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Radiation Effect Analysis of CMOS Automatic Gain Control (AGC) Circuit

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1. Introduction

AGC is a system that automatically controls the gain and is often used in many applications that require a wide dynamic range, such as Compact Muon Solenoid (CMS) trackers, Hard X-ray Modulation Telescope (HXMT) optical sensors, and RF communication systems[1-4]. When using such an AGC, a wide dynamic range input signal can be received with minimum noise. However, CMOS AGC used in a radiation environment may malfunction due to the influence of radiation, resulting in an incorrect input signal. Therefore, in this paper, the radiation effect on the CMOS AGC system used in the radiation environment is analyzed and the radiation effect is verified through actual experiments.

2. Methods and Results

In this chapter, the AGC system is explained, and operation influenced by radiation is analyzed through simulation to determine which circuit is most sensitive to radiation among circuits constituting the system. After that, it is composed of an IC chip using the CMOS 0.18um process, and the actual radiation effect according to the cumulative dose is analyzed.

2-1. AGC system introduction

AGC is a system that automatically controls the gain. As shown in Fig. 1, Variable Gain Amplifier (VGA) whose gain is adjusted by the control voltage V_C, Peak Detector (PD) that measures the peak value of VGA output and converts it to DC, PD It consists of a comparator and a charge pump (CP) that adjusts the control voltage V_C by comparing the output voltage of the output and the desired output amplitude value V_{Ref}.

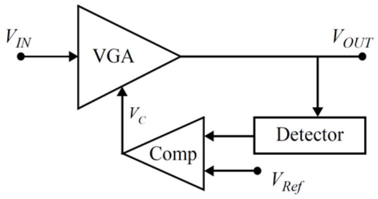

Fig. 1. AGC Block Diagram

To explain the principle of AGC, in general, when a signal comes in, it is amplified by VGA. The output value of the amplified VGA is transformed into a DC level by the PD and the peak value is detected. This DC value goes into the comparator and is compared with the set reference voltage V_{Ref}. The V_C voltage is controlled by operating the charge pump according to the logarithmic relationship with V_{Ref}. The gain of the VGA is determined by the V_C voltage, and the size of the output signal of the AGC is adjusted. Through this feedback loop, a constant output is sent out to the set V_{Ref}.

2-2. AGC simulation and radiation effect analysis

AGC usually receives the optical sensor output as an input and outputs a stable signal according to V_{Ref}, and removes noise through V_{Ref} voltage so that it can receive an input signal with a wide dynamic range. However, when used in a radiation environment, leakage current flows in the NMOS constituting the AGC due to the cumulative radiation effect, the TID effect [5-6]. In order to confirm the effect of this leakage current on the system, a simulation was conducted by modeling the general operation of the AGC and the cumulative radiation effect of the NMOS.

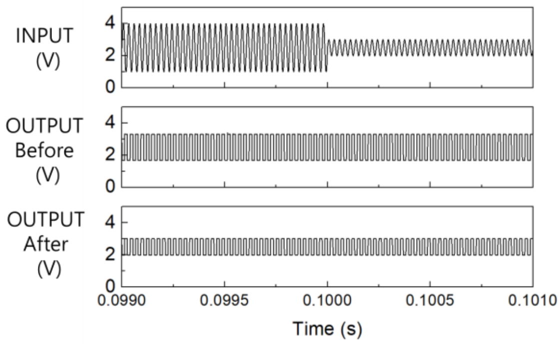

Fig. 2. Simulation result of AGC before and after radiation effects

As shown in Fig. 2, when an input whose signal peak changes is applied, AGC outputs 3.3V, which is the set V_{Ref} voltage. If leakage current occurs due to the TID effect, AGC outputs 3V lower than 3.3V, falling short of V_{Ref} voltage. As shown in Fig. 3, it was confirmed that an error occurred in peak measurement due to the difference in sourcing/sinking ratio between PMOS and NMOS in the charge pump of the peak detector constituting the AGC. Also, as shown in Fig. 4, it was confirmed that the change in gain for the control voltage V_C of the VGA to be controlled was out of the existing linear range and an error occurred.

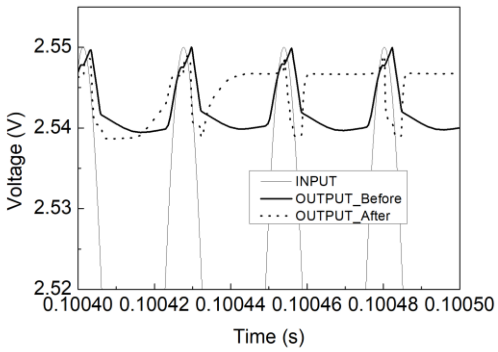

Fig. 3 Radiation Effect of Peak Detector

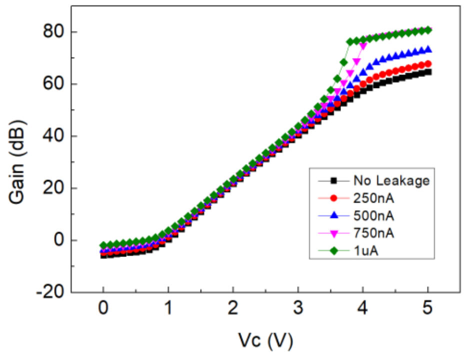

Fig. 4 Gain variation of VGA according to control voltage V_C

2.3 AGC chip design and radiation experiment result

In order to confirm the actual radiation effect on the AGC, it was implemented as an IC chip using a CMOS 0.18um commercial process. The radiation test was conducted at the Advanced Radiation Research Institute (ARTI) in Korea at a rate of 5 kGy/h per hour, and a TID experiment for gamma rays with a cumulative total of 25 kGy.

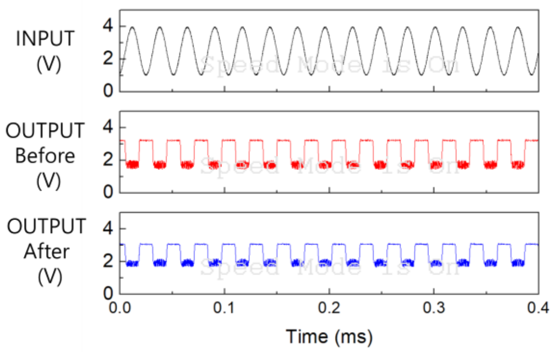

Fig. 5. Test result of AGC before and after radiation effects

As a result of the TID experiment, as shown in Fig. 5, when the V_{Ref} voltage is 3.3V, the AGC before irradiation outputs a V_{Ref} voltage of 3.3V, and the AGC after irradiation outputs a voltage of 3.05V, which is lower than the set V_{Ref} voltage under the dose condition of 25kGy.

In addition, when checking the output voltage of the AGC according to the cumulative dose, it was confirmed that it gradually moved away from the V_{Ref} voltage as shown in Fig. 6. This effect increases the noise level and reduces the dynamic range of optical sensors used in CMS, HXMT optical sensors and rf sensors used in real radiation environments.

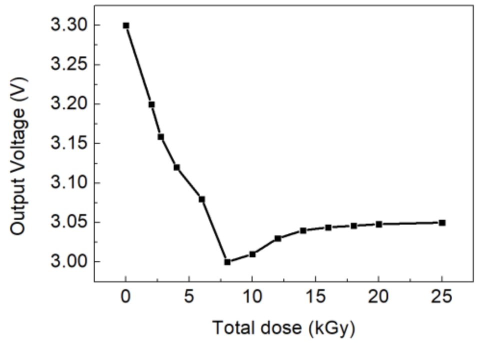

Fig. 6 Output voltage of AGC according to Total dose

3. Conclusions

In this paper, the radiation effect of AGC used in a radiation environment was confirmed through a circuit design simulation tool. As a result of the simulation, it was confirmed that the Peak Detector and Variable Gain Amplifier, which constitute the AGC, are mainly affected. In order to confirm the actual radiation effect, it was implemented as an IC chip, and as a result of the experiment, a signal of 3.05V was output, which is lower than the V_{Ref} voltage set at 25kGy. Through this result, it was proved that AGC, which helps stable output in optical sensor and rf communication, is affected by radiation, and confirmed the necessity of IC circuit development using radiation-hardening technology.

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