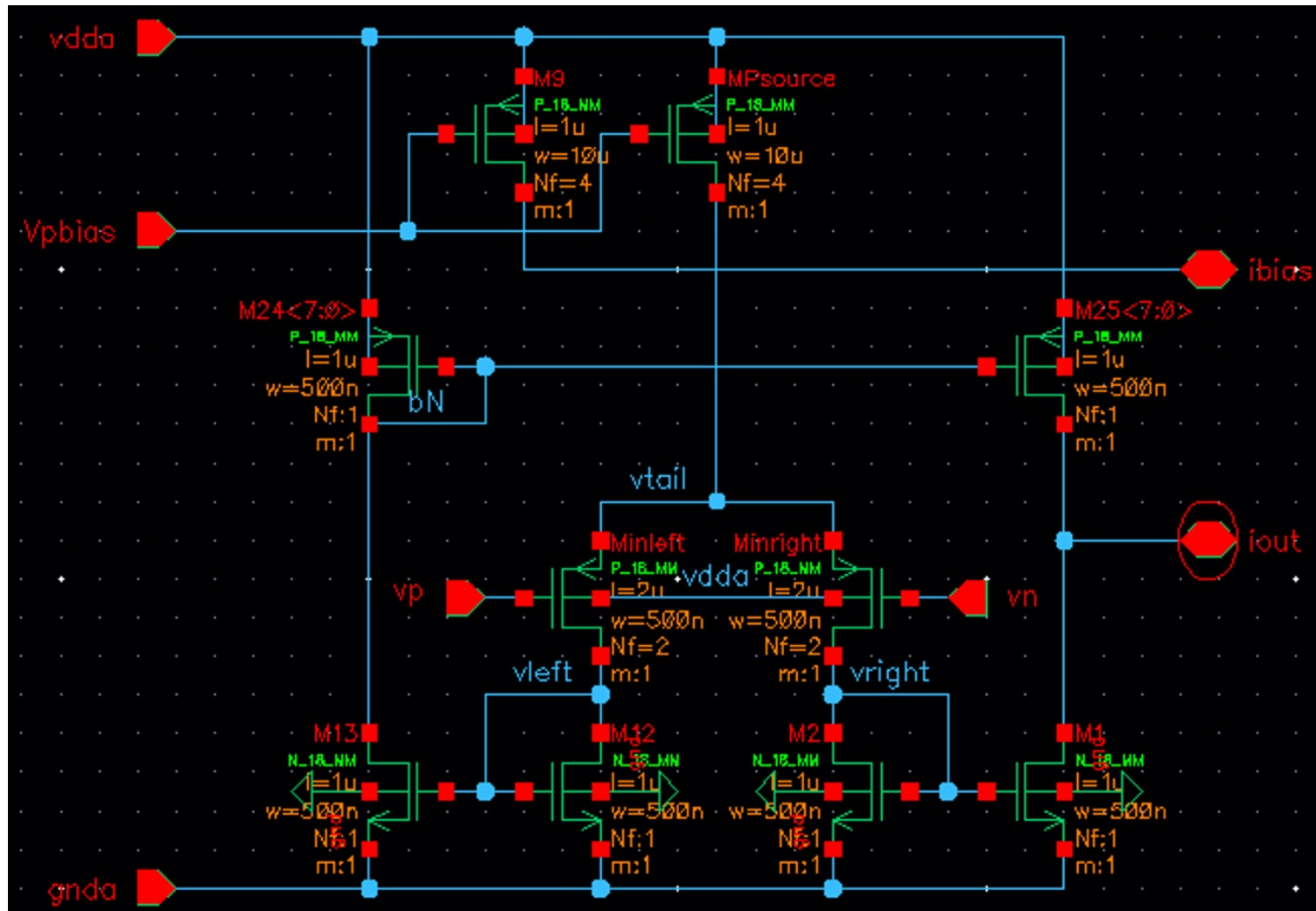


USING A TRANSCONDUCTOR FOR DC FEEDBACK (THIS IS AN UNUSUAL SOLUTION...)



The Transconductor

- Our Transconductor is shown here
 - Explanation on next page





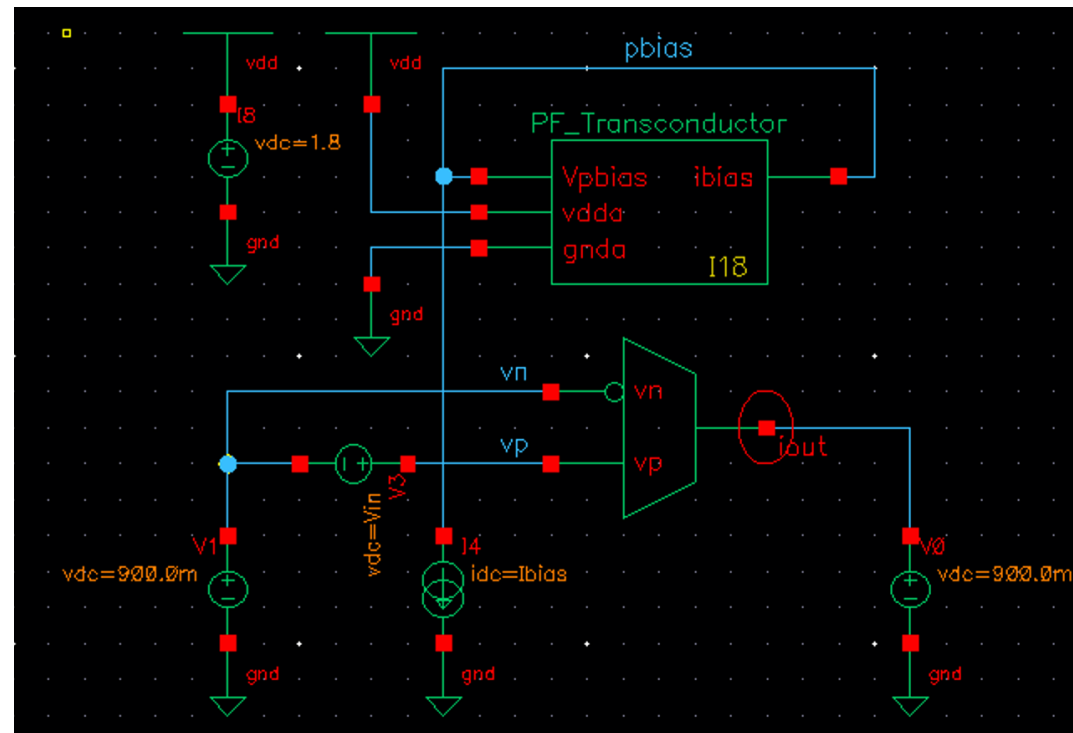
Transconductor

- It is a differential amplifier with PMOS inputs v_p and v_n
 - Input MOS are long: $W/L = 1\mu/2\mu$
- The ('tail') bias current comes from $M_{p\text{source}}$, with gate bias voltage $V_{p\text{bias}}$.
- An identical PMOS M_9 provides a current output i_{bias} . By connecting i_{bias} to $V_{p\text{bias}}$ (outside), we generate a PMOS mirror from which we can pull the bias current to ground. (This 'trick' avoids a PMOS at the top level schematic.)
- The currents on the left and the right are mirrored and added at the output.
NOTE: We will connect the output to a 'fixed' voltage V_{out} .
- In an ideal case, $I_{\text{out}}=0$ if $v_p == v_n$.
- The maximal / minimal output currents should be I_{bias} . (if all mirrors are 1:1)



Simulating the Transconductor

- Use $i_{bias} = 100\text{nA}$ (small!) and fix $V_{out} = 0.9\text{V}$.
- Set v_p to 0.9V and vary v_n from $v_p - 0.5\text{V} \dots v_p + 0.5\text{V}$ (DC sweep!)
- Observe I_{out} . **What is the transconductance?**
- In which (input) dynamic range does the circuit work?





Changing i_{bias}

- Change i_{bias} (1nA...1uA)
 - How does the transconductance change ?
 - How does the dynamic range change ?
-
- We see that we can easily get small transconductances, but for small transconductances, the dynamic range is small...
-
- Difficult: Try $i_{\text{bias}} = 10\text{uA}$. Why does the circuit stop working?



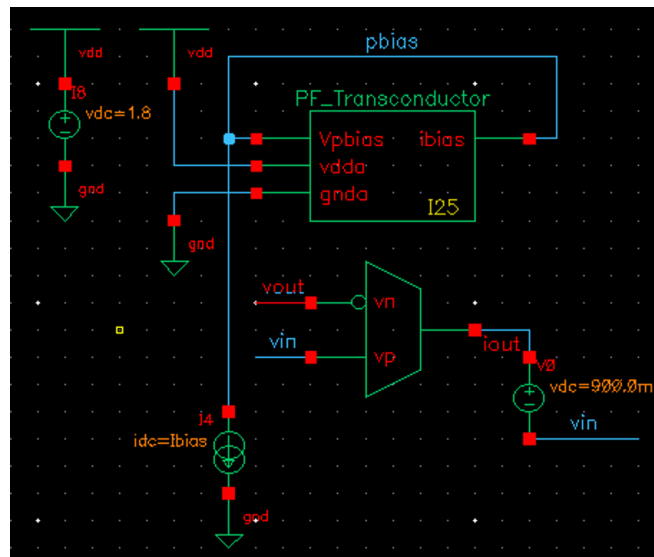
DC input range

- We want to see for which input voltages the circuit works.
- Vary v_p from -400mV to 900mV (and sweep v_n around v_p)
 - When does the circuit stop working?
 - Why?
Hint: What is the saturation condition for the differential PMOS pair?
- Replace the lower NMOS mirrors by N_LV_18_MM. These transistors have lower threshold.
 - Difficult: Why does this help?
- We now have a circuit which works well down to 0 at the input 😊
- Can the *output* go to 0 as well?



Using the Transconductor in the Charge Amplifier

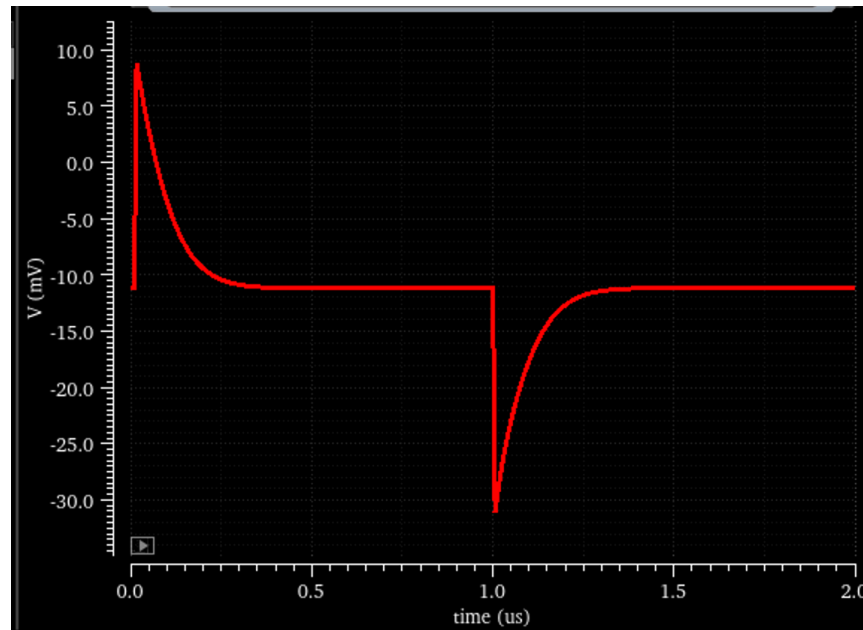
- Now use the transconductor in the feedback of the ideal CSA (implemented with a vcvs)
 - (remember how we used a vccs on sheet 1!)
- Connect vp and vn to the input and the output of the CSA
 - This will force $v_p = v_n$
- As our transconductor cannot drive into ground, use a dc voltage source to shift its output level to 900mV
 - We will not need this later with a real amplifier...





It works!

- Use $Q_{in} = 1\text{fC}$ and $I_{bias} = 50\text{nA}$ or so.
- If you did everything correctly, it should work, in principle:



- Vary I_{bias} and observe how the time constant changes.
- We have a current controlled discharge time !



Saturation

- Use 50nA again.
 - Increase the input charge from 1 fC to 10 fC and to 30fC
 - How do the pulse shapes change?
 - Why?
 - What happens if you double I_{bias} ?
 - Is this what you expect ?
-
- The constant current discharge can be useful, because the width of the signal becomes proportional to the input charge.
 - Try this: $I_{\text{bias}}=50\text{nA}$, $Q_{\text{in}} = 10,20,30 \text{ fQ}$

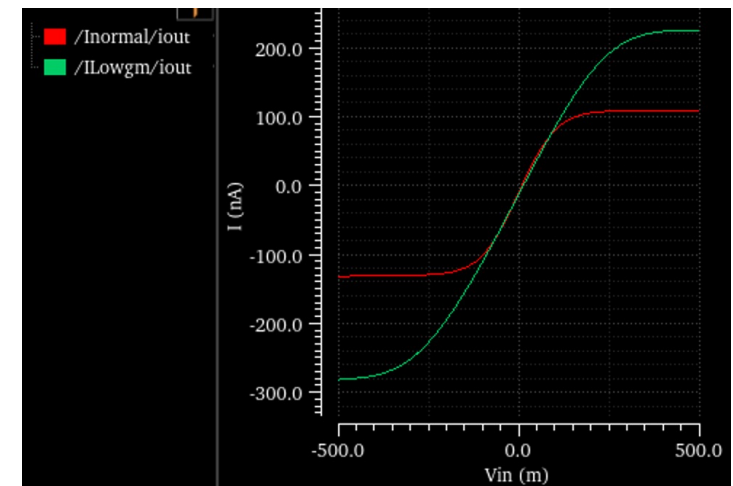


Optional: Back to RC Shape

- The 'saturation' occurs quite early because the linear input range of our transconductor is small for small I_{bias}
 - For experts: The input diff. pair is in weak inversion
- If we increase I_{bias} , the range gets better, BUT the transconductance increases and we get a too fast discharge. (input pair gets into strong inversion)

- A **trick** can solve this:

- Use a 'large' I_{bias} current in the differential pair
- Use a current mirror in the output branch to divide this current down to 1/8 or less



- Try this in a 2nd transconductor. Compare in a dc simulation to your first version. Is the input range wider for same transconductance? (You must use different I_{bias} currents!)



No more analogLib tricks

- Finally, use a NMOS gain stage instead of the vcvs in the main CSA.
 - For instance $W/L = 5\mu/500n$ biased at $5\mu A$
- The input will now settle to a voltage around the NMOS threshold
- The transconductor output drives into that voltage so that you do not need the 900mV shift and more.