INTEGRATED CMOS BANDGAP REFERENCES

KW1-06

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A bandgap voltage reference is a voltage reference circuit widely used in analog and mixed-signal integrated circuit.

The operating principle of the bandgap voltage reference is to balance the negative temperature coefficient of a forward-biased pn junction with the positive temperature coefficient of the thermal voltage $V_T$. Therefore, an approximately temperature-independent reference voltage is generated in the bandgap voltage reference.

The aim of this Final Year Project is to design an integrated CMOS bandgap reference that fulfills the design specification by using the circuit simulators Topspice and Hspice with 0.5µm CMOS technology.

The integrated CMOS bandgap reference is divided into three parts:
- Startup Circuit
- Bandgap Core
- Output Circuit

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>2.2V to 5V</td>
</tr>
<tr>
<td>Output voltage</td>
<td>1.2V±5%</td>
</tr>
<tr>
<td>Temperature range</td>
<td>-40°C to +85°C</td>
</tr>
<tr>
<td>Total supply current</td>
<td>&lt; 60µA</td>
</tr>
<tr>
<td>Model library</td>
<td>** TT, SS, FF, FS, SF</td>
</tr>
<tr>
<td>CMOS process</td>
<td>0.5µm CMOS technology</td>
</tr>
</tbody>
</table>

** TT = typical nmos, typical pmos
** SS = slow nmos, slow pmos
** FF = fast nmos, fast pmos
** FS = fast nmos, slow pmos
** SF = slow nmos, fast pmos
Circuit schematic of the integrated CMOS bandgap reference

- **Startup Circuit** – starting up the bandgap reference when the power supply is turned on
- **Bandgap Core** – generating the desired reference voltage
- **Output Circuit** – sustaining the reference voltage generated in the bandgap core

The reference voltage generated in the above circuit is given by:

\[
V_{ref} = V_{EB2} + \left[ \left( \frac{R_{2a}}{R_1} \right) \ln(N) \right] V_T + \left[ \left( \frac{R_{2b}}{R_1} \right) \ln(N) \right] V_T
\]

Proposed IC layout of the bandgap core with the startup circuit
The temperature coefficient of the bandgap reference is given by:

\[
\text{Tempco}_{TT} = \frac{V_{\text{ref}}(\text{max}) - V_{\text{ref}}(\text{min})}{V_{\text{ref}}(25 \degree C)} \times \frac{10^6}{T_{\text{max}} - T_{\text{min}}}
\]

\[
= \frac{1.21878457 - 1.21856558}{1.2186861} \times \frac{10^6}{85 - (-40)}
\]

\[
= 1.43757 \text{ ppm/} \degree C
\]

Reference voltage generated in the bandgap reference (VDD = 3V and TT Library)

The line regulation of the bandgap reference at 25°C is given by:

\[
\frac{V_{\text{ref}}(V_{\text{DD}}(\text{max})) - V_{\text{ref}}(V_{\text{DD}}(\text{min}))}{V_{\text{DD}}(\text{max}) - V_{\text{DD}}(\text{min})}
\]

\[
= \frac{1.21940434 - 1.21843815}{5 - 2.2} = 0.34507 mV/V
\]

Reference voltages generated in the bandgap reference (VDD = 2.2V, 2.9V, 3.6V, 4.3V, 5V)

The diagram shows that the finalized integrated CMOS bandgap reference fulfills the required design specification with total supply current less than 60µA in all cases.

The finalized bandgap reference is able to function properly under different operation conditions required by the design specification provided by the Lexiwave Technology (Hong Kong) Limited.

Reference voltages generated in the bandgap reference for TT, SS, FF, FS and SF libraries (VDD = 2.2V, 3V, 4V, 5V)