Design of a Bandgap Voltage Reference

ECE584 Spring 2011

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Abstract:

[The purpose of an abstract is to entice the reader to read the entire paper. It must clearly state the nature and the importance of the work described and provides key results. Here is an example of a possible abstract.]

Many analog and mixed-signal ASIC (Application Specific Integrated Circuit) designs employ a stable voltage reference and PTAT (Proportional to Absolute Temperature) current references. Voltage references are used, for example, in the design of data converters. Current sinks/sources are needed for the biasing of on-chip amplifiers or other analog circuitry.

This paper describes the design of a simple bandgap voltage reference along with a pair of PTAT current sink outputs which might be used on a analog or mixed-signal ASIC. When simulated at the typical process corner, the bandgap voltage output was 1.\text{xxx} Volts and the current sink outputs were $x \ \mu\text{A}$ and $y \ \mu\text{A}$. The circuits described herein met all specifications when simulated over a wide range of temperatures and operating voltages. Extensive simulation data is presented to support this claim. The circuit is estimated to occupy an area of $x \ \mu\text{m}^2$ while consuming $y \ \mu\text{Watts}$ when operated from a 5 Volt supply. Total noise at the bandgap output in a 10 MHz bandwidth is $x \ \mu\text{V}$.

Introduction:

[Describe what you were asked to design and what the design can be used for. Summarize in your own words the specifications that were given to you. For example, ]

In this midterm project we were asked to design a bandgap voltage reference along with a pair of PTAT current source outputs. A bandgap voltage reference is a circuit which produces a voltage of approximately 1.25 Volts and which is stable with respect to changes in supply voltage and temperature. Bandgap voltage references are used in the design of on-chip analog-to-digital or digital-to-analog converters.

A current source is a circuit which provides a constant current regardless of its terminal voltages. The compliance of a current source is defined as the range of terminal voltages over which the output current is constant and at its prescribed value. In this design we were asked to generate a pair of PTAT current sink outputs ($1 \ \mu\text{A}$ and $10 \ \mu\text{A}$). PTAT current sources are useful in the biasing of op amps because if weakly or moderated inverted input devices are used in the design of the op amp, the transconductance of the input devices will be nearly temperature independent.
Design:

Describe your design. Justify all design decisions. I recommend you decompose the circuit into its parts and describe each part separately. For example …

The operating principle of a bandgap voltage reference is illustrated in Figure 1 below [All:02]. The circuit operates by summing two voltages. One voltage possesses a negative temperature coefficient while the other a positive temperature coefficient.

Put figure here. See page 153 of text. Do not scan. Redraw something similar using a drawing program.

Figure 1: Operating principle of bandgap voltage reference

In my design I created the bandgap output by connecting a resistor carrying a PTAT current (voltage drop across resistor has positive temperature coefficient) in series with a diode-connected bipolar transistor (emitter-base voltage has negative temperature coefficient). The circuit is illustrated in Figure 2.

Put figure here. Show PTAT current reference sourcing current into series combination of resistor and diode-connected BJT.

Figure 2: Bandgap output circuit

The bandgap voltage output is predicted to be 1.xxx volts based on the following calculations.

{Put in a discussion along with equations on how the gain G from Figure 1 was computed and how resistor values were chosen. Be succinct. Do not ramble on.

The circuit shown in Figure 3 was used to implement the x μA PTAT current reference depicted in Figure 2.

Put figure here. It must be able to be read easily!

Figure 3: Circuit used to implement x μA current reference.
The circuit has one current source output which is used in the generation of the bandgap voltage output along with two PTAT current sink outputs (1 μA and 10 μA) realized by FETs x, y, z. The calculated output resistance for the two outputs was x Ω.

[Discuss how the circuit of Figure 3 works and what went into determining the sizes of the various transistors. Conclude with a summary of FET sizes.]

The width and length values of all components are provided in Table I.

<table>
<thead>
<tr>
<th>Reference ID</th>
<th>Width</th>
<th>Length</th>
<th>Multiplier</th>
</tr>
</thead>
</table>

Table I: Width and length values for components in Figure 3.

Simulation Results

[Present simulation results. The various plots should be prepared using Excel.]

The circuit described above was simulated using the Cadence electrical simulator Spectre®. The bandgap voltage output as a function of temperature is presented in Figure 5 below. The supply voltage was 5 Volts and typical (typ), worst case power (wcp), and worst case speed (wcs) process parameters were used.

Figure 4: Bandgap output as function of temperature for typical, worst-case speed, and worst case power process corners with a supply voltage of 5 Volts.

[Comment on the performance. Does it meet spec? Did you get similar results when V_{dd} was 3.3 Volts?]

The 1 μA current sink output as a function of temperature (°C) is presented in Figure 5 below. The supply voltage was 5 Volts. We simulated circuit operation using typical (typ), worst case power (wcp), and worst case speed (wcs) process parameters.
Figure 5: 1 $\mu$A current sink output as function of temperature for typical, worst-case speed, and worst case power process corners with a supply voltage of 5 Volts.

[Comment on the performance. Does it meet spec?]

The 10 $\mu$A current sink output as a function of temperature is presented in Figure 6.

Figure 6: 10 $\mu$A current sink output as function of temperature for typical, worst-case speed, and worst case power process corners with a supply voltage of 5 Volts.

[Comment on the performance. Does it meet spec? What is the slope and does it agree with theory? You might consider repeating but with a supply voltage of 3.3 Volts.]

The current sink outputs were connected to DC voltage sources and the DC voltage sources were swept from 0 to 5 Volts in order to determine the compliance of the current sink outputs. The results of this simulation for typical process parameters, room temperature, and a supply voltage of 5 Volts are presented in Figures 7 and 8.

Figure 7: Compliance of 1 $\mu$A PTAT current sink output.

Figure 8: Compliance of 10 $\mu$A PTAT current sink output.

[Comment on the performance. Over what range of voltages is the current at its correct value. Does it meet spec? Does it agree with your analytical predictions? Does the slope agree with theory?]

Finally, a noise performance was performed. The total noise at the bandgap output in a 10 MHz bandwidth was $x \mu$V.
Summary/Conclusions

A 1.xx Volt bandgap voltage reference was successfully designed and simulated along with a pair (1 μA and 10 μA) of PTAT current sink outputs. The performance of the design reported in this paper is summarized in Table II shown below.

[Summarize performance in terms of temperature independence, area occupied, noise performance, power consumption, etc. Area can be estimated by summing the area occupied by all components in the design and then multiplying by a factor of 4. The factor of 4 is based on my experience over the years. This accounts for the wires needed to connect up the various components. Use a table to provide the summary. Also describe what you might do differently if asked to repeat the design.]

Put Table II here.

Table II: Performance Summary

References


Additional references.

In completing this project I collaborated with Minnie Mouse, Daffy Duck, and Pluto.