Design and Implementation of a CMOS BGRV Circuit with Temperature Sensing

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Abstract. This paper proposes a bandgap reference voltage circuit (BGRV) with low temperature coefficient and independent of supply voltage for applications to low power management integrated circuits. Also by using of the temperature characteristics when the IC chip temperature exceeds the warning temperature, it will generate a high level of alert. This proposed temperature sensing CMOS BGRV circuit is design and implemented using the TSMC 0.35μm 2P4M process technology. Based on simulated and measured results, the chip size is 651×732μm² with power dissipation about 3.172mW, and the operation temperature range form -20°C to 100°C with temperature coefficient about 10.12 ppm/°C. The chip supply voltage can from 1.9V to 3.3V, and its output reference voltage can stable at 1.19V. The positive TC voltage which linearly varies from 0.89V to 1.49V between -20°C and 100°C, and when the temperature exceeds the warning temperature, the output voltage of comparator is 3.3V.

Introduction

Currently portable electronics products are constantly updated toward compact size. Therefore it requires a BGRV to offer different reference bias voltage for power management circuits and mixed-mode IC. In general, the power management circuits and mixed-signal IC are very sensitive to temperature changes [1]. All kinds of sensors are integrated in the IC chip, and especially electronic products for temperature monitoring and sensing become more important. They need a temperature sensing circuit which binds to the IC chip, and the temperature sensor is the only sensor without physical structure. The most common use of a temperature sensor is the use of BGRV with the PTAT current generate scheme. In this paper we design a temperature sensing CMOS BGRV circuit consisting of bandgap reference voltage core circuit, PMOS two-stage operational amplifier, reference current source circuit with start-up and hysteresis comparator. This circuit uses a voltage with positive temperature coefficient (TC) to compare with bandgap reference voltage which is not affected by temperature through the comparator. It aims to generate a high level of alert when sensing the temperature rising to alert level. It can prevent overheating of electronic products and then control it. Therefore, this CMOS BGRV temperature sensing circuit that can be applied to multivariate sensor, control of the overheated CPU, and reference bias voltage of a variety of low-power power management module.

Architecture and Circuit Design

In this article, the architecture of temperature sensing CMOS BGRV circuit composes of bandgap reference voltage core circuit generated by PTAT current, an PMOS two-stage OPA and a comparator, as shown in Figure 1. This CMOS bandgap core reference voltage makes use of linear combination of PTAT current and BJT $V_{BE}$ to generate bandgap reference voltage source, $V_{REF}$. The voltage is $V_{REF} = I_{R_3}+V_{EB3} = \frac{V_T \ln(n)}{R_1}R_3+V_{EB3}$, where n is the ratio of the area of Q1 and Q2 [2]. And the $V_{REF}$ independent of temperature, power supply, and process drift.
The PTAT current flowing through M3 has a positive temperature coefficient and through R2 produces a positive TC voltage $V_{PTC}$, i.e. $V_{PTC} = \frac{V}{R_1 \ln(n) R_2}$.

If temperature is increased to 60°C, this $V_{PTC}$ will be exceed the voltage $V_{REF}$ and the comparator output is at high potential state (High). Whereas if the temperature is lower than 60°C, the comparator output will remain at a low potential state (Low) as shown in Figure 2.

To enhance the overall performance of the CMOS BGVR with a temperature sensing circuit in order to get high accuracy of the reference output voltage and reduce process variation of its influence, and the $V_{BE}$ of BJT connected with the input of OPA of the bandgap reference voltage core circuit is low, it should use with high input common-mode range of the PMOS input differential pair OPA architecture as shown in Figure 2[3, 4]. Table 1 is the proposed CMOS BGRV core circuit two stage OPA's specifications.

The PMOS two-stage OPA and hysteresis comparator require a stable tail bias current source $I_{REF}$. It is realized through a constant-Gm current references circuit which is independent of supply power and environment temperature [4]. As shown in Figure 4, the constant-Gm current references circuit is composed of the low voltage current mirror (M2~ M5 and M10~M13), cascade bias circuit (M1, M6~M9 and M14) and start-up circuit (M15 ~ M18).

<table>
<thead>
<tr>
<th>Par. Spec.</th>
<th>DC Gain</th>
<th>Unit-Gain Bandwidth</th>
<th>Phase Margin</th>
<th>ICMR</th>
<th>CMRR</th>
<th>PSRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Sim</td>
<td>74.4dB</td>
<td>27MHz</td>
<td>77.3°</td>
<td>0.07V~1.9V</td>
<td>77.6dB</td>
<td>99.1dB</td>
</tr>
<tr>
<td>Post-Sim</td>
<td>74.47dB</td>
<td>24.5MHz</td>
<td>73.8°</td>
<td>0.1V~1.9V</td>
<td>81.5dB</td>
<td>98.9dB</td>
</tr>
</tbody>
</table>

In this article, a three-stage hysteresis comparator architecture is used. As shown in Figure 5, the three-stage source-coupled with positive feedback comparator circuit is composed of the PMOS differential pair stage, CS amplifier stage and two inverter stages (to improve the transient response of the comparator) [4, 5]. The first stage is the internal feedback of the hysteresis comparator. This
circuit has two feedback paths. The positive feedback path is [the parallel feedback of MP1, MP2, MP3, and gate-source connection voltage of MP4. The negative feedback path is serial feedback of the current through MN1, MP3, MN2, and current of CS amplifier of MP4. If the negative feedback factor is less than the positive feedback factor, the overall positive feedback will produce hysteresis curve.

![Circuit Diagram]

Figure 5. Hysteresis comparator

![Hysteresis Voltage Graph]

Figure 6. Hysteresis voltage of comparator

Hysteresis comparator of this article is served as the comparison between positive TC voltage $V_{PTC}$ and the reference voltage ($V_{REF}$). If the temperature is too high, the output of the hysteresis comparator will generate a high state of alert. This paper chooses additive hysteresis characteristic in order to avoid malfunction of the comparator. It may be not yet higher than 60°C, but because of noise interference, it produces high pulse at the output. The hysteresis voltage is 300mV, shown in Figure 6.

**Simulation and Measured Result**

By using TSMC 0.35 μm CMOS 2P4M process to simulate the designed circuit, the result of post-sim under five different coners is shown below. Figure 7 shows the temperature coefficient of bandgap reference output voltage $V_{REF}$ about 7~11 ppm/°C under the operation temperature from −20°C to 100°C. The variation of output reference voltage under five different coners is about 5mV at 25°C. The output reference voltage $V_{REF}$ can stable at about 1.197V at 27°C and 60°C, respectively.

![Temperature Coefficient Graph]

Figure 7. $V_{REF}$ Voltage vs Temperature (Post-sim)

![PTC Temperature Graph]

Figure 8. $V_{PTC}$ Voltage vs Temperature (Post-sim)

The voltage difference $\Delta V_{BE}$ between base and emitter of two BJTs is proportional to absolute temperature, which positive TC can generate PTAT ($V_{PTC}$) reference voltage. The PTAT current flowing through MP3 has a positive TC [6], and it generates a positive TC voltage $V_{PTC}$ when passing through R2. From Figure 8, the results show that when the operating temperature is between -20°C and 100°C, the positive TC voltage $V_{PTC}$ rises from 0.8869V to 1.4934V. At 27°C, the positive TC $V_{PTC}$ is about 0.953V, and at 60°C, the positive TC voltage $V_{PTC}$ is about 1.276V.

Figure 9 show the operating temperature is between -20°C and 100°C. If the temperature is increased to 60°C, this $V_{PTC}$ will be larger than the voltage $V_{REF}$. Then the output of comparator is at a
high-level state \( (V_O \approx 3.3V) \). While, if the temperature is kept below 60°C, the output of comparator will remain at a low-level state \( (V_O \approx 0V) \).

After summarizing the analysis of all component circuits, the IC electronic microscope layout of the proposed temperature sensing CMOS BGVR circuit are shown in Figure 10. And the chip size is about \( 651 \times 732 \mu m^2 \) [7]. And from the measurement results displayed in Figure 11 and 12, when the operating temperature is increased to 60°C, this \( V_{PTC} \) will be larger than the voltage \( V_{REF} \). Then the output of comparator is at a high-level state \( (V_O) \). \( V_O \) is approximately 3.26V. On the contrary, if the temperature is kept below 60°C, the output of the comparator will be kept at a low-level state \( (V_O) \). \( V_O \) is approximately 246mV. And from Figure 11 and 12 shows the measurement result that the CMOS BGVR circuit output reference voltage \( V_{REF} \) can stable at about 1.20V at 27°C and 60°C, respectively.

Summary

Based on the aforementioned discussions, we can conclude that the implemented COMS BGVR with temperature sensing circuit has \( 651 \times 732 \mu m^2 \) chip size with power dissipation about 3.172mW. The chip supply voltage can from 1.9V to 3.3V, and its output reference voltage can stable about at 1.20V. The positive TC voltage which linearly varies from 0.89V to 1.49V between -20°C and 100°C, and when the temperature exceeds the warning temperature, the output voltage of comparator is 3.3V. Finally, the simulation and actual measurement results are summarized in Table 2 below that shows that this CMOS BGVR with temperature sensing circuit output reference voltage variation is less than 5mV, and the temperature coefficient is 10.12ppm/°C at 27°C. Therefore, this CMOS BGVR temperature sensing circuit that can be applied to temperature sensor, control of the overheated SOC, and reference bias voltage of a variety of low-power power management module.
Table 2. Expected specification, simulation and measurement results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Pre-sim</th>
<th>Post-sim</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply</td>
<td>3.3V</td>
<td>3.3V</td>
<td>3.3V</td>
<td>3.3V</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>≤ 2.5mW</td>
<td>1.4715mW</td>
<td>3.172mW</td>
<td>3.527mW</td>
</tr>
<tr>
<td>$V_{ZEO}(27^\circ C)OutputVoltage$</td>
<td>1.2V</td>
<td>1.192V</td>
<td>1.1976V</td>
<td>1.2V</td>
</tr>
<tr>
<td>$V_{ZEO}(60^\circ C)OutputVoltage$</td>
<td>1.2V</td>
<td>1.1926V</td>
<td>1.1976V</td>
<td>1.23V</td>
</tr>
<tr>
<td>$V_{ZEO,TemperatureCoefficient}$</td>
<td>≤ 5ppm</td>
<td>10.12ppm</td>
<td>6.28ppm</td>
<td>208ppm</td>
</tr>
<tr>
<td>$V_{ZEO}(60^\circ C)OutputVoltage$</td>
<td>&gt;1.2V</td>
<td>1.2716V</td>
<td>1.2357V</td>
<td>1.28</td>
</tr>
<tr>
<td>$V_{ZEO}(27^\circ C)OutputVoltage$</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>$V_{ZEO}(60^\circ C)OutputVoltage$</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

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References


