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A wide-input high PSRR bandgap reference circuit

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Abstract
Because the conventional bandgap reference voltage source with low power supply rejection (PSR) and narrow input voltage. Based on SMIC0.18μm BiCMOS process, use two bipolar transistors in saturated region while forming base and emission voltage ∆VBE, a novel high PSR bandgap voltage reference circuit with wide input voltage and small temperature coefficient was proposed, independent of supply voltage reference current source circuit owns the feature of changing with the temperature, which decreases the effect of temperature towards the output reference voltage. Spectre simulator results showed that output reference voltage VREF = 1.206V ± 1mV in the range of -55 ℃ to 125 ℃ with a supply voltage from 1.5V to 5V.The temperature coefficient was 6.562ppm/℃, and the PSR was -87.49dB at 1KHz with the supply voltage of 5V.

Keywords: bandgap reference; wide input voltage; low temperature coefficient; high PSRR

1. Introduction

Bandgap reference voltage source as a basic module is widely used in power management, analog-digital converter (ADC), digital-analog converter (DAC) and other circuit structure. Its performance directly affects the performance of the overall circuit [1, 2]. With the continuous improvement of circuit performance requirements, the input power supply voltage range, the temperature drift coefficient and the power supply rejection ratio of the bandgap reference voltage source put forward higher requirements. The operational amplifier module in the traditional bandgap reference structure, using characteristics of positive and negative input terminal of the operational amplifier with two different emitter area of the tube forming a base positive temperature coefficient of the collector pressure difference of V_{BE}, due to the structure of the operational amplifier offset voltage and input common mode voltage limits the bandgap voltage reference output precision and the minimum input voltage, which leads the traditional bandgap reference circuit is more and more difficult to meet the requirements of wide range input than inhibition and high power, so in the traditional structure on the continuous improvement or new bandgap reference source structure is urgently needed [3].

Based on the traditional bandgap reference circuit structure based on the improved design of the bandgap reference circuit of a novel structure, mainly used in a wide range of input voltage, high rejection ratio and low linear adjustment rate of LDO linear regulator [4]. Using SMIC 0.18μm CMOS technology to achieve the layout area of 1.25 * 0.55mm^2, Spectre simulation tools showed that the low dropout (LDO) linear regulator chip test and simulation showed similar, achieves the expected target.

2. Circuit Structure

2.1 Traditional band gap reference voltage source circuit

The working principle of the bandgap reference voltage source is: the base level of the forward biased bipolar transistor (1).

$$V_{BE} = V_T \ln(I_C / I_S) \tag{1}$$

Characteristic of negative temperature coefficient. The ratio of the two emitter junction area to the N bipolar transistor operates in the same current state, and their base stage voltage difference is (2).

$$\Delta V_{BE} = V_{BE1} - V_{BE2} = V_T \ln(\frac{I_C}{I_{S1}}) - V_T \ln(\frac{I_C}{N \times I_{S2}}) = V_T \ln N \tag{2}$$

Characteristic of positive temperature coefficient. The bandgap reference voltage is above two and the temperature characteristic of voltage with different weights and the positive temperature coefficient ΔV_{BE}, negative temperature coefficient offset V_{BE}, get a temperature independent reference voltage V_{REF} [5]. Figure 1 shows the traditional CMOS bandgap reference source circuit structure.

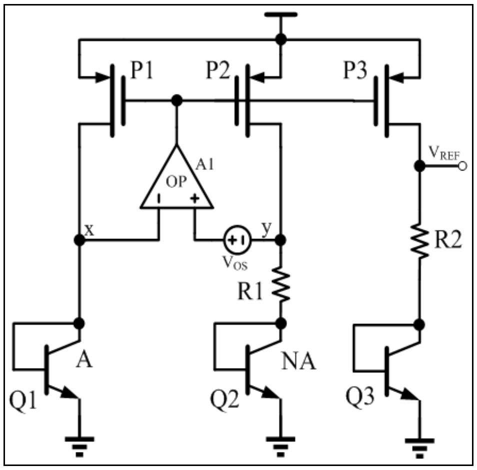

Fig 1: Schematic of the traditional band gap reference voltage source circuit structure

In Figure 1, the amplifier A1 and transistors P1 and P2 form a negative feedback structure, the positive and negative input x, y operational amplifier two node voltage equal to the emitter area of more than two N bipolar transistors Q1, Q2 form a voltage across the resistor R1 (3).

$$\Delta V_{BE} = V_{R1} = V_{BE,Q2} - V_{BE,Q1} \quad (3)$$

As the input current of the operational amplifier is zero, the positive temperature coefficient current flowing through the P2 is (4).

$$I_{P2} = \frac{\Delta V_{BE}}{R_1} = \frac{V_T \ln N}{R_1} \quad (4)$$

Therefore,

$$V_{REF} = V_{BE,Q1} + (1+\frac{R_2}{R_1})V_T \ln N \quad (5)$$

The appropriate R_1, R_2 and N values are selected to obtain the output reference voltage with zero temperature coefficient V_{REF}[5]. However, in the actual circuit, due to the CMOS process, affected by the operational amplifier offset voltage V_{OS}, as shown in Figure 1, the positive and negative input voltage equal operational amplifier A1, get (6)and(7).

$$V_{BE,Q2} - V_{OS} = V_{BE2,Q1} + R_1 I_{P2} \quad (6)$$

$$V_{REF} = V_{BE,Q1} + (1+\frac{R_2}{R_1}) \cdot (V_T \ln N - V_{OS}) \quad (7)$$

The offset voltage is amplified, and the V_{OS} itself also changes with temperature, which has a serious impact on the output accuracy of the reference voltage [1]. On the other hand, bandgap voltage reference input voltage minimum common mode input voltage at the same time by the size of the operational amplifier and the output reference voltage limit, shown in Figure 1 the minimum input voltage structure (8).

$$\min(V_{DD}) = V_{TN} + 2V_{DSsat,P2} + V_{R2} \geq 1.6\text{V} \quad (8)$$

Based on the above analysis with the output precision and minimum input supply voltage limiting circuit operational amplifier structure in the bandgap reference circuit, in order to get a wide range of input, high PSRR bandgap reference voltage circuit and a low temperature coefficient, the need for further improvement of the circuit.

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2.2 Improved circuit and Implementation

From the previous analysis, shows that the offset voltage and the minimum input voltage of the operational amplifier affect the output precision and the input voltage range of the bandgap reference. The traditional bandgap voltage reference circuit is improved, and a new structure of high performance bandgap reference voltage source circuit [5]. The improved band gap reference circuit is shown in figure 2.

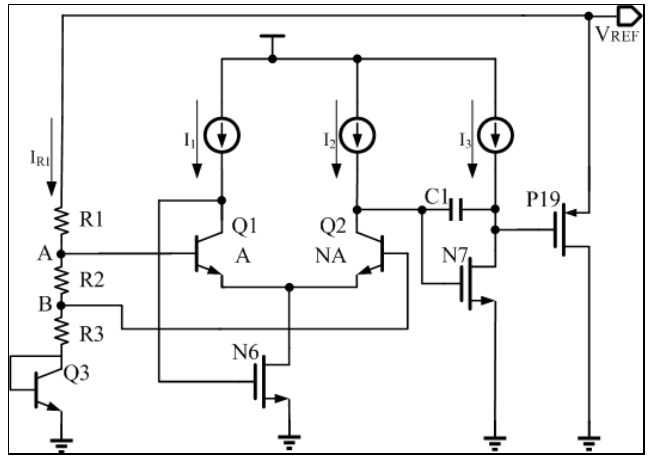

Fig 2: the improved band gap reference source

As shown in figure 2, bipolar transistors Q1, Q2 instead of the traditional bandgap reference circuit in the differential input structure, detection of A and B point voltage. The transistor Q1and Q2, resistance R_1, R_2, N7 and P19 so that the entire system loop in a deep negative feedback state. Through Q2,Q1 the emitter junction area of more than N times,bipolar transistors collector current is equal to the $I_1=I_2$,positive temperature coefficient of base-emitter voltage ΔV_{BE} formed on the resistor R_2 , produces a positive temperature coefficient current on R_2,is given by (9).

$$I_{R2} = \Delta V_{BE} / R_2 = V_T \times \frac{\ln N}{R_2} \quad (9)$$

The structure avoids imbalance the piezoelectric effect on the circuit. The second stage amplifier structure of the circuit of the N7 is improved, and the circuit gain and the power supply rejection ratio are improved. The introduction of the Miller compensation capacitor C_1 makes the system loop more stable. In order to provide a stable current and voltage bias for the core circuit, a constant current source bias circuit with a start-up circuit is introduced, and the designed band gap reference voltage source is shown in Figure 3. The current circuit I_1~I_3 is P7~P9, P16~P18 current mirror structure; the current mirror structure has the advantages of higher precision,while the P1~P5 and P7~P9 to suppress the ripple interference from the power supply voltage, improve the power supply rejection ratio. As shown in Figure 3, the minimum input supply voltage of the bandgap reference circuit is lower, and a high power supply rejection ratio is achieved at the same time to achieve a wide range input, and the minimum input supply voltage of the structure is (10).

$$\min(V_{DD}) = V_{REF} + V_{SDsat,P6} + V_{SDtri,P4} \quad (10)$$

The N2 width ratio is K times of the N1, and the resistance R, N1 and N2 constitute the micro current source independent of the supply voltage, and the current of the resistance R is (11).

$$I_R = \frac{V_{gs,N1} - V_{gs,N2}}{R} \quad (11)$$

P1~P3, P11~P13 composed of I4=I5=I6's current mirror structure was obtained (12).

$$I_R = \frac{2(1-\frac{1}{\sqrt{K}})^2 L}{\mu_n C_{ox} W} \times \frac{1}{R^2} \qquad (12)$$

The current has a positive temperature coefficient characteristic. When the circuit is started, no current flowing through the resistor Rs, V_{Rs}=0V, so that the P1~P3, P11~P13 begin working, V_{Rs} rise, after the start of the stability of the current resistance of the resistor Rs is ignored, the start circuit structure is simple and practical. The N4, N5, P4~P6, P14 and P15 are composed of reference current source is independent of the supply voltage, which has the same temperature characteristics as the current source I_R. When V_{REF} was reduced, I_{R1} current decreases, V_{BE} decreases, P19 gate voltage increases, I_{P19} decreases and the reference current source I_{SS} to branch current I_{R1} increased; On the contrary, when the I_{R1} increases when I_{P19} increases, the decrease of I_{R1}. With the increase of temperature of T, reference current source is increased with the increase of temperature, so V_{REF} increased. While V_{BE} led to an increase in I_{P19} current compensation reference current source to increase the amount of is increases, the reduced temperature change effect on the bandgap reference output so that the output is more stable, improve the power supply rejection ratio. In Figure 3, the effect of the base level current of the transistor is neglected. Select the appropriate R_1, R_2, R_3 and N to obtain the zero temperature coefficient of the reference voltage (13).

$$V_{REF} = V_{BE,Q3} + I_{R1}(R_1 + R_2 + R_3) = V_{BE,Q3} + (\frac{R_1 + R_2 + R_3}{R_2}) V_T \cdot \ln N \qquad (13)$$

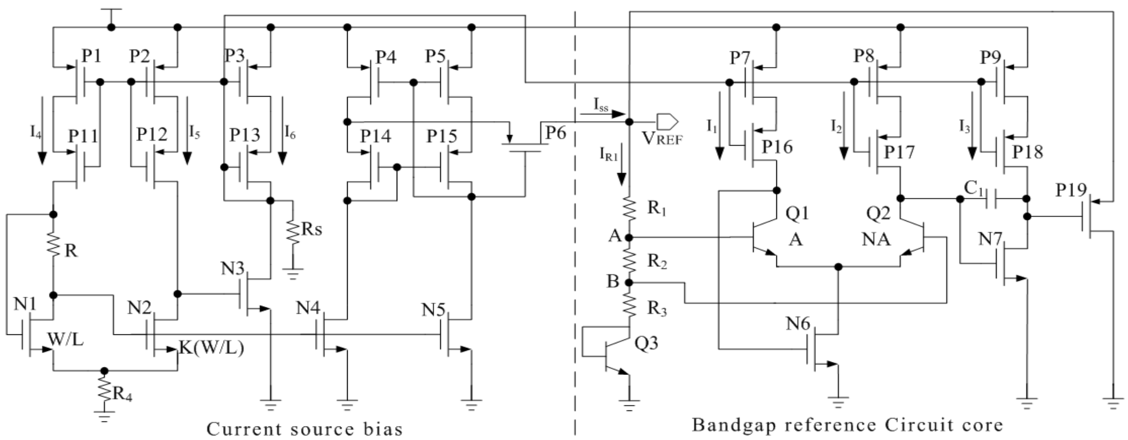

Fig 3: Schematic of the implemented BGR circuit.

3. Simulation Results

SMIC process simulation of the bandgap reference voltage source using 0.18μm Spectre process parameters. The simulation results are as follows:

In the power supply voltage of 1.5V, 3.3V and 5V in three cases, the output voltage with temperature in the range of -55℃ ~125℃ change curve as shown in figure 4. Figure 4 can be seen in the temperature range from -55℃ ~125℃ under the condition of the input power supply voltage is 1.5V, 3.3V and 5V in three cases of V_{REF} reference output voltage value of 1.206V + 1mV, output voltage temperature coefficient were 12.18ppm/℃, 8.497ppm/℃ and 6.658ppm/℃. The simulation results showed that the bandgap has the properties of low temperature drift in a wide input range, extreme temperature range.

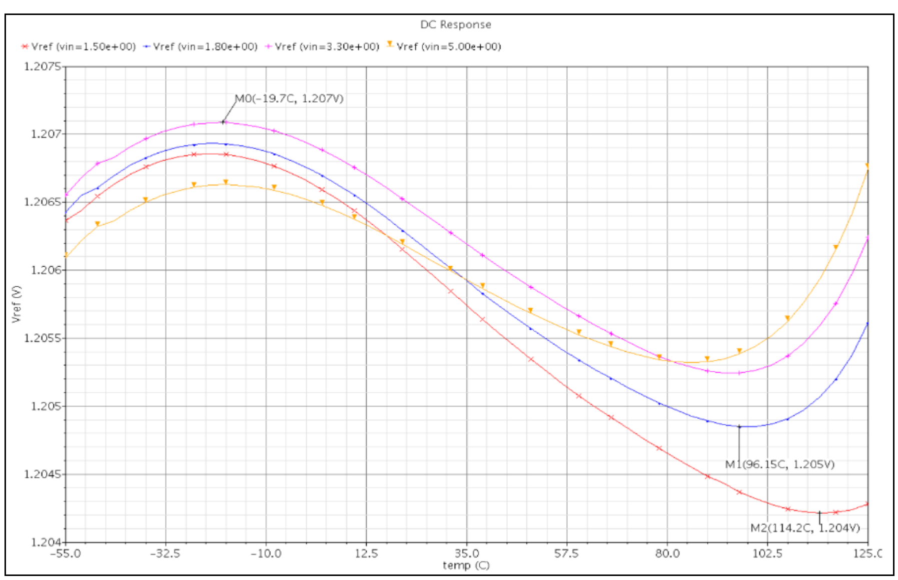

Fig 4: 1.5V, 3.3V and 5V input reference voltage with temperature change curve.

Figure 5 the small signal characteristic curve of the band gap reference circuit. In the typical process model (TT) under 25℃, the circuit in the frequency range of 1Hz~1MHz scanning, figure 5 shows that the power supply of AC small signal bandgap reference with the inhibition ratio in the 1KHz frequency is -87.49dB,meet the design requirements.

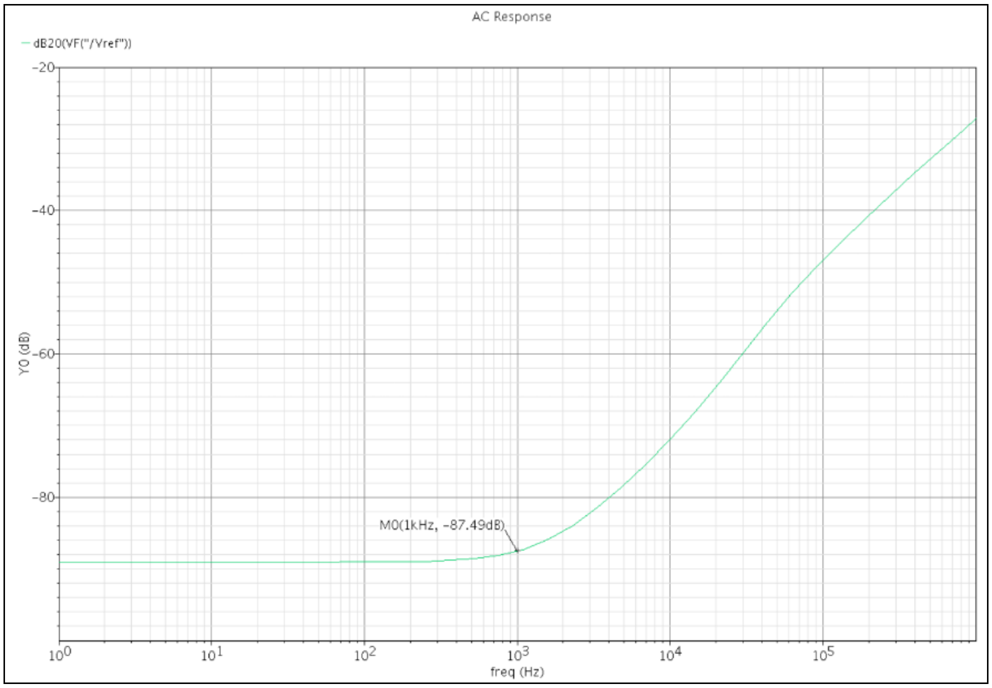

Fig 5: characteristic curve of AC small signal with band gap reference source

In room temperature 25℃ case, the reference output voltage with the supply voltage range from the 0V~5V curve as shown in Figure 6, Figure 6 simulation results for V_{REF} benchmark output began to stabilize at 1.206V from the input supply voltage range of 1.5V~5V, the error is less than 1mV.

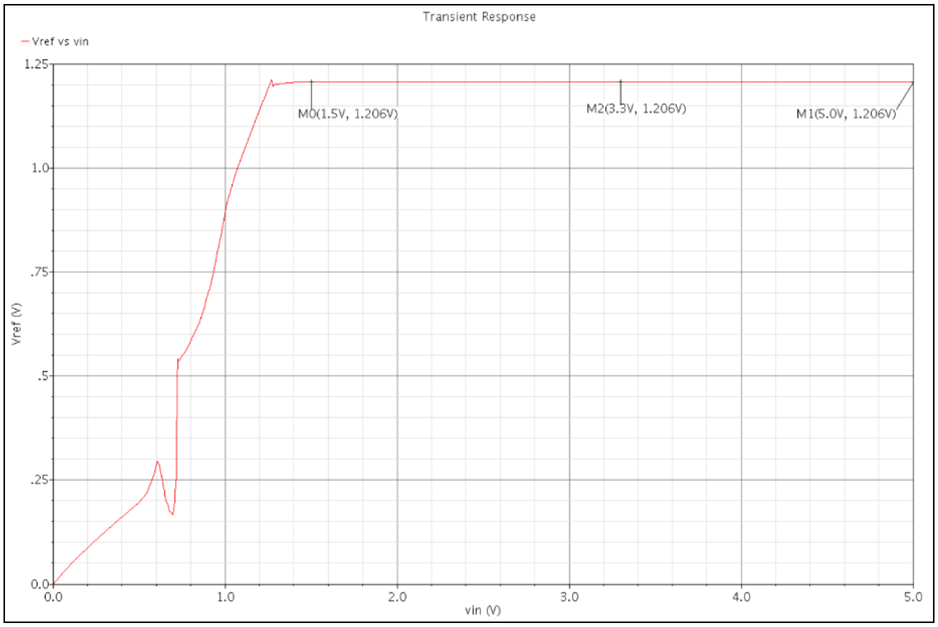

Fig 6: variation curve of reference voltage with power supply voltage 0V~5V

The influence of layout design performance bandgap also decided the result of success. Considering the influence of layout design parameters on the performance of the circuit, the layout of the layout and the redundancy of the device are used to minimize the effects of the process parameters. The bandgap reference circuit with LDO linear regulator chip test, the input power supply voltage at 1.5V, 3.3V and 5V under the condition of temperature measured at 25 ℃ and 75℃ when the reference output as shown in table I. As can be seen from the table I, the band gap reference has a stable baseline output of about 1.2V in a wide range of input voltage.

Table 1: supply voltage 1.5V, 3.3V and 5V benchmark output test with different temperature

Input (V)	1.5V		3.3V		5V	
Temperature (℃)	25	75	25	75	25	75
1	1.199	1.202	1.202	1.204	1.203	1.204
2	1.194	1.197	1.2	1.202	1.201	1.202
3	1.198	1.2	1.2	1.203	1.201	1.202
4	1.198	1.201	1.202	1.203	1.201	1.204
5	1.201	1.202	1.203	1.204	1.203	1.203
6	1.199	1.2	1.201	1.202	1.201	1.203
Mean	1.198	1.200	1.201	1.203	1.202	1.203
Max	1.201	1.202	1.203	1.204	1.203	1.204
Min	1.194	1.197	1.2	1.202	1.201	1.202

4. Conclusions

In this paper, a high performance band gap reference voltage source circuit is designed, which has a novel structure and high performance. Using BiCMOS 0.18μm process,simulation showed that bandgap voltage reference source with stable output voltage is 1.2V with a supply voltage from 1.5V to 5V. The supply voltage rejection ratio up to -87.49dB in 1KHz, the performance of the temperature coefficient is 9.621ppm/℃. After the test, can provide the reference voltage stability for LDO linear regulator, meet the design requirements.

5. References

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