ESE 518 Project Presentation

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Design Overview

Design a front-end channel (charge amplifier and shaper) with the following specifications:

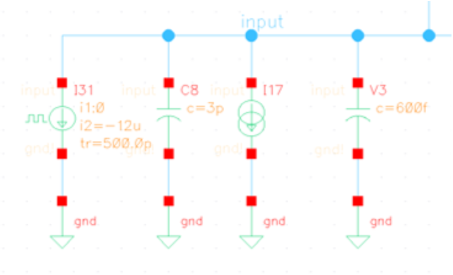
- Sensor
  - Silicon pixel, capacitance 3pF, leakage current 100pA, maximum energy 10keV, maximum rate 10kcps, interconnect capacitance 600fF.
- Charge Amplifier
  - Input transistor optimized at 1mW power dissipation;
  - Transistor-level schematics, with optimized transistors (loads, sources, cascodes);
  - Bias voltages can be ideal voltage sources.
- Shaper(filter)
  - 2nd order filter with real coincident poles;
  - Ideal voltage amplifiers;
  - Optimized peaking time;
  - Output baseline 200mV.

Sensor

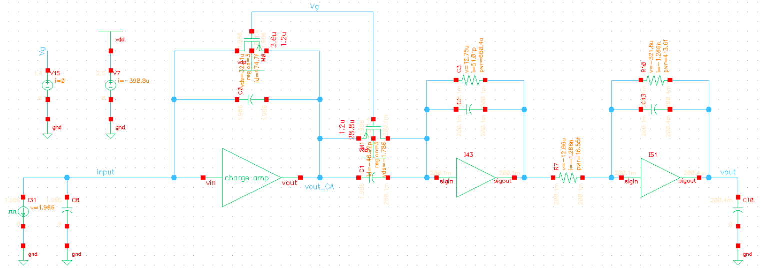
- The sensor can be modeled with current sources in parallel with capacitors.
- The main current source $i(t) = Q\delta(t)$.
  - $Q = N_e \cdot q = \frac{E}{E_i} \cdot q$:
    4.44×10^{-17}C for 1keV and 4.44×10^{-16}C for 10keV.
  - $Q\delta(t)$ is approximated by a trapezoid-size signal with height I, base 1.5ns (0.5ns rise time, 0.5ns fall time and 0.5ns pulse width) and area to be Q. $I = 44.4$nA for 1keV and 444.4nA for 10keV.
  - The maximum rate is 10kcps, so the pulse period is set to be 100μs assuming the events happen at maximum rate. The above settings also guarantees the rule of thumb that $\tau_w < \frac{1}{10R}$.
- An ideal 3pF capacitor is used to model the sensor capacitance.

Sensor (cont.)

- Leakage current is modeled by a 100pA current source and the interconnect capacitance is modeled by an ideal 600fF capacitor.
- The equivalent circuit of the silicon sensor is shown to the right.



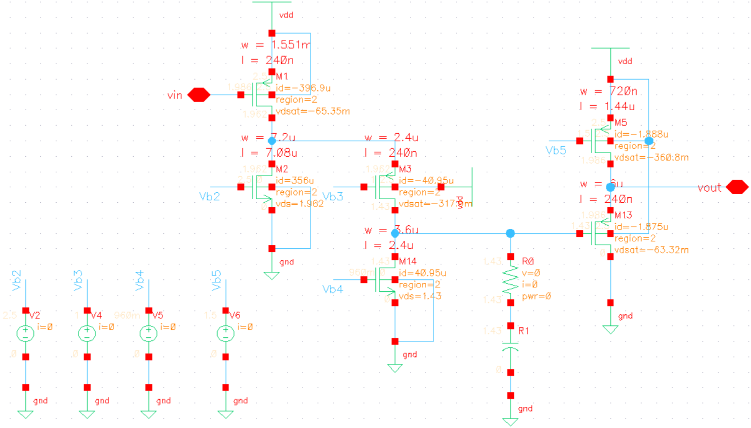
Overall Design of the Front-End Channel



Overall Design of the Frond-End Channel: Transfer Function

- $H(f) = \frac{C_c}{C_F} \frac{R}{1+sRC} \frac{R}{R_0} \frac{1}{1+sRC}$.
- We design the charge gain $N = \frac{C_c}{C_F} = 8$.
- Let $\tau = RC$, $v_{\mathrm{out}} = QH_0 \frac{t}{\tau} e^{-t/\tau}$.
- Note that the output voltage achives maximum $v_{\mathrm{max}} = Q\frac{H_0}{e}$ at $t_{\mathrm{max}} = \tau$.
- We will return to discuss more about the results after we show how the charge amplifier and the shaper are designed.

Charge Amplifier



Charge Amplifier

DC operating points are annoted in the schematic on last page, which shows all transistors are in saturation region. Transistor sizes are shown in the table below.

	M1	M2	M3	M4	M5	M6
W (μm)	1551	7.2	2.4	3.6	0.72	6
L (μm)	0.24	7.08	0.24	2.4	1.44	0.24

Charge Amplifier: Input MOSFET Optimization
Input Impedance

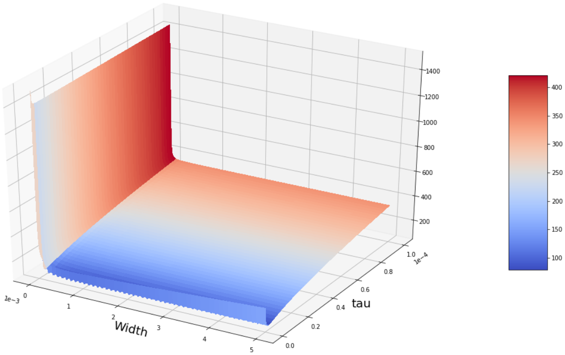
- We first talk about $C_{IN} = C_S + C_F + C_G$.
- $C_S = 3$pF (with an additional interconnect capacitance 600fF) as given. $C_G = C_W \cdot W$. We need to find C_F.
- The above analysis for C_{IN} will be used when we optimize ENC over transistor width and peaking time.

Charge Amplifier: Input MOSFET Optimization ENC

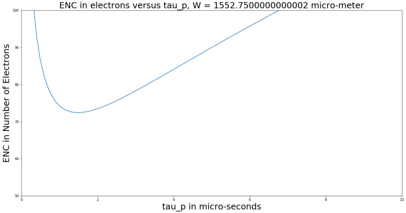
- $(ENC)^2 = \frac{A_{vwp}}{\tau_p} S_{vw} C_{IN}^2 + 2\pi A_{vfp} \cdot S_{vf} C_{IN}^2 + A_{iwp} \cdot S_{iw} \cdot \tau_p$.
  - Series white noise:
    $A_{vwp} = 0.924$, $S_{vw} = \gamma n \frac{4kT}{g_m}$.
  - Series $1/f$ noise:
    $A_{vfp} = 0.59$, $S_{vf} = \frac{K_f}{c_{ox} WL}$.
  - Parallel white noise (from leakage current):
    $A_{iwp} = 0.924$, $S_{iw} = 2qI_L$.
- A Python script was used to obtain the width and peaking time values that minimize ENC.

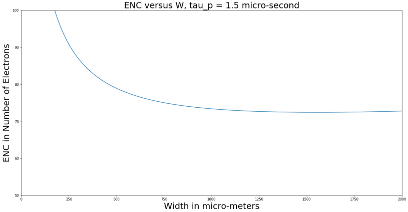
Charge Amplifier: Input MOSFET Optimization ENC

M1: $W = 1552.75\mu\text{m}$, $L = 0.25\mu\text{m}$, $g_m = 8176\mu\text{S}$.
$\tau_p = 1.5\mu\text{s}$, $ENC = 73e^-$.

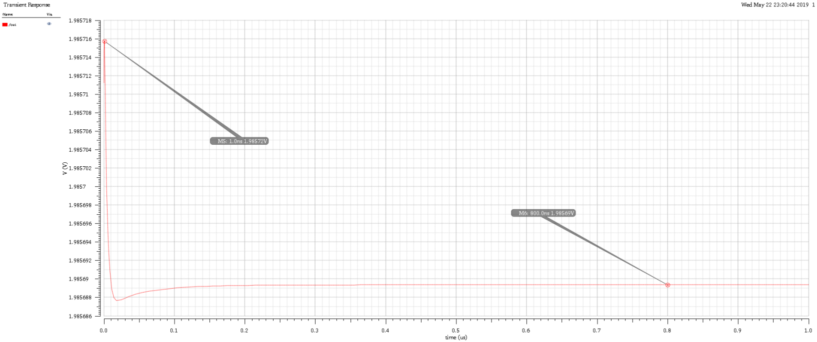


Charge Amplifier: Input MOSFET Optimization
ENC vs. τ_p and W



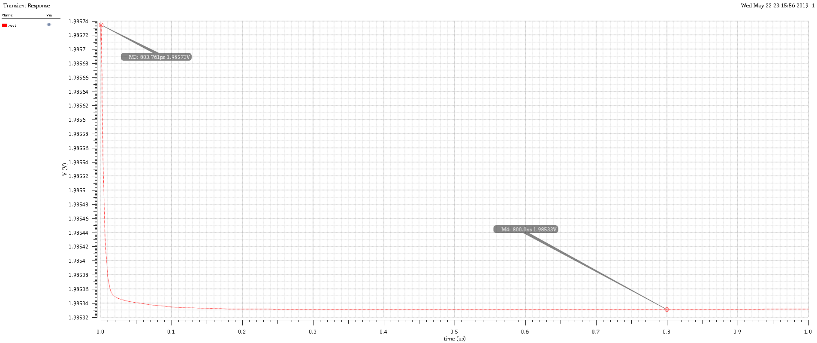


Charge Amplifier: Simulation Result



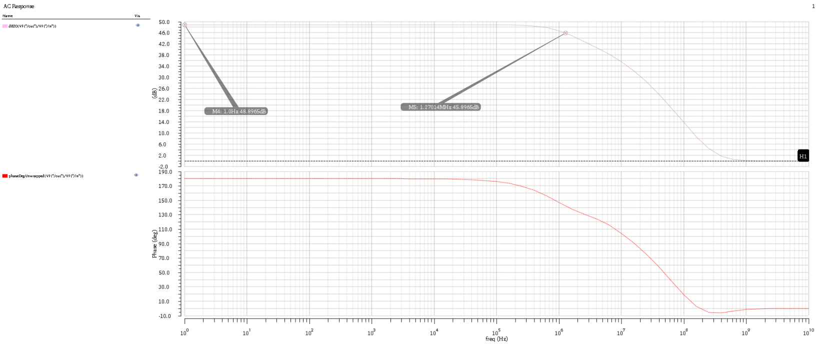
Output voltage of the charge amplifier for 1keV input is around 0.04mV.

Charge Amplifier: Simulation Result



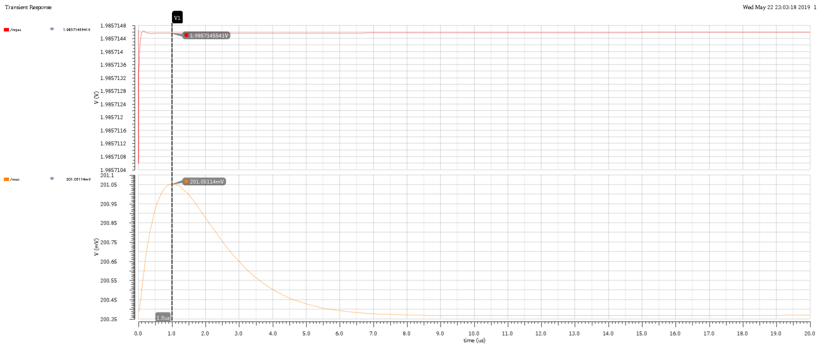
Output voltage of the charge amplifier for 10keV input is around 0.4mV.

Charge Amplifier: Simulation Result



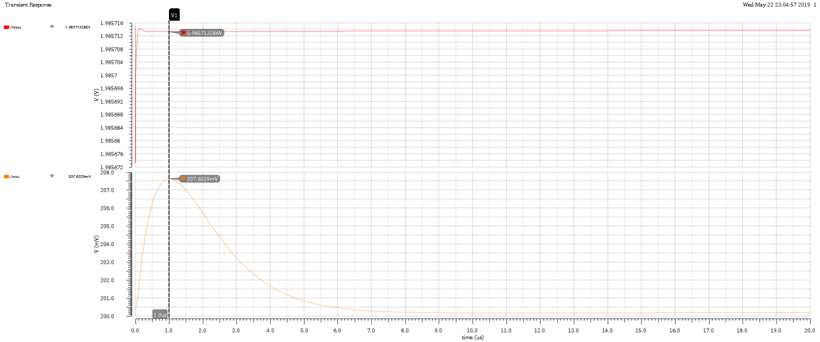
AC simulation shows the gain of the charge amplifier is around 48.9dB. $\tau \approx 125.4$ns, which satisfies the rule of thumb that the rise time should be less than $0.1\tau_p$.

Front-End Channel Simulation Result



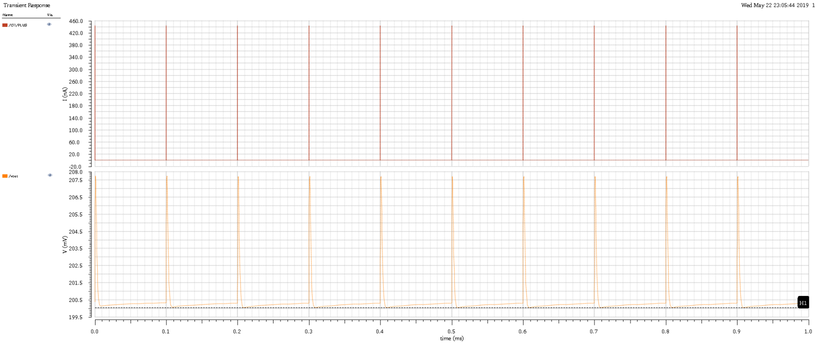
Output response of the front-end channel for 1keV input is shown above.

Front-End Channel Simulation Result



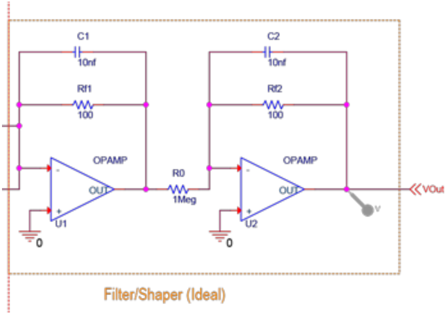
Output voltage of the charge amplifier for 10keV input is shown above.

Front-End Channel Simulation Result



We run the input pulse at its maximum rate for 1ms in transcient simulation, which shows 200mV baseline is achieved.

Overall Filter Design: Circuit



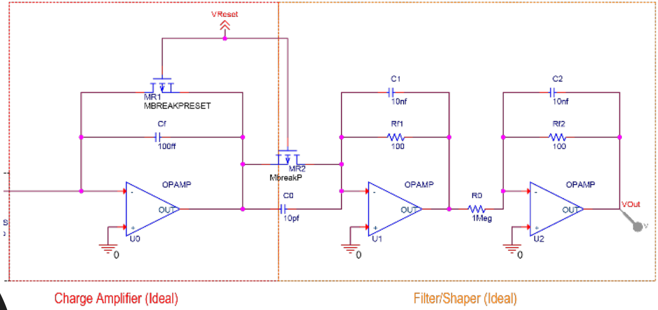
Design Notes:

Time Constant τ = 1µs

Features: 2 real coincident poles

Ideal Transfer Function: $\frac{1}{(1+s\tau)^2}$

Overall Filter Design: Equations



Design Notes:

Actual System Transfer Function:

$G(s) = \frac{C_0}{C_f}\frac{R}{R_0}\frac{R}{(1+s\tau)^2}$ where $R = R_{f1} = R_{f2}$,

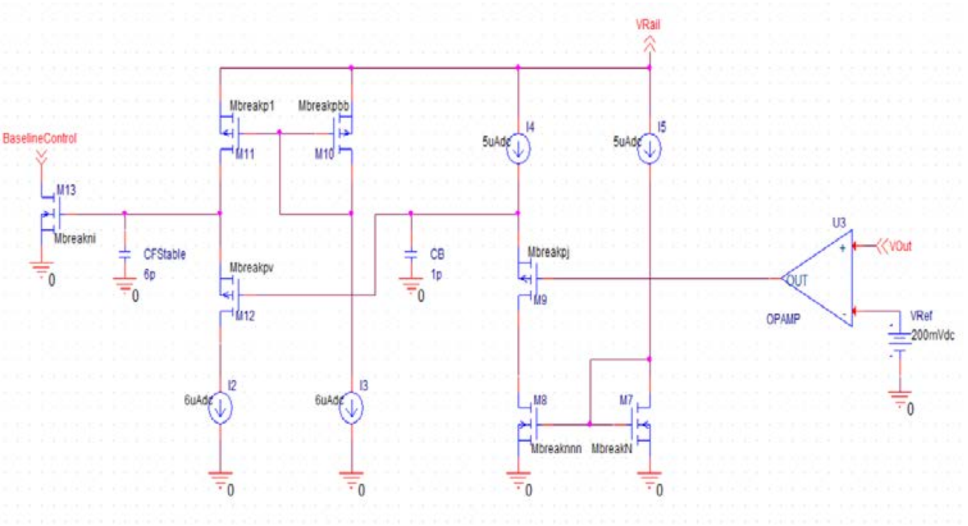
$\tau = R_{f1}C_1 = R_{f2}C_2$

G(s) must be equivalent to $\frac{H_0}{(1+s\tau)^2}$ where H_0 is the gain of the charge amplifier

Therefore, $R_0 = 100R^2$ and R is chosen to minimize R0 @ 1Meg

Output Voltage Stabilization

Any fluctuation in the output baseline (output of the shaper) may introduce an error in the measurement of the peak amplitude.



Conclusion

- Charge gain: $N = 8$
- Peak time: 1.1μs
- ENC: $106e^-$
  assuming ENC(shaper)/ENC(charge amp) $= 0.46$
- Dynamic range: $Q_{\max}/ENC = 26.2$ for 10keV.