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# Design of Radiation-Hardened Self-Reset Preamplifier for Nuclear Fission Detectors

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## 1. Introduction

Micro-pocket fission detectors (MPFDs) were developed to measure the neutron flux within a reactor in real-time by Kansas State University (KSU) and Idaho National Laboratory (INL) [1]. The small-size detectors offer many as in-core detectors, such as their small size, suitability for high neutron flux environments, consistent charge deposition, and the ability to discriminate gamma rays. To implement the in-core neutron detector for monitoring power distribution, a readout system should be designed to be fitted for the MPFDs. Previous research had focused on using discrete components for readout system. However, these commercial components suffered from drawbacks like large size, high power consumption, and intricate designs unsuitable for miniaturized applications. Consequently, there is a need to redesign the readout system for MPFDs, opting for application-specific integrated circuits (ASICs) to overcome these limitations.

A charge-sensitive amplifier (CSA) is a crucial component within the radiation detector system, tasked with converting the current signal produced by radiation detectors into voltage [2-3]. Input charges are accumulated in the feedback capacitor ($C_F$) within the CSA, and then the output of the CSA is directly proportional to the input charges. Therefore, the output voltage is approximately determined as

$$V_{out} = \frac{Q_{in}}{C_F} \qquad (1)$$

In high radiation environments, the pile-up phenomenon can occur due to the fast input signal. Providing input signals to the charge-sensitive amplifier (CSA) before the capacitor is discharged can lead to a gradual increase in the CSA output, eventually resulting in saturation. The other issue arises from total ionizing dose (TID) effects. Radiation exposure to the metal-oxide-semiconductor field-effect transistor (MOSFET) prompts the generation of electron-hole pairs (EHPs) in the oxide region of MOSFET [4]. While some carriers swiftly recombine or escape from the oxide region, others become trapped in the SiO2-Si interface. This leads to various issues, including threshold voltage shift, noise increase, and leakage current increase [5]. Therefore, the preamplifier may not provide accurate signal information.

This paper presents a radiation-hardened-by-design (RHBD) preamplifier with two techniques: self-reset technique and TID effects compensation method. These methods are designed to mitigate the radiation effects in high-dose fields.

## 2. Circuit Implementation

### *2.1 Circuit Description*

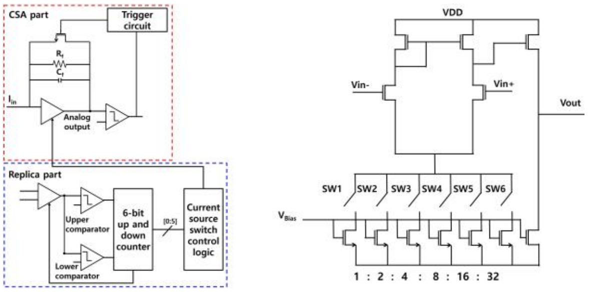
Fig. 1 illustrates the block diagram of the proposed radiation hardened CSA, along with the operational amplifier (OPAMP) utilized in this configuration. The preamplifier comprises two main parts: CSA and replica parts. The CSA part of the RHBD preamplifier consists of an OPAMP, a comparator, a feedback network, and a trigger circuit responsible for activating the feedback switch for self-reset purposes. The replica circuit part is devised to mitigate TID effects and comprises a replica OPAMP circuit akin to that used in the CSA part, two comparators, 6-bit up-and-down counter, and control logic.

### *2.2 Self-Reset Technique*

In high radiation environments, the preamplifier output may saturate owing to fast input signals. In such instances, the comparator produces a reset signal, which is subsequently transmitted to the trigger circuit. This trigger circuit then activates the feedback loop switch, facilitating the discharge of charges from the feedback capacitor and resetting the preamplifier, as depicted in the timing diagram in Fig. 2.

### *2.3 Strategy for Radiation Hardening*

The replica OPAMP serves as a sensor to detect variations caused by TID effects. To maintain a constant common-mode voltage, two inputs of the replica OPAMP receive a constant DC voltage. If radiation-induced changes result in an output increase, the upper comparator triggers a HIGH signal, prompting the 6-bit up-and-down counter to function as a down counter, thereby reducing system current. Conversely, if the



(a) (b)

Fig. 1. RHBD preamplifier block diagram is separated into CSA part and replica part (a). The OPAMP for the CSA has the binary current source stage to compensate for TID effects (b).

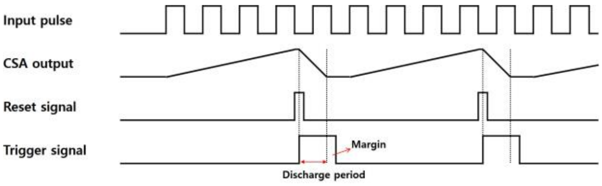


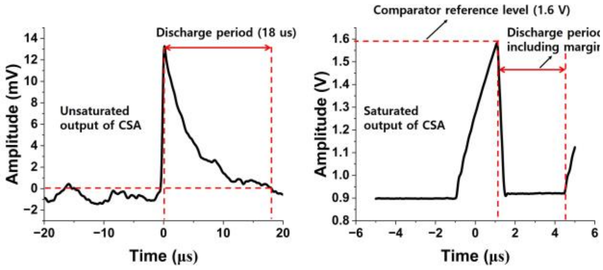
Fig. 2. Timing diagram of self-reset technique. When the preamplifier output is saturated, the comparator generates a reset signal. Then, the feedback switch is closed by the trigger circuit once it produces a trigger signal with sufficient pulse width to discharge the feedback capacitor.

output decreases, the lower comparator generates a HIGH signal, causing the counter to operate as an up counter, increasing preamplifier current. Digital logic generates signals to control switches in the binary current source of both OPAMPs. Consequently, the proposed preamplifier compensates for TID effects by regulating OPAMP current levels. The binary current source can supply current ranging from 1I to 64I.

## 3. Circuit Test Results

Fig. 3 illustrates the verification test results for the self-reset technique. In Fig. 3 (a), it demonstrates that the proposed preamplifier can function as the traditional CSA for a single signal. However, when the preamplifier output saturates due to fast input signals, as depicted in Fig. 3 (b), the self-reset technique rapidly discharges the output. Notably, the self-reset technique exhibits a shorter discharge period compared to the conventional CSA with a large RC time constant in its feedback network.

Fig. 4 presents the outcomes of an irradiation test conducted at the Korea Atomic Energy Research Institute (KAERI) utilizing a Cobalt-60 gamma-ray source. During the test, the test chip was subjected to a maximum dose of 231 kGy (SiO2) at a rate of 10.46 kGy/h. The digital code of the binary current source undergoes changes as the total radiation dose increases. Specifically, as the radiation dose rises, the digital code decreases. This alteration in the digital code adjusts the binary current source to compensate for circuit performance. Consequently, despite the increasing radiation dose, the output of the preamplifier remains constant, as depicted in Fig. 5. Thus, the proposed preamplifier system exhibits the ability to maintain its performance even in high radiation environments such as nuclear power plants (NPPs).



(a) (b)

Fig. 3. Verification test results for the self-reset technique of the CSA part. The Proposed preamplifier can be operated as a conventional CSA for a single signal (a). However, when the output of the preamplifier increases to 1.6 V, which is set as a comparator reference voltage, and then rapidly discharges to the common mode voltage (b). A discharge period is measured at 15 μs and 3.37 μs, respectively.

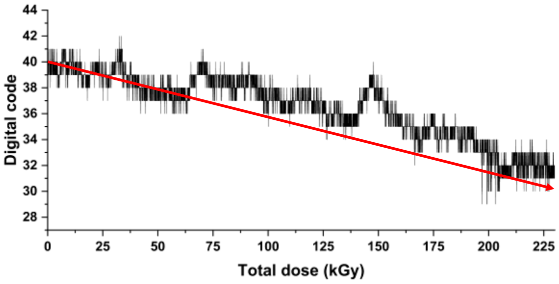


Fig. 4. Irradiation test result for verifying TID compensation technique against TID effects. Variation in the control code for binary current source is observed depending on the total dose. The test was conducted by using a Co-60 source up to 231 kGy ($SiO_2$).

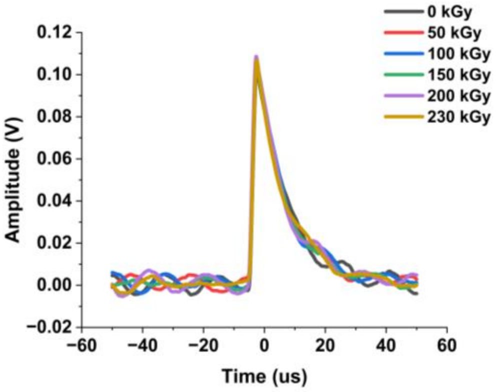


Fig. 5. Output variation of preamplifier during radiation exposure.

## 4. Conclusions

This article introduces a RHBD preamplifier designed for radiation detectors, particularly for the signal readout of MPFDs. The article proposes the utilization of self-reset and TID effects compensation techniques to address challenges in such environments. The verification test of the proposed RHBD circuit was carried out using a Cobalt-60 gamma-ray source, exposing up to 231 kGy (SiO2). An electrical analysis of the circuit will be conducted, and the findings will be presented at an upcoming conference.

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