Exercise:
Charge Amplifier

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Motivation

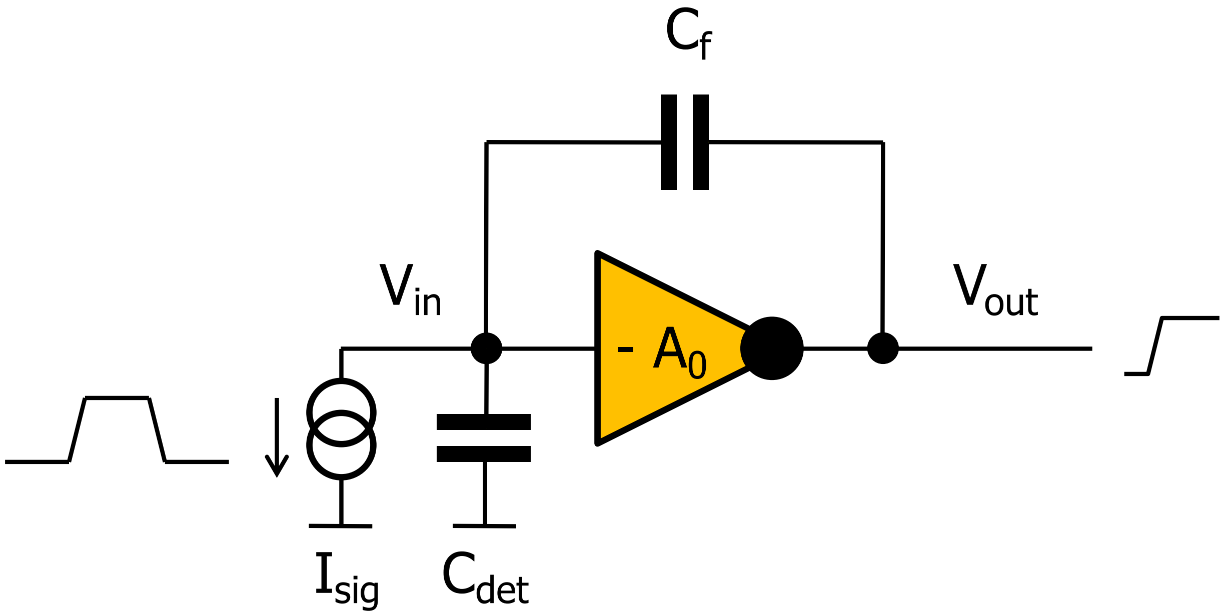
- Many sensors deliver charges (e.g. photo diodes)
- We want to amplify such (small) charge signals
  - Our goal will be to see, e.g. 1000 electrons. Can we see 100?

- A critical question will be the noise in the circuit
- We will reduce the noise by
  - Dimensioning the transistors in the amplifier
  - More current
  - Filtering

- We will start with an idealized circuit and refine it step by step
- We will have to consider the capacitance of the ‘detector’ at the input

Ideal Charge Amplifier

- An ideal charge amplifier consists of an inverting amplifier with large gain A_0 and a 'small' feedback capacitor C_f.



- The input charge is delivered by a trapezoidal current pulse
- For the start, we neglect the input capacitance C_{det}.

Basic Operation

- The current shall have rise/fall times 1ns and a plateau of 5ns.
- What plateau current do you need to deliver Qin = 1 fC ?

- Use a vcvs as amplifier
  - Ground the positive input
  - Use a gain of -100 to start with
  - Set C_{det} = 0 for a start
- Start with C_f = 100fF. Make sure it is discharged at t=0.

- Simulate the circuit. What is the output voltage after Q_{in}?
- Calculate the amplitude of the output signal (after all charge has arrived) as a function of Q_{in}, A_0 and C_f.
  - Hint: When C_{det} = 0, all input charge must flow to C_f. Input and output voltage are related by A_0.
  - When later C_{det}>0, some charge is left on C_{in}.

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Discharging C_f

- Inject two consecutive charge packets at t=10ns and t=100ns
- The output does not 'come back to 0'. This is not good.

- Add a discharging *resistor* R_f in parallel to C_f.
- What value do you need to discharge in roughly 1µs? Simulate and calculate.

- The resistor effectively removes the charge (stored on C_f) from the input node.
- Tricky: Can you use a vccs to achieve the same effect?

Adding a Source Follower

- Add a source follower (MOS + current source) to the output
  - You could try a vdc first to understand what happens.
- Connect R_f after the SF.
  - What changes? Why?
- Connect C_f after the source follower
  - What changes? Why?

Adding a Detector

- (Without Source Follower)

- Now add a detector capacitance of, say, 10 pF.
- How does the output change? Why?

- Derive a formula of the signal height as function of Q_{in}, A_0. C_f and C_{det}.

- What can you do to get more voltage?
- Try this out!

- Try out some extreme cases an compare simulation result and calculation.

A Real Amplifier

- Replace the idealized amplifier (i.e. the vcvs) by an NMOS gain stage with an ideal current source load.

- Simulate the gain
  - What is a good operation point?
  - What is the best operation point?

- Simulate the charge amplifier output (with C_{det}).
  - Do you find what you expect?

- Increase the current more and more.
  - What happens?
  - Why?