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2019-Autumn	12D : 원자력계측제어 및 자동원격 (Nuclear I&C and Automatic Remote System)	10.24(Thu) 13:00	2층 로비 (2F)	Design of a Radiation Hardened Bandgap Reference Circuit for Cold Junction Compensation under High Radiation Environments	Minuk Seung and Wooyoung Choi(Yonsei Univ.), Seop Hur and Inyong Kwon(KAERI)	PDF보기	-

Design of a Radiation Hardened Bandgap Reference Circuit for Cold Junction Compensation under High Radiation Environments

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1. Introduction

Today, the thermocouple thermometer is widely used in various industry [1]. It has the advantage of the low cost, wide measurement rage, stability, fast response and so on. Therefore, it has been also utilized in nuclear power plants (NPPs) to measure temperature for the NPPs safety [2].

The critical principle of the thermocouple is Seebeck effect. If one side is connected to the hot junction, and the other is connected to the cold junction as known as a reference junction, a voltage difference is generated by the different temperature between two different metals [3]. The temperature can be measured by using Eq. 1 when the reference junction temperature is constant.

$$V_T = S \cdot (T_H - T_C) \qquad (1)$$

The traditional method is to use the 0℃ water-bath. However, it is not commonly used in these days because the water bath is relatively bulky to use in practical sites. Another approach is to utilize hardware compensation such as a CMOS integrated circuit. In this paper, the reference junction compensation is implemented by using a bandgap reference (BGR) circuit.

These circuits require accurate voltage and stability. However, the output voltage of a BGR slightly changes when variations due to temperature, supply voltage, and process are occurred.

Moreover, in high dose radiation environment, the BGR circuit is affected by another variation due to incident radiation. When radiations penetrate into oxide region of MOSFET, it generates electron-hole pairs. Some carriers are promptly recombined but other carriers can be trapped in the SiO_2-Si interface [4]. This effect occurs the threshold voltage variation at CMOS devices, resulting in change of the output reference voltage of the BGR circuit [5]. Therefore, it is necessary to minimize the influence of radiation.

This paper shows the concept of the BGR circuit to prevent radiation effects. First, we will explain the concept of radiation hardened by design (RHBD) topology. Second, we are going to show the result of the

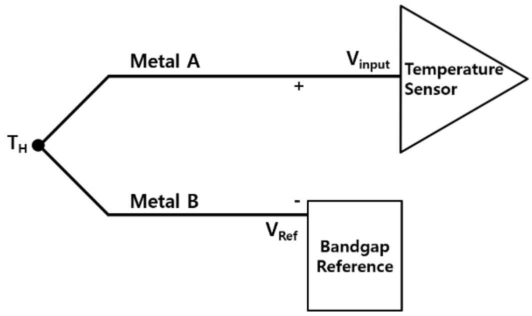

Fig. 1. Thermocouple thermometer diagram

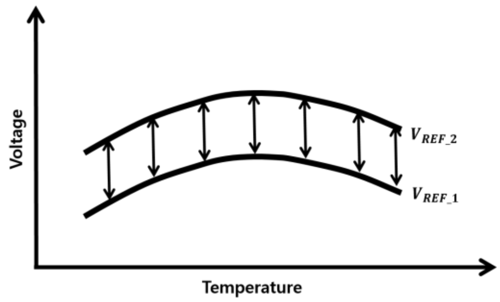

Fig. 2. Concept of operating method

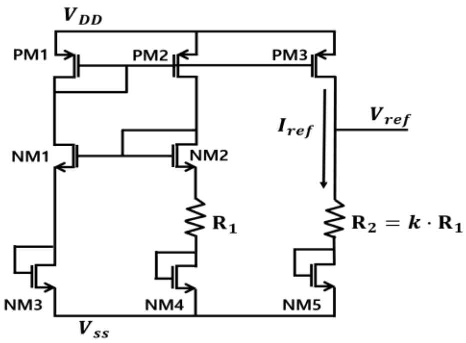

Fig. 3. Traditional bandgap reference circuit

2. Concept of compensation and proposed design

simulation of bandgap reference circuit. Finally, the conclusion and future work are shown.

2.1 Cold junction compensation

The Fig. 1 shows a common thermocouple thermometer diagram. The BGR supplies constant voltage at the cold junction of the thermocouple.

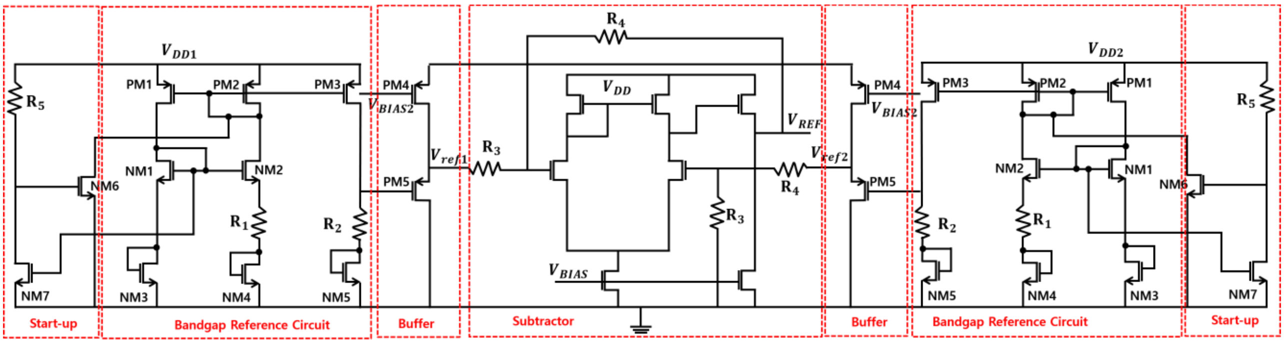

Fig. 4. Proposed design of the radiation hardened bandgap reference

Therefore, the voltage putting the temperature sensor can be measured and calculated the target temperature using Eq. (2).

$$V_{input} = V_{Ref} + V_T = S \cdot T_H \quad (2)$$

2.2 Concept of Proposed Design

Two conventional BGR circuits have the same temperature coefficient (TC) but different output references as shown in Fig. 2 and Fig. 3. The proposed circuit is designed with a subtractor and two identical BGR circuits. Then, the final reference voltage can be calculated by the difference between the two conventional reference voltages. Therefore, the final reference voltage is defined like Eq. (3).

$$V_{REF} = V_{REF2} - V_{REF1} \quad (3)$$

Generally, a reference voltage of a traditional BGR changes depending on the supply voltage. In Fig. 3, PM1, PM2, NM1 and NM2 are the current reference circuit providing constant current to the whole system. As supply voltage decreased, current decreased either because of the channel-length modulation effect.

Fig. 4 shows the schematic of the proposed design by using the voltage subtracting radiation hardened bandgap reference. The two identical BGR circuits with different supply voltages are effected by radiation uniformly, then the each reference voltage, V_{ref1} and V_{ref2} are increased due to increased leakage current in single transistors induced by incident radiation. The final output, V_{REF} as a temperature indicator, is eventually obtained by the subtraction of each reference voltage of the two identical BGRs.

3. Simulation condition and result

Fig. 5 shows the simulation of radiation effects in BGR. Since cumulated total ionizing dose (TID) lead to leakage current of MOSFET, we put current sources as radiation circuit models to every NMOS transistors [4]. We assume that every radiation model

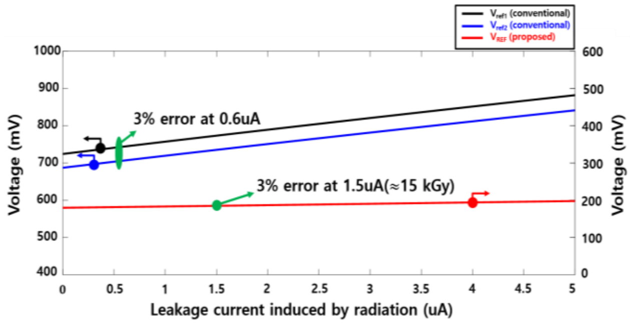

Fig. 5. Output reference voltages of the conventional BGRs and the proposed BGR versus the radiation effects

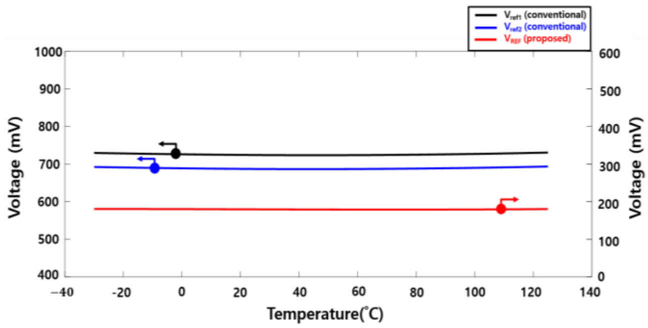

Fig. 6. Output reference voltages of the conventional BGRs and the proposed BGR versus temperature

TABLE I: Comparison with conventional BGR and proposed BGR

	Conventional BGR1	Conventional BGR2	Proposed BGR
Supply voltage (V)	2.8	1.5	-
Voltage reference @ 25 °C (mV)	724	687	179.7
Error (*due to temperature*)	0.95%	0.99%	0.87%
Temperature coefficient (PPM/°C)	62	64.6	56.2
ΔV_{out} (*due to radiation*)	157.7 mV	154.1 mV	18.1 mV
Error (*due to radiation*)	21.8%	22.43%	10.1%

is the same amount of leakage current. When the Vgs is 500 mV and dose is 5 kGy, the leakage generally presents several hundred of nanoampere [6]. The simulation was proceeded upto the leakage current of 5 uA corresponding to 50 kGy for harsher environments. It shows that the two identical conventional BGRs have about the radiation error rate of 22 % while the proposed BGR has 10.1 %. Generally, the error rate induced by radiation is acceptable by 3 % in nuclear industry. Impressively, in the proposed BGR circuit, the 3 % error was measured at 1.5 uA pointed by the green arrows in Fig. 5 with the reference voltage of 185 mV while the radiation error rates of the conventional BGRs were 6.3 % and 6 % at the same point.

Fig. 6 shows the output voltages versus temperature change. Each conventional BGR has the temperature error of 0.95 % and 0.99 %, and the proposed BGR has 0.87 % in the range of -30 to 125 ˚C. Table I shows the comparison with the conventional BGRs and the proposed BGR. The simulation results show that the proposed BGR has more stable for radiation effects and temperature variation than the conventional BGRs.

4. Conclusions

The radiation hardened bandgap reference circuit is designed in this paper. The key idea is that the circuit can mitigate the radiation variation by subtracting reference voltages of two identical BGRs, resulting in supplying constant output voltages. The whole circuit was designed in a 180 nm standard CMOS process. With statistical simulations, the proposed design achieves about the radiation error rate of 10.1 % and the temperature coefficient of 56.2 ppm/˚C in the range of -30 to 125˚ C, while the conventional bandgap circuit has 21.8 % and 62 ppm/˚C, respectively. Therefore, the proposed design BGR is about 54.5 % more stable for radiation dose. Fig. 7 is the layout of BGR which has been manufacturing and After the chip fabrication is completed, the irradiation test will be proceeded.

Acknowledgements

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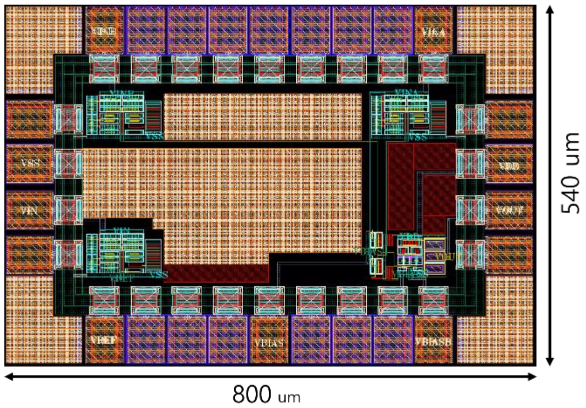

Fig. 7. The layout of proposed bandgap reference circuit

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