Design of a High Precision Bandgap Voltage Reference

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***Abstract*—As a way of generating high precision voltage reference, bandgap voltage reference is a very important module in the analog integrated circuits and mixed-signal integrated circuits to provide a temperature and power supply insensitive output voltage. The bandgap voltage reference circuit presented here in this paper is an improved conventional bandgap reference circuit. A self-biasing structure and a current mirror structure are used. It can get the PTAT(Proportional to absolute temperature) current, and then get the voltage that is proportional to temperature. The output voltage of an Op-amp is adopted as the op-amp's offset voltage to make the power consumption lower, and high value polysilicon resistors of low temperature coefficient are used to reduce the impact of resistor drift on the circuit. The errors caused by current mismatch is eliminated in the improved CMOS bandgap, and at the same time the DC PSRR (power supply rejection ratio) is increased because of the increase of the feedback factor.**

Keywords-Bandgap Reference; temperature coefficient; CMOS; opamp;PSRR

I. INTRODUCTION

Although digital technology has become the development trend of modern electronic products, as the basis for digital circuit, analog circuits still play an irreplaceable role. The original signals generated by most electronic devices, such as electromagnetic records, microphone, are analog [1]. These signals must be processed such as amplification, A/D conversion before digital processing. Meanwhile, after digital processing, the signal must be converted to analog to be accepted by the real world. With the rapid development of portable electronic products, power dissipation and precision becomes the key factors of performance of modern integrated circuits. An important way to reduce power consumption is to reduce the supply voltage. Furthermore, as the feature size of modern integrated circuits gets smaller, the operating voltage of IC products also becomes lower and lower.

The research on low-voltage analog circuit design using CMOS technology becomes very important since the CMOS technology has been developed a lot and is widely used. How to design a suitable low-voltage bandgap circuit to meet the new analog integrated circuits and mixed-signal integrated circuits design requirements is a new task for designers to perform.

To meet the requirements of low voltage and low power, second-order temperature compensation is used in the bandgap voltage reference circuit design discussed in this paper to achieve a high precision voltage reference source. What has been done is to improve the classic CMOS bandgap to reduce the current mismatch error , to increase the feedback factor, and to make the circuit has a high power supply rejection ratio. The simulation of the bandgap voltage reference is carried out, and the layout design is performed too [2].

II. STRUCTURE AND PERFORMANCE ANALYSIS OF THE CIRCUIT

A. Bandgap voltage reference

Bandgap reference circuit characterize in its high precision. No matter what the structure is, the basic principle is to make temperature compensation for the voltage which is independent of the power supply voltage. The temperature compensation, in accordance with the compensation principle, can be divided into first-order temperature compensation and high-order (usually second) temperature compensation [3].

The idea is to add one (or more) voltages which have specific relationship with temperature with a compleme-ntary voltage (usually VBE) to get a bandgap voltage which is basically independent of temperature and supply voltage. Figure 1 shows the principle of a second-order temperature compensation bandgap reference.

B. A typical CMOS bandgap circuit

Almost every bandgap reference is designed based upon the PTAT unit. Using op-amp in the design can make the current of PTAT more accurate. The principle of designing a bandgap reference either in CMOS technology or in BICMOS technology is the same. But since there is no NPN transistor in CMOS technology, the vertical PNP transistor must be used in CMOS technology. A typical CMOS bandgap reference is show in Figure 1[4], where:

$$V_{REF} = V_{EB2} + \frac{R_2 V_T \ln N}{R_3} \tag{1}$$

By designing the values of R1, R2 and R3 resistor reason-ably, we can get the bandgap reference voltage VREF which has nothing to do with temperature.

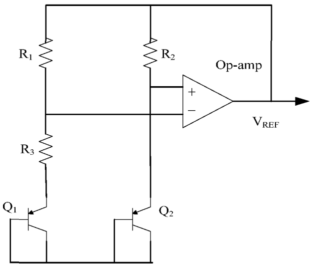

Figure 1. A typical CMOS bandgap reference circuit

C. *Precision of band-gap reference*

Precision is one the most important indicators of a bandgap reference circuit. It is mainly affected by the noise and the circuit mismatch in bandgap voltage reference circuit. With the decreasing of the feature size of integrated circuits, the influence of mismatch on the precision of the bandgap voltage reference circuit becomes more and more important. The precision of the traditional first-order temperature compensation bandgap voltage reference is usually 50ppm / ° C ~ 100ppm / ° C [5], and it can not satisfy the demanding of a variety of high-performance chips.In order to improve the precision of bandgap voltage, two measures are usually taken:One approach is to optimize the structure of the traditional first-order temperature compensation bandgap voltage reference circuit to minimize the offset error of mismatch [6]. Another method is to make a high-order (usually second-order) temperature compensate- on for the bandgap voltage reference circui using BiCMOS technology. For the first approach, to ensure the depth of feedback, multi-stage amplifier is usually needed to meet the requirements of low-voltage and high-gain. And there is no doubt it will bring new problems, such as the increased power consumption and the instability of the circuit because of the introduction of extra poles. The biggest error of the bandgap voltage reference comes from the current mismatch and the absolute error of resistors [8][9]. So, the best way to increase the precision of the bandgap voltage reference is to reject the current mismatch and the absolute error of resistors.

D. *PSRR*

As in other analog circuits, the power lines of a bandgap voltage reference circuit often contain noise. Power supply rejection ratio is actually the linear adjustment rate under the small signal model, i.e the changes of the output voltage due to the changes of power supply [10]. It reflects the capacity for the circuit to reject power supply noise. For the bandgap voltage reference circuit, the value of PSRR mainly depends on the characteristics of the PSRR of the op-amp circuit.

$$PSRR = \frac{dV_{REF}}{dV_{IN}}\Big|_f \tag{2}$$

III. CIRCUIT IMPLEMENTATION

The implementation of the bandgap reference circuit is shown in Figure 2. The entire circuit is divided into three parts: start circuit, operational amplifiers, reference generating circuit. This circuit is effective to reduce the errors caused by the circuit offset voltage. The cascode single-stage amplifier circuit is used in the design. A PMOS active current mirror is used as the load to achieve differential input, single output, which increases the speed of the circuit. The static current is limited by adjusting the function of the circuit. Meanwhile, the start current of PTAT which is proportional to temperature flows into the op-amp, and makes temperature compensation to let the static working point of the op-amp more stable.

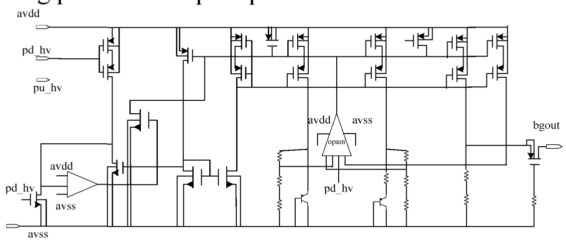

Figure 2. The entire bandgap reference circuit

IV. SIMULATION RESULTS AND ANALYSIS

In order to verify the performance of the circuit, simulation has been done based TSMC.11 technology library. The simulation conditions is: temperature range of -40 ~ 140 degrees centigrade, simulation models are tt, ss, fs, sf, ff. the simulation result is shown in Figure 3. It can be seen from the simulation results that the reference voltage is relatively stable in the model tt and less affected by the temperature. The precision is about 13.5 ppm/℃.

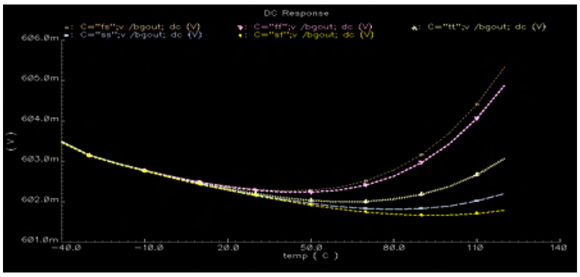

Figure 3. Relationship curve in model fs, ss, ff, sf, tt

Now, set the simulation model to tt, and connect different avdd (1-1.3V) to the circuit to see the curve of temperature and reference voltage under different avdd. The results is shown in Figure 4. The reference voltage of the circuit remain the same when the avdd changes between 1V and 1.3V, which shows that the circuit is good at anti-interference.

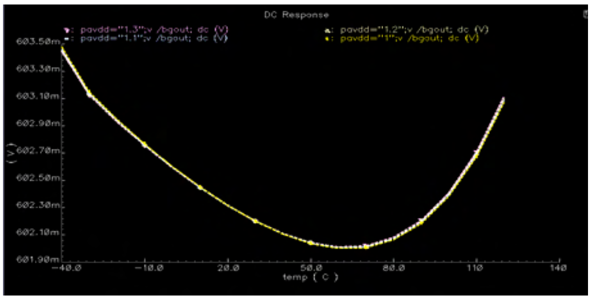

Figure 4. Relationship curve in model tt avdd=1.3V,1.2V,1.1V,1V

Simulation to open-loop gain of the internal amplifier has been done under the conditions of avdd =1.3V to test the circuit's power supply rejection ratio (PSRR). It can be seen in Figure 5 that the power supply rejection ratio (PSRR) of the circuit is more than 60dB when frequency range is less than 10k. That is to say the effect of the noise can be rejected efficiently.

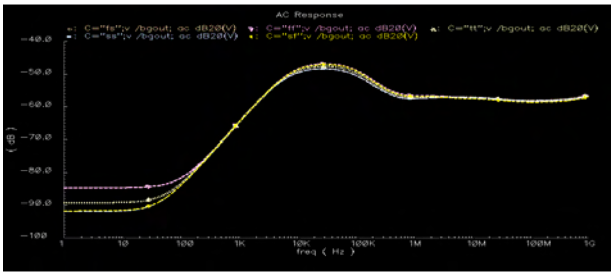

Figure 5. A typical CMOS bandgap reference circuit

V. LAYOUT DESIGN

The layout of the bandgap reference circuit designed is shown in Figure 6. Upper part of the figure 7 is the core circuit of the bandgap voltage reference, the lower half of the figure 7 are the bias circuit, the input transistor of op-amp, the feedback compensation circuit of the amplifier and the cascode circuit of op-ampr respectively from left to right. A protection ring is placed in the outer part of the circuit to isolate outside noise interference on the bandgap reference circuitIn order to reduce the influence of resistance mismatch on the bandgap reference circuit, the resistors used in the circuit are of the same type, polysilicon resistors, which is formed with the same small resistor in series.
Because the offset of the op-amp may bring errors to the output of the bandgap reference circuit , so it is necessary to take measures to reduce the input offset of the op-amp. Therefore, the large-size devices are used for the input of op-amp's, and the common centroid structure are used for the P&R of the layout. In addition, common centroid structure are also used for all the PNP transistor to reduce the influence of the mismatch.

It is very difficult to get a bipolar transistor of good performance in the standard CMOS process. The performa-ncees of the lateral PNP transistor are improved by doing the following:

First, to make the width of the base of the lateral PNP transistor as small as possible, and then a large area metal covering is used to change its surface properties. also the layer, the collector metal layer has been extended to the surface PN junction of two. Use of metal layer to control and reduce the negative potential of the positively charged silica surface for the impact of PN junction to reduce the reverse leakage.

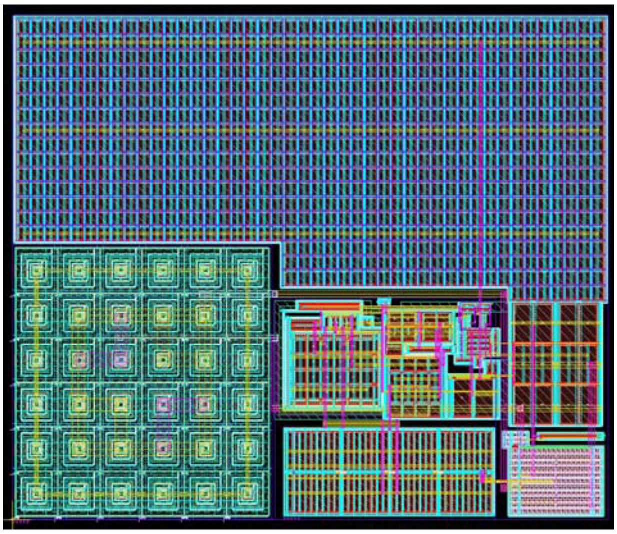

Figure 6. Layout of the whole circuit

At the same time, OPAMP bandgap of the territory as part of the time in the design layout to take into account the overall planning, not only to do easy lead, but also to ensure the best overall map of the N well together, to reduce the unnecessary area Waste.

The differential input control OPAMP require the most stringent symmetry, a little bit of deviation will cause great error. OPAMP differential input signal as a static signal, so the symmetry of the device symmetry important than the signal line, and therefore the way the device is the first choice centrosymmetric. Figure 7.

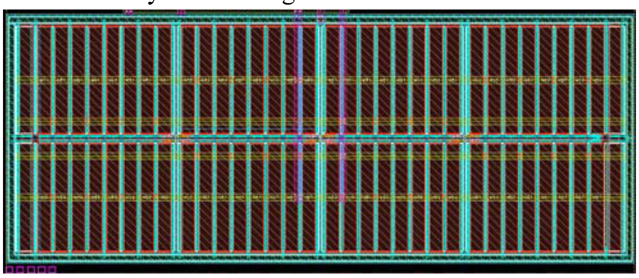

Figure 7. Centrosymmetric

Will complete the DRC, LVS's layout extraction and circuit parameters of family planning, and the extracted parasitic capacitance into the circuit resistance to conduct simulation. In taking a different avdd obtained when the reference voltage and temperature curves between the comparison chart.

It can be seen from the Figure 8 that by adding parasitic extraction from layout, the relationship curves between reference voltage and temperature remains essentially unchanged, indicating that the layout design has good compatibility, and the effects the parasitic capacitance on the circuit are minimized.

To test the DC characteristic of the circuit, the simulation mode is set to tt, and different avdd (1-1.3V) are imposed to the circuit. Comparing the curve between reference voltage and temperature under the different avdd, it can be seen that the voltage remain constant. The result is shown in Figure 9.

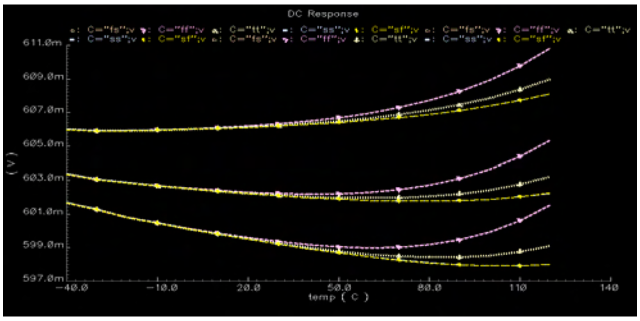

Figure 8. Model = fs, ss, ff, sf, tt curves between reference voltage and temperature

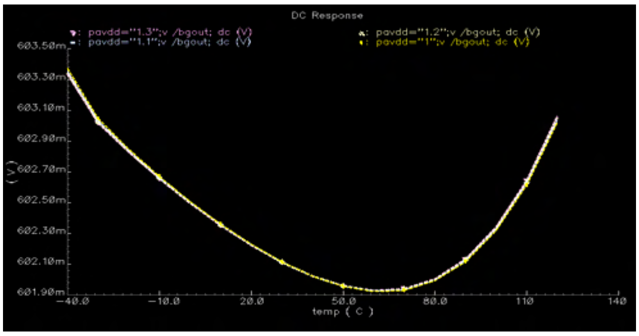

Figure 9. Model = tt avdd = 1.3V, 1.2V, 1.1V, 1V curves between reference voltage and temperature

VI. CONCLUSION

It is very important to research the bandgap reference which with high precision, high noise immunity, and that can adapt to low-voltage. A high-precision bandgap reference circuit is presented in this paper. The current mismatch effects is eliminated effectively by using the CMOS technology, and the impact of mismatch of layout on the bandgap reference circuit design is also focused. The simulation results show that the PSRR is more than 60dB, and the temperature accuracy is 13.5ppm /℃ when the circuit work at low frequency. The performances of the bandgap reference circuit are good, and it can be used for high precision analog integrated circuits.

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