A Novel Front-End Amplifier for Gain-less Charge Readout in High-pressure Gas TPC

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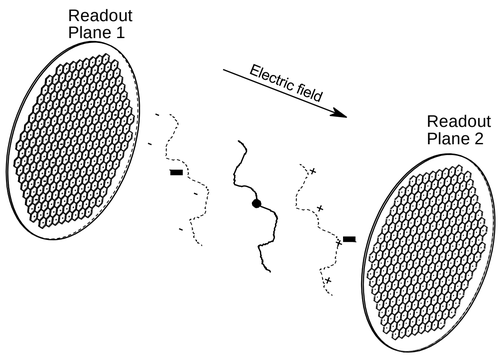
Abstract

We present a novel low-noise Charge-Sensitive Amplifier (CSA) manufactured in a standard 0.13 μm CMOS process. The CSA is part of an integrated sensor, with an array of which, forms a charge readout plane in a high-pressure gaseous Time Projection Chamber (TPC) for 0νββ search. A novel front-end amplifier composed of a source-drain follower and a common-source amplifier is proposed. The potential on both the source and drain node of the input transistor follows its gate.Hence the effective input capacitance contributed by the input transistor is significantly reduced. If both the CCE and the input metal routing are also shielded and the shield is coupled to the source or drain node, the input capacitance can be greatly reduced. The simulation shows that the equivalent noise charge is about 30e-.

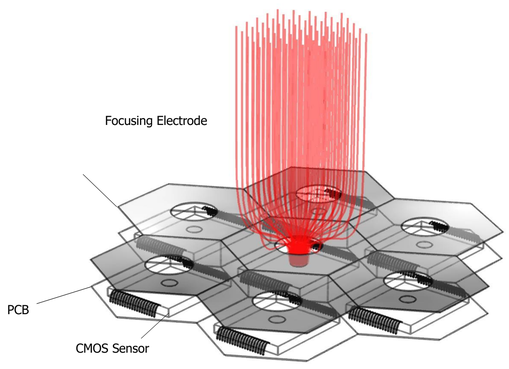
Introduction

***Neutrino-less double beta decay is a low background and low noise experiment [1].Topmetal* sensor for a next-generation high-pressure gaseous (TPC) to search for neutrinoless double-beta decay (*0νββ*):**

- *Topmetal* sensor advantage: directly collecting ionization charges without gas-electron multiplication
- Energy resolution: < 1% FWHM ⟷ ENC<30e-
- Charge Collection Electrode : 1 mm diameter
- Pitch: 5~10 mm
- 10^5 sensors for a large plane

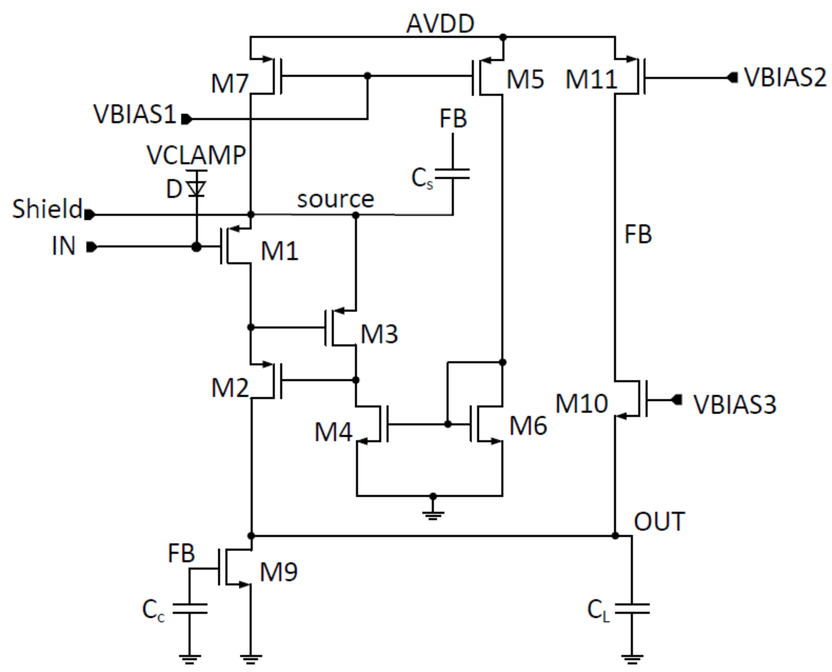


Conceptual design of a TPC



Readout Plane

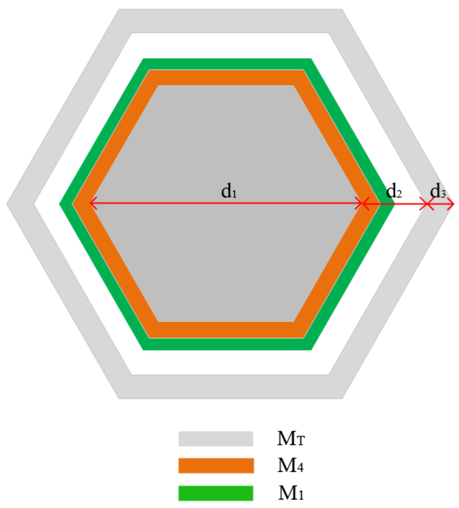
Charge-Sensitive Amplifier (CSA)



CSA:

- M1~M4 constitute a source-drain follower, the voltage on source and drain of M1 follows its gate, respectively.
- The input capacitance is decreased from the 4pf down to 7.4fF, reducing the ENC.
- C_s is the coupling capacitance between metal layers. C_L is the next stage input capacitance. The conversion gain is determined by C_s/C_L.
- C_c is the coupling capacitance between the metal layer and the substrate, used as a low-pass filter to stabilize the bias voltage (FB).
- The output DC voltage is biased by M10 and M11.
- The total current consumes about 2.8mA.
- The rise time (20% ~ 80%) is less than 1.8us.

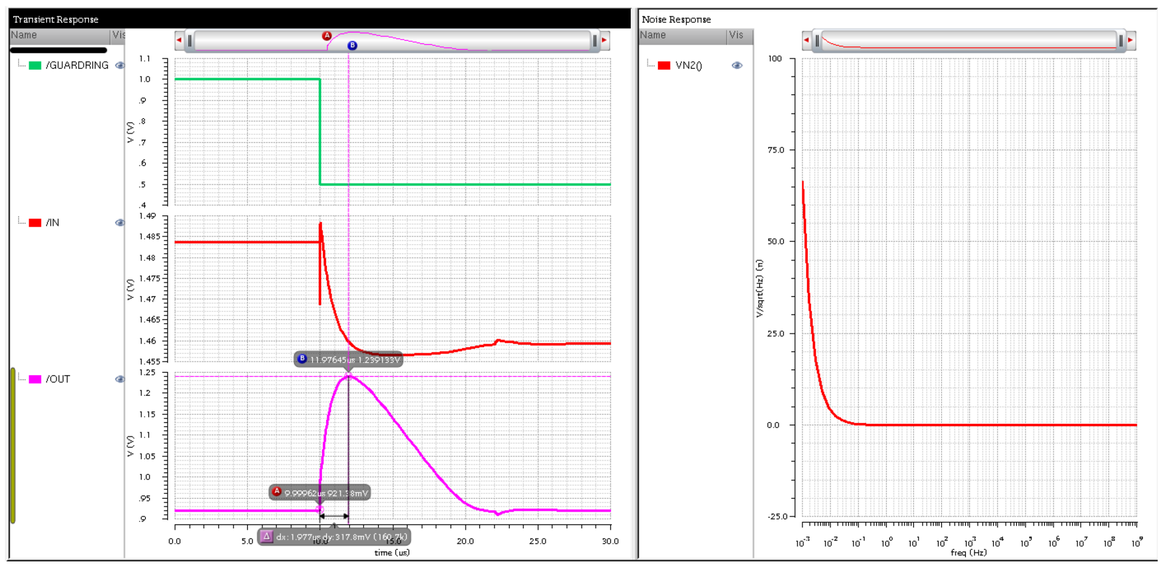
Charge Collection Electrode (CCE)



CCE:

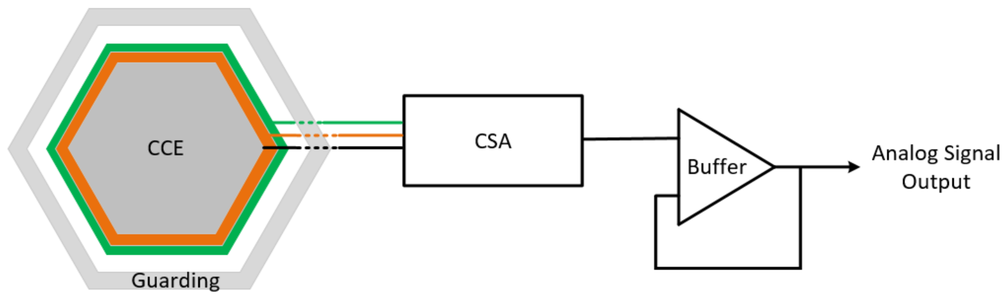
- top metal exposured around media
  - directly collecting ionization charge
  - DC coupled to the front end
- hexagon shape with a diameter of d_1 = 1 mm
  - 4 pF capacitance
- top-metal guardring surrounding the CCE with a spacing of d_2 = 3.5 μm and a width of d_3 = 4.7 μm
  - injecting charge by a parasitic capacitance of 0.834 fF
  - focusing electric field

Simulation Results

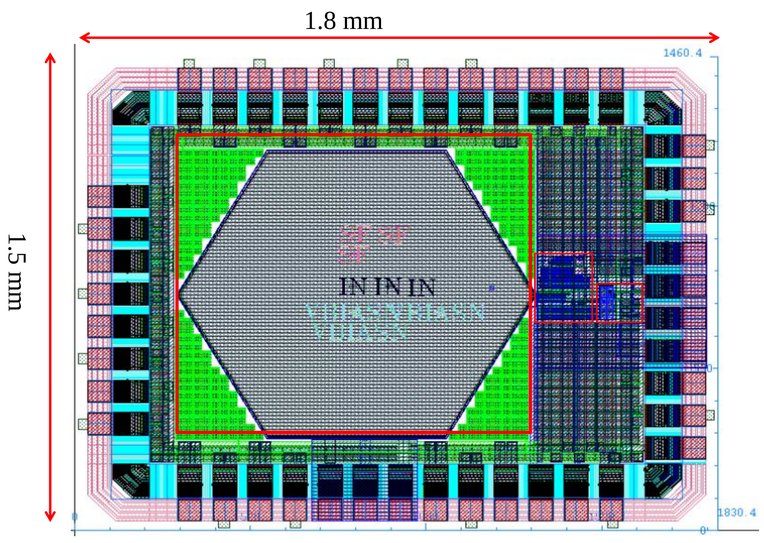


- The conversion gain of the CSA is about 890mV/fC.
- The post-simulation results show that the equivalent noise charge of the CSA is 30e-.

Test Chip



Building Blocks:
CCE, CSA and Unit-Gain Buffer



Layout

- CCE
- CSA
- Unit-Gain Buffer

Summary and Outlook

A low-noise charge-sensitive amplifier has been tapped out in a 0.13 μm process. The post-simulation shows it has an equivalent noise charge of 30 e-. The characteristic satisfies the requirement of the *0νββ* experiment. We will test the chip in the future.

Acknowledgments and References

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Reference:

[1] Gao, C. , et al. "A Low-Noise Charge-Sensitive Amplifier for Gainless Charge Readout in High-Pressure Gas TPC." Topical Workshop on Electronics for Particle Physics 2019.