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A Low-Noise Charge-Sensitive Amplifier for Gain-less Charge Readout in High-pressure TPC

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We present a low-noise Charge-Sensitive Amplifier (CSA) manufactured in a standard 0.35μm CMOS process. The CSA is part of an integrated sensor named Topmetal-S, with an array of which, forms a charge readout plane in a high-pressure gaseous TPC for $0\nu\beta\beta$ search. A single-ended folded cascode amplifier with a 73dB open-loop gain and 340MHz gain-bandwidth product forms the main amplification stage in this CSA. Measurements show that the conversion gain of the CSA with a 3fF feedback capacitor is 168mV/fC. The equivalent noise charge of the CSA after a trapezoidal pulse shaper is 28.7e- rms with a 5pF detector capacitance.

Summary

The search for Neutrinoless Double-Beta Decay ($0\nu\beta\beta$) at tonne-scale and beyond requires techniques that are capable of observing a sharp peak at $Q\beta\beta$ in the total beta energy spectrum and final state identification through 2-β tracking. A direct charge sensor, Topmetal-S, with only one charge collection electrode on a single sensor and with the intention to tile many such sensors on a large plane, is being developed for $0\nu\beta\beta$ experiments in a high-pressure gaseous Time Projection Chamber (TPC) without gas-electron avalanche. This scheme eliminates the conventional avalanche fluctuations but demands exceedingly low internal noise on the Charge Sensitive Amplifier (CSA) to achieve sufficient energy resolution by charge measurement alone.

Given a power consumption and circuitry, the electronic noise of the CSA is proportional to the input capacitance primarily contributed by the Charge Collection Electrode (CCE). An exposed hexagon metal with a diameter of 1mm is proposed as the CCE on the topmost layer. Its capacitance with respect to the ground is around 5pF. The charge collected by the CCE is directly DC coupled into the CSA. A guard ring is implemented to surround the CCE. The coupling capacitance between the guard ring and the CCE is about 1.186fF, as extracted from the layout. A negative step pulse can be injected through the guard ring to preliminarily test the CSA.

The CSA is composed of an inverting amplifier and a small feedback capacitor (Cf) which is a well-controlled component around 3fF. The charge (Q) collected on the charge collection electrode is fully integrated on Cf. The output signal amplitude (VO) is approximately equal to Q/Cf. Hence the charge conversion gain defined by AQ=VO/Q=1/Cf is determined by Cf. A regulated single-end folded cascode amplifier is proposed in this CSA. A p-type transistor is chosen as the input device because it has a lower flicker noise contribution compared to an n-type transistor. The open-loop gain of the amplifier is about 73dB and the gain-bandwidth production is around 340MHz. All biases could be tunable through digital-to-analog converters with low-pass filters, respectively. The operation point of 1 V as a normal reference could be tuned by adjusting the gate voltage of an n-type transistor added above the input p-type transistor. A reset transistor parallel to Cf continuously discharges Cf and restores the baseline. The RC constant could be extended into several milliseconds by varying the gate voltage of the reset transistor. The total current consumes about 2mA and the rise time (20% ˜ 80%) is less than 440ns.

The CSA has been implemented in Topmetal-S, which is manufactured in a standard 0.35μm CMOS process. For testing, the analog signal is transmitted off chip through an analog buffer. Measurements show that the conversion gain of the CSA with a 3fF feedback capacitor is about 168mV/fC. The equivalent noise charge of the CSA after an off-chip digital trapezoidal pulse shaper is 28.7e- rms with a detector capacitance of 5pF.

Its characteristics satisfy the requirements of the experiment. Detailed design and measurements will be discussed.

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