Design of Bandgap Reference and Current Reference Generator with Low Supply Voltage

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Abstract

A design of a CMOS bandgap voltage reference and reference current generator is described and the measurement results are presented in wide temperature range. Using by the resistive subdivision method, the reference circuit is operated with low supply. The measured reference voltage is 630mV and temperature coefficient of bandgap reference is 29ppm/°C from -10°C to 100°C with 1.2V supply voltage. The reference current of generator which uses the reference voltage is 50.2uA in that temperature range.

1. Introduction

Low voltage operation is important design issue in mobile electronic devices, because of demanding for low power consumption. As the process technologies are developing and the line widths are reducing also the maximum allowable supply voltage will scale down. Although the supply voltage can be reduced by process technology, the voltage and current reference circuits must be changed for low power operation.

The output voltage of the conventional voltage reference is 1.24V which is nearby the same voltage as the bandgap of silicon. However, this circuit used bipolar junction transistor (BJT) formed in a p- or n-well is not operated with sub 1.2 supply voltage[1]-[3]. Some ways to overcome this limitation have been proposed in [4]-[8].

Reference [4], [5], and [6] are based on resistive subdivision method of bandgap voltage, [7] is solved by using dynamic-threshold MOS transistor resulting in lower apparent bandgap voltage and [8] is designed by method of the higher order curvature temperature compensation with the Malcovati topology[11].

In this paper, a precise linear CMOS bandgap voltage reference was designed by using resistive subdivision method as described in [4]. A temperature compensated reference current generator was designed by bandgap reference voltage. The voltage reference have been designed and optimized for low supply voltage and wide temperature range.

2. Conventional Bandgap Reference

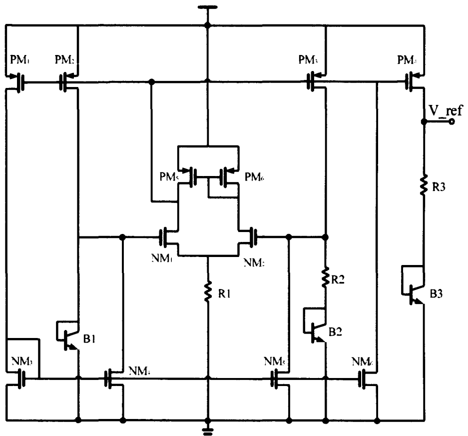

Figure 1. Conventional bandgap reference

The conventional bandgap circuit is composed of an operational amplifier, several bipolar transistors and resistors as shown in Fig. 1. The output voltage of the BGR is the sum of the base-emitter voltage of bipolar transistor and voltage of the upper resistance.

$$V_{ref} = V_{BE3} + I_{PM4} \cdot R_3 \qquad (1)$$

If the dimension of current mirror transistor (PM1) is the same as that of transistors (PM2, PM3 and PM4), the current through the transistor (PM4) is,

$$I_{PM4} = I_{PM3} = I_{PM2} = \frac{V_T \ln(A_{B2} / A_{B1})}{R_2} \qquad (2)$$

Where A_{B1} and A_{B2} are the emitter areas of B1 and B2, respectively. The output voltage can be expressed by following equation (3) when the emitter area of B2 is n times larger than that of B1.

$$V_{ref} = V_{EB3} + \frac{R_3}{R_2} V_T \ln(n) \qquad (3)$$

V_{EB3} has a negative temperature coefficient, whereas V_T has a positive temperature coefficient, so that V_{ref}

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is determined by the ratio of the resistance as well as are ratio of the bipolar transistor. This circuit topology can generate the reference voltage of 1.24V by adjusting the resistor ratio and BJT's area ratio. However, this topology is not used in low supply voltage operation.

3. Circuit Implementation

3.1 Low Supply Bandgap Reference

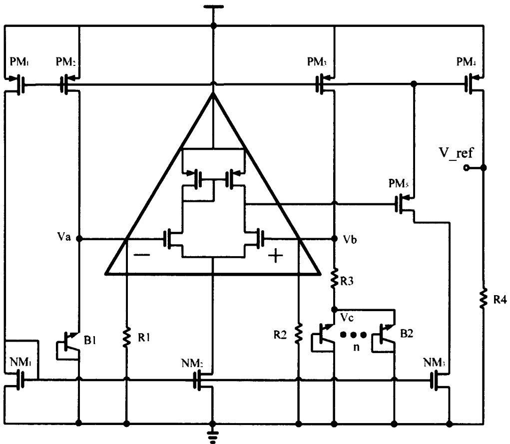

Figure 2. Schematic of the bandgap reference

In Fig. 2, The PMOS transistor dimensions of P2, P3 and P4 are the same, and the resistance of R1 is the same as that of R2[4].

$$I_a = I_b = I_{ref} \quad (4)$$

$$V_a = V_b \quad (5)$$

Therefore, $I_{R1} = I_{R2}$, $I_{B1} = I_{R3}$.

I_{R2} and I_{R3} are proportional to V_a and V_T,

$$I_{R2} = \frac{V_a}{R_2}, \; I_{R3} = \frac{\partial V_{R3}}{R_3} \quad (6)$$

When the dimension ratio of the B1 and B2 is n, according to equation (4) and (5),

$$\partial V_{R3} = V_b - V_c = V_a - V_c = V_T \ln(n) \quad (7)$$

I_{ref}, current of R4, can be substituted I_b which was given by

$$I_b = I_{B2} + I_{R3} = I_{ref} \quad (8)$$

The reference voltage becomes

$$V_{ref} = \left(\frac{V_a}{R_2} + \frac{\partial V_{R3}}{R_3} \right) \cdot R_4 \quad (9)$$

Here, V_a is V_{EB1} of BJT, and ∂V_{R3} is $V_T \ln(n)$.

Therefore, the output of the BGR can be written as follows:

$$V_{ref} = \frac{R_4}{R_2} \cdot \left(V_{BE1} + \frac{R_2}{R_3} V_T \ln(n) \right) \quad (10)$$

The output voltage of the BGR can be freely chosen by adjusting the resistor ratio, and be a more suitable voltage for low supply operation.

The designed BGR circuit was composed of a power-down circuit for start-up, a self-bias, a bandgap core and a two stage operational amplifier as shown in Fag. 3.

3.2 Current Reference Generator

Another block which was used all of the IC chips is current reference. The role of temperature-compensated current generator is very important, because this current must be stably used by reference current of analog blocks. The designed reference current generator was not used combination of PTAT and IPTAT but generated the reference current with the bandgap reference voltage [9][10].

The current reference generator circuit was consisted of a power-down circuit, a current mirror and a simple current reference core of the differential amplifier structure.

4. Measured Results

The bandgap reference and current reference generator were implemented with a Mixed-RF 0.13um CMOS technology. For the temperature test, the IC has been exposed to temperatures in the working range from -10°C to 100°C in the thermal chamber. We maintained during several minutes in a testing temperature for temperature stabilization and measured once a 5 degree in the investigated temperature range.

The reference voltage is about 630mV with 1.2V supply voltage for the temperature range from -10°C to 100°C as shown in Fig. 4. And the temperature coefficient is measured around 29ppm/°C.

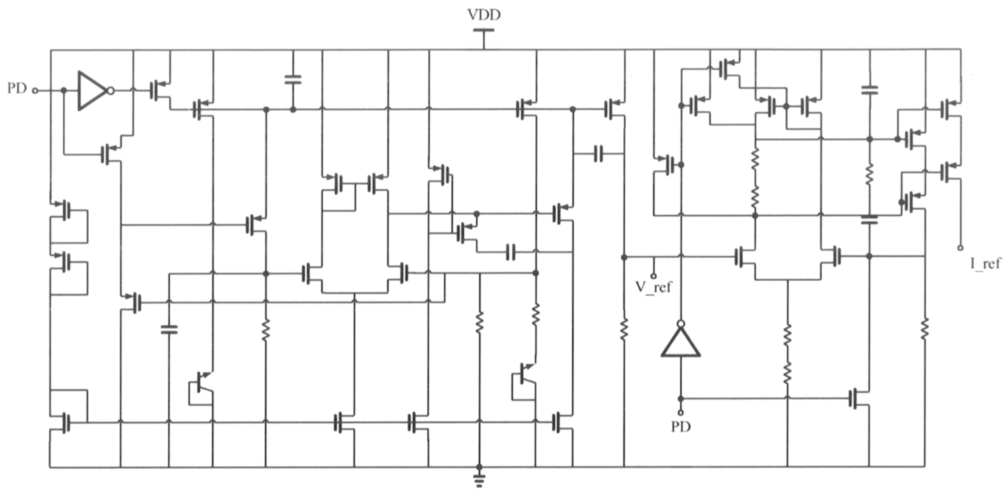

Figure 3. Schematic of the bandgap reference and current reference generator

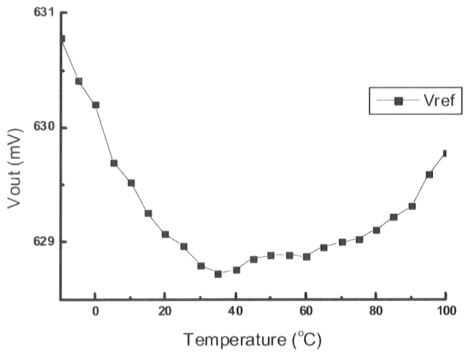

Figure 4. Measured output voltage of bandgap

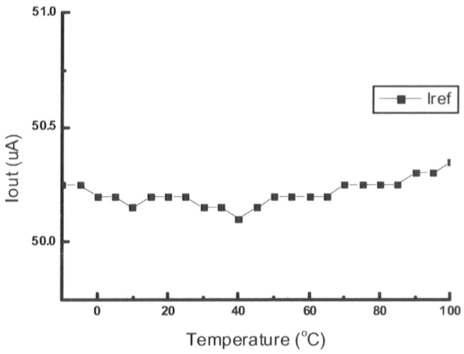

Figure 5. Measured output current of generator

Fig. 5 shows the output current variations of the current reference generator as s function of the test temperature range. The reference current was designed 50uA. Although the reference current has offset current of 200nA, the variation is only 100nA in that temperature range.

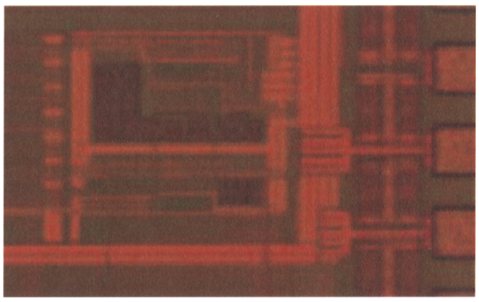

Figure 6. Micrograph of reference circuit

The area of the fully reference circuit is 0.038 mm^2 and micrograph of the reference block in the IC chip is shown in Fig. 6.

The measured characteristics of the voltage and current reference circuit are summarized in Table. 1.

Table 1. Measured results of the reference circuit

Parameter	Value
Supply (V)	1.2
Temp. Range (°C)	-10 ~ 100
Reference Voltage (mV)	630
Temp. Coefficient (ppm/°C)	29
Reference Current (uA)	50.2
Current Variation (uA)	0.1
Area (mm^2)	0.038

5. Conclusion

This paper presented a CMOS bandgap reference and current reference generator circuit which produces an output reference voltage of 630mV and an output current of 50.2uA, respectively, with 1.2V supply voltage.

The reference circuit achieves a temperature coefficient of 29ppm/°C and a generated reference current variation of 100nA with temperature range from -10°C to 100°C.

Those results show that proposed bandgap voltage and current reference circuit is a suitable candidate for the low supply voltage applications.

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