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Review of a Time-variant bandpass filter for Fast Analog FEE

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ABSTRACT

A time-variant circuit is examined in the context of readout electronics for silicon sensors. It consists of a time-variant differentiation and a two-stage integrator. To lower mean power consumption, the circuit can alternate between the on and off states. This will improve noise performance and restore output undershoot and offset.

Keywords: Integration, Time variant circuit, undershoot, Offset.

I. INTRODUCTION

Medical imaging-based spectroscopy for positron emission tomography (PET) hugely utilizes hard X-rays and soft γ-rays provided by compound semiconductor detectors among which cadmium zinc telluride (CdZnTe). [**P. Yannick et al. (2021)].** For high resolution needs, low-noise readout electronics interfacing the sensors is crucial for accurate measurement of electric charges deposited by ionizing radiation and the arrival time of the incident photons. In the design of analog front-end electronics (FEE) for particle beam energies detection, the noise performance and DC baseline are optimises using customize circuits. Noise can quickly degrade system performance, especially at very low energy values. The filter must have strong selectivity to enhance this performance. For this, *CR-RC*^{n} filters are used, however, they are prone to undershoot in high count rate applications. A pole zero cancellation circuit (PZC) is used to fix this undershoot, but the bandpass feature of the filter is lost [**P Grybos et al (2008)].** The readout circuit is thus susceptible to low-frequency noise. In addition, CdZnTe detectors are subject to imperfections such as leakage current and shot noise. These various sources of flaws can create distortions in the signal by altering the operating point of the circuit. This signal can then be subject to a baseline drop that will degrade the energy resolution of FEE. In this work, we propose a correction circuit to solve the above-mentioned problem while preserving the bandwidth characteristics of the circuit. The proposed circuit is based on time-variant circuit. It is a bandpass filter based on complementary switches, which increase noise performance by stabilizing the output baseline of the front-end circuit and restoring the bandpass nature of the circuit. As a result, it is possible to switch the output swing while maintaining the observed baseline and a specific voltage, with the discriminator threshold level in control. Results from post-layout simulation tests conducted in a 65 nm CMOS process from TSMC under 1.2 V supply voltage have confirmed the design.

II. PROPOSED CIRCUIT

The backbone filter circuit is a CR-RC^2 shaper, where a classical PZC is added along with a baseline restorer (BLR) module. The proposed circuit for undershooting cancellation and baseline restoration is based on a time-variant circuit called the TV-BLR and proposed by **Pancha et al. (2022)**.

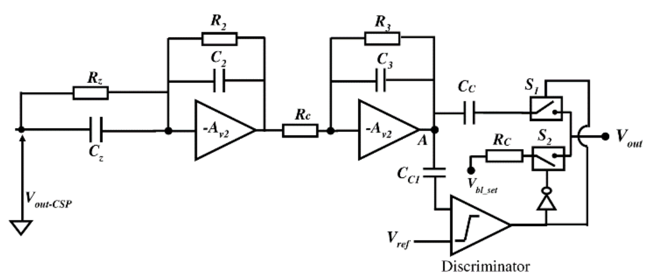

Figure 1: Time variant filter

The circuit is presented in figure 1 and operates in two modes. Firstly, when a charge is detected at the input, a signal is generated by the preamplifier and ends up at node A. Then, the TV-BLR circuit starts working. It consists of two switches and a discriminator. When the amplitude of the signal at node A is sufficiently large (above the threshold value), the discriminator generates a logic trigger significant as equivalent time over the threshold (ToT) signal **[T. Orita et al (2015)],** large enough to toggle the control switches S_1 and S_2. In this case, S_1 is closed, and S_2 is open, connecting the output to the upstream part of the circuit. The circuit formed by Cc, Roff, RC +Ron thus takes the configuration of a first-order high pass filter. This is referred as step 1. In the second step, the states of switches are permuted, connecting output node to the ground.

$$\begin{cases} \dfrac{V_{out}}{i_{in}} = H_s \dfrac{\tau_{csa}}{(1+\tau_{csa}s)} \dfrac{(1+\tau_z s)}{(1+\tau_1 s)} \dfrac{\tau_2}{(1+\tau_2 s)} \dfrac{\tau_3 s}{(1+\tau_3 s)} \rightarrow step1 \\ \dfrac{V_{out}}{i_{in}} = 0 \rightarrow step2 \end{cases} \quad (1)$$

$$\begin{cases} v_{out}(t) = H_s \tau_3 \tau_{csa} \dfrac{Q_{in}}{t_c} \left(\dfrac{t^2 e^{-t/\tau_2}}{2\tau_2^2} \right) + v_{noise}(t) \rightarrow \text{Step1} \\ v_{out}(t) = 0 \rightarrow \text{Step2} \end{cases} \quad (2)$$

Equations (1) and (2) are respectively in the transfer function and the time domain response of the circuit.

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III. RESULTS OF SIMULATION

The time domain response of the circuit is depicted in the next figure 2. The preamplifier's integrated signal is boosted and the low-frequency noise components are removed throughout the integration time (step 1). The system's signal-to-noise ratio is decreased at this time due to the high amplitude gain. The circuit can process more interaction flow because the integration time is constrained to between 100 and 150 ns depending on the ToT the discriminator provides. Step 2 allows the system to be quickly reset for the next event after the event has been read. In situations where the discharge period is lengthy, the combination of these two processes not only assures that the baseline is always zero but also makes up for the energy lost as a result of undershooting.

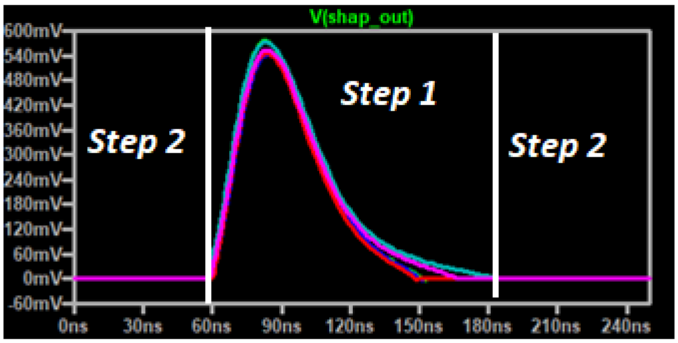

Figure 2: Output response of TV filter circuit

According to equation 2, at stage 1, the signal amplitude increases while the temporal noise decreases. Additionally, in stage 2, the circuit noise is extremely similar to that of the ground, which is very little. As a result, the circuit's overall noise is significantly reduced when averaged across one period **[P. Y. Hertz et al. (2023)]**.

IV. LIMITATIONS

This circuit can be very useful for baseline restoration and noise optimization. However, the output swing is limited to approximatively $V_{dd} - V_{thn}$ due to the topology of the open loop amplifier. Hence, the input energy range is closed.

V. FUTURE WORK

The future work is to improve the output swing of the circuit and to build step by step the entire FEE with the presented scheme. Otherwise, it will be helpful to improve the efficacy of the filter.

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