The Design of Low Power Bandgap Reference

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Abstract. This paper presents a novel low power bandgap reference circuit, the bandgap reference adopts half a period working mechanism. The operational amplifier doesn't work during the switched capacitor network sampling. And the operational amplifier works after the charge balanced. The bandgap reference runs discontinuously. The design implements in standard 0.18um CMOS process. The simulation result shows that, the circuit consumes 19.8 uAat 3.3V. The noise of the circuit in low frequency achieves $3.9uV/\sqrt{Hz}$ and the temperature coefficient is 21 ppm/°C.

1. Introduction

Reference voltage block is the fundamental part of the power module of electrical system, its performance parameters, such as accuracy stability and so on, decides the performance of the electrical system. In recent years, especially, electronic products become miniaturization and portability, reference voltage block needs lower power dissipation. The design of the reference voltage block adopts bandgap reference structure generally. In 2012, Zhou zekun presents a high precision high-order curvature-compensated bandgap reference compatible with standard BiCMOS process. Experimental results of the proposed bandgap reference demonstrate that a temperature coefficient of 5ppm/°C is realized at 3.6V power supply while dissipating a maximum supply current of 25uA[1]. In the same year, Peng-Yu Chen presents a bandgap reference which uses a low-gain amplifier to generate an accurate reference voltage. The average power consumption is approximately 24.6uW at 1V supply voltage, which export 434.2mV[2]. In 2013, Cao Ying shows a total-ionizing-dose radiation tolerance of bandgap reference in deep-submicron CMOS technology, which reaches a temperature coefficient of 15ppm/°C from -40°C to 125°C and consumes 50uA[3]. In the same year, A. Mart'inez-Nieto designs a low temperature coefficient, curvature-compensated CMOS bandgap voltage reference, which implements in standard 0.18um CMOS process with 1.8V power supply. The circuit has a 4-bit trimming circuit to compensate for process variations. The output voltage is 1.225V and shows a TC lower than 2ppm/°C over a temperature range of 160°C and the power dissipation is 620uW[4]. In 2014, Tommaso Vergine presets a bandgap reference circuit which has been designed to be Radiation-Hard up to 1Grad. The circuit has been developed in a commercial 65nm CMOS technology with 1.2V of nominal voltage supply. The power consumption is 240uW and the output voltage is 331.6mV[5]. In the same year, Bill Ma proposes a novel CMOS bandgap reference with high-order curvature-compensation by using MOS transistors operating in weak inversion region. The experimental results show that the bandgap reference achieves 4.5ppm/°C and consumes 36uA at 1.2V[6]. All research mentioned above employ typical bandgap reference structure with the mechanism of working continuously. The principle of the typical bandgap reference structure amplifies the voltage with ratio-resistance, which introduces the thermal noise unavoidably. In allusion to problems proposed, this paper presents a mechanism of half a period which reduces the working time of the operational amplifier

to lessen the power dissipation. This bandgap reference circuit adopts capacitance to amplify the voltage with lower thermal noise.

2. Ratio-capacitance Bandgap Reference Circuit

Based on principle of switched capacitance, capacitance ratio bandgap reference divided the working time into two non-overlap parts employing two non-overlap clock, as showed in Fig.1. The capacitance C_1 samples $V_{BE1}-V_{BE2}$ in the first phase and the output voltage of the circuit is maintained by load capacitance. According to the principle of charge conservation, the charge of capacitance C_1 transfers to capacitance C_2 . The multiple of C_1 to C_2 will amplify the value of $V_{BE1}-V_{BE2}$ while the switch at the output end closing with the output voltage V_{bg} .



Fig.1 Capacitance Ratio Bandgap Reference

3. Half a period Working mechanism

 $V_{bg} =$

Capacitance ratio bandgap reference divides the working time into two parts. The operational amplifier is used as a buffer in the first phase while sampling the difference of voltage. According to the principle of charge conservation, the circuit multiply the difference of voltage. The stable output reference voltage is composed of the negative temperature coefficient of the voltage and the magnified positive temperature coefficient of the voltage.

Power dissipation of the operational amplifier is the main source in the bandgap reference. A universal method of low-power design is to reduce the power consumption. Reducing the working time is also an effective way to design a low power bandgap reference. The operational amplifier in the capacitance ratio bandgap reference doesn't need to work in the first phase without loss of charge in the sampling capacitor. And the operational amplifier in the bandgap reference works in closed loop, exporting the stable output voltage as reference voltage directly in the second phase. This paper saves the power dissipation of the operational amplifier in the first phase with closed operational amplifier. Bottom plate sampling technique, replacing the closed operational amplifier used as a buffer, has been used in the design for saving the charge at the negative port. After optimizing the structure, showed in Fig.1 for lower power dissipation, enable signal EN_Phase₂ has been added to the operational amplifier, as Fig.2. The charge in the capacitance C₁ transfers to the capacitance C₂ in the second phase with the opening operational amplifier. For the time being, the output end of operational amplifier links to the output end of the circuit when the output voltage of the operational amplifier becomes the reference voltageV_{bg}.

$$V_{BE1} + n\Delta V_{BE}.$$
(1)
$$V_{EE1} \rightarrow C_{2} \qquad Phase_{2}$$

$$V_{EE1} \rightarrow C_{1} \qquad Phase_{2} \qquad Phase_{2} \qquad V_{bg}$$

$$V_{EE2} \rightarrow Phase_{2} \qquad Phase_{2} \qquad V_{bg}$$

Fig.2 Half-period Capacitor Ratio Bandgap Reference

The operational amplifier in the bandgap reference adopts the mechanism of half cycle work time which can reduce the power consumption availably. After turning on the operational amplifier, the circuit charge the parasitic capacitance, which decreases the settling time of the output voltage with the half a period working mechanism. So the half a period working mechanism needs faster operational amplifier which will increase the power consumption of the circuit. A peak value of the output voltage will be produced because of non-overlap clock, which influences the accuracy of the bandgap reference. As shown as Fig.3, the enable signal EN_Phase_2 has been optimized to resolve the problem of the parasitic capacitance. Ensuring the parasitic capacitance charged, the enable signal EN_Phase_{2F} will be enabled advanced.



Fig.3 Optimized Half-period Capacitor Ratio Bandgap Reference

4. Simulation Experiments and Analysis

Considering the current applying to the load outside and the load capacitance inside, the speed of the clock should be chosen. The parasitic capacitances should reach the balanced state before the operational amplifier working in the closed loop. Ahead of the second phase, the operational amplifier has been enabled to ensure stable output voltage while the capacitance ratio multiplies the voltage. In logic, the falling edge of the EN_Phase_{2F} is synchronized with the rising edge of the Phase₂ but, actually, the falling edge of the EN_Phase_{2F} enables the operational amplifier in advance. The time in advance of EN_Phase_{2F} can be decided considering the value of the parasitic capacitance. In this paper, the ratio of capacitance between C1 and C2 is elected as 4, after taking area of the chip, power consumed by generating the VBE1 and V_{BE2} and the noise character of the capacitance. The temperature characteristic of the capacitance ratio bandgap reference from -20°C to 80°C has been shown as Fig.4 with the variety of 7mV at the end of the circuit. The output voltage can be stable at 10.75us with steady power supply, as shown in Fig.5.



Fig. 4 Simulation Result of Temperature characteristic Fig. 5 Simulation Result of transient response

Table 1 shows the simulation result. After comparing this work with others, the power dissipation of the circuit is superior to others.

Performance Parameter	This work	[2]	[3]
Supply Current(uA)	19.8uA	24.6uA	50uA
Temperature Coefficient (ppm/°C)	21 ppm/ °C	13.29ppm/℃	15 ppm/℃

Table 1 Analysis of Simulation Result

5. Summary

After analyzing and discussing the application and development direction of bandgap reference, this paper presents a low power ratio-capacitance bandgap reference circuit, which can reduce power dissipation. The circuit adopts cascade Op-amp which can improve response speed and accuracy of the circuit. Simulation result shows that the total power dissipation is 19.8uA at 3.3V, low-frequency noise achieves $3.9 \text{uV}/\sqrt{\text{Hz}}$ and the temperature coefficient of the circuit is $21 \text{ppm}/^{\circ}\text{C}$.

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